Yours faithfully
John Ward

ELECTED PRESIDENT. 1907

TRANSACTIONS

OF THE

Institution of Engineers and Shipbuilders

IN SCOTLAND

(INCORPORATED).

VOLUME LI.

FIFTY-FIRST SESSION, 1907-1908.

EDITED BY THE SECRETARY.

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FIFTY-FIRST SESSION, 1907-1908.

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PRESIDENTS OF THE INSTITUTION

SINCE FOUNDATION IN 1859.

1857-59	**WILLIAM JOHN MACQUORN RANKINE**, C.E., LL.D., F.R.SS.L. & E., Professor of Civil Engineering and Mechanics, Glasgow University.
1859-61	**WALTER MONTGOMERIE NEILSON**, Hyde Park Locomotive Works, Glasgow.
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1865-67	**JAMES GRAY LAWRIE**, Engineer and Shipbuilder, Glasgow.
1867-69	**JAMES MORRIS GALE**, C.E., Engineer, Glasgow Corporation Water Works.
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1870-72	**DAVID ROWAN**, Marine Engineer, Glasgow.
1872-74	**ROBERT DUNCAN**, Shipbuilder, Port-Glasgow.
1874-76	**HAZELTON ROBSON ROBSON**, Marine Engineer, Glasgow.
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1897-99	**GEORGE RUSSELL**, Mechanical Engineer, Motherwell.
1899-01	**ROBERT CAIRD**, LL.D., F.R.S.E., Shipbuilder, Greenock.
1901-03	**WILLIAM FOULIS**, Engineer, Glasgow Corporation Gas Works.
1903-05	**ARCHIBALD DENNY**, Shipbuilder, Dumbarton.
1905-07	**JAMES GILCHRIST**, Marine Engineer, Glasgow.
Elected 23rd April, 1907,	**JOHN WARD**, Shipbuilder, Dumbarton.

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2.—Mr **Robert Royds**, M.Sc., for his paper on "The Most Economical Mean Effective Pressure for Steam Engines."

ADVERTISEMENT.

The responsibility of the statements and opinions given in the following Papers and Discussions rests with the individual authors; the Institution, as a body, merely places them on record.

MEMORANDUM OF ASSOCIATION

OF THE

INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND.

1. The Name of the Association is "THE INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND."

2. The Registered Office of the Association will be situate in Scotland.

3 The Objects for which the Association is established are :—

(1.) The Incorporation of the present Institution of Engineers and Shipbuilders in Scotland, under the 30th and 31st Victoria, cap. cxxxi., and

(2.) To facilitate the exchange of information and ideas amongst its Members, to place on record the results of experience elicited in discussion, and to promote the advancement of science and practice in Engineering and Shipbuilding.

(3.) The doing all such other lawful things as are incidental or conducive to the attainments of the above objects.

4. The Income and Property of the Association, whencesoever derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly by way of dividend, bonus, or otherwise howsoever, by way of profit, to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them.

Provided that nothing herein shall prevent the payment in good faith of remuneration to any Officers or Servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association.

5. The fourth paragraph of this Memorandum is a condition on which a Licence is granted by the Board of Trade to the Association, in pursuance of Section 23 of the "Companies Act, 1867." For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which may be duly observed by the Association.

6. If the Association acts in contravention of the fourth paragraph of this Memorandum, or of any such further Conditions, the liability of every Member of the Council of the Association, and also of every Member who has received any such dividend, bonus, or other profit as aforesaid, shall be unlimited.

7. Every Member of the Association undertakes to contribute to the Assets of the Association – in the event of the same being wound up during the time that he is a Member, or within one year afterwards, for payment of the Debts and Liabilities of the Association, contracted before the time at which he ceases to be a Member, and of the Costs, Charges, and Expenses of winding up the same, and for the adjustment of the rights of the Contributaries among themselves—such amount as may be required, not exceeding Ten Pounds, or, in case of his liability becoming unlimited, such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

WE, the several persons whose names and addresses are subscribed, are desirous of being formed into an Association in pursuance of this Memorandum of Association :—

Names, Addresses, and Description of Subscribers—

DAVID ROWAN, 217 Elliot Street, Glasgow, Engineer.
W. J. MACQUORN RANKINE, C.E., LL.D., &c., 59 St. Vincent St., Glasgow.
M. R. COSTELLOE, 26 Granville Street, Glasgow, Measuring Surveyor.
BENJAMIN CONNOR, 17 Scott Street, Garnethill, Engineer.
JAMES DEAS, 16 Robertson Street, Glasgow, Civil Engineer.
JAMES M GALE, 23 Miller Street, Glasgow, Civil Engineer.
W. MONTGOMERIE NEILSON, C.E., Hyde Park Locomotive Works, Glasgow.

Dated the Twelfth day of July, Eighteen Hundred and Seventy-One.

ROBERT ROSS, of Glasgow, Solicitor, Witness to the above signatures.

NOTE.—By Special Resolution passed on 2nd October, 1902, and confirmed on 20th October, 1902, the Articles of Association dated 12th July, 1871, as modified and altered in 1873 and 1880, were annulled, and the following Articles of Association (with the exception of Articles Nos. 23, 25, and 27) were substituted, and they were registered with the Registrar of Joint Stock Companies on 28th October, 1902.

By Special Resolution passed on 20th March, 1906, and confirmed on 17th April, 1906, the Articles Nos. 23, 25, and 27 of the Articles registered on 28th October, 1902, were cancelled, and the Articles Nos. 23, 25, and 27 below were substituted. This Resolution was lodged with the Registrar of Joint Stock Companies on 28th April, 1906.

ARTICLES OF ASSOCIATION

OF THE

INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND.

SECTION I.—PRELIMINARY

1. For the purpose of registration, the number of Members of the Institution is declared unlimited.

2. These Articles shall be construed with reference to the provisions of the Companies Acts, 1862 to 1900; and terms used in these Articles shall be taken as having the same respective meanings as they have when used in those Acts.

Objects of the Institution.

3. The Objects of the Institution are those set forth in the Memorandum of Association.

SECTION II.—CONSTITUTION.

Constitution.

4. The Institution shall consist of Members, Associate Members, Associates, Students, and Honorary Members.

Who may be Members.

5. Candidates for admission as Members shall be persons not under 25 years of age, who have been educated as Engineers or Shipbuilders and have occupied a responsible position in connection with the Practice or Science of Engineering or Shipbuilding.

Who may be Associate Members.

6. Candidates for admission as Associate Members shall be persons not under 22 years of age, who have

been educated as Engineers or Shipbuilders and are engaged in the Practice or Science of Engineering or Shipbuilding.

Who may be Associates.

7. Candidates for admission as Associates shall be such persons, not included in the classes enumerated in the two preceding Articles, who, not being under 25 years of age, are considered by the Council eligible on account of their scientific attainments, or are considered by the Council qualified by knowledge bearing on Engineering Science or Practice.

Who may be Students.

8. Candidates for admission as Students shall be persons not under 18 years of age who are engaged in study or employment with a view to qualifying themselves as Engineers or Shipbuilders. Before attaining the age of 25 years they must apply for election as Members or Associate Members if they desire to remain connected with the Institution. They may not continue to be Students after attaining the age of 25 years.

Who may be Hon. Members.

9. Honorary Members shall be such distinguished persons as the Council shall recommend and the Institution shall appoint. The number of Honorary Members shall not exceed Twelve.

Members, etc., under former Articles of Association.

10. All persons whose names shall on 30th April, 1902, be on the Roll of the Institution under the former Articles of Association as Members, Associates, or Honorary Members, and whose Subscriptions are not more than two years in arrear at that date, shall become Members, Associates and Honorary Members respectively within the meaning of these Articles, and that without procedure of any kind on the part of such persons.

Graduates under former Articles of Association.

11. All persons whose names shall on 30th April, 1902, be on the Roll of the Institution under the former Articles of Association as Graduates, and whose Subscriptions are not more than two years in arrear at that date, shall be considered and treated as Students within the meaning of these Articles, and shall have the privileges, and be subject to the regulations affecting Students;

and, notwithstanding the terms of Article 8 hereof, such Graduates as are over 25 years of age shall be allowed to remain as Students for one year from and after 30th April, 1902, but no longer.

Abbreviated Titles of Members, etc.

12. The abbreviated distinctive titles for indicating the connection with the Institution shall be the following, viz.—For Members, M.I.E.S.; for Associate Members, A.M.I.E S.; for Associates, A.I.E.S.; for Students, S.I.E.S.; and for Honorary Members, HON. M.I.E.S.

Candidates, how recommended and elected.

13. Every Candidate for admission as a Member, Associate Member, Associate or Student of the Institution, shall obtain the recommendation of at least three Members, such recommendation and the relative undertaking by the candidate being according to Form A contained in the Appendix. Such recommendation and undertaking shall be lodged with the Secretary, and the Council shall consider the same at their first Meeting thereafter, and if they approve the recommendation shall be mentioned in the notice calling the next general meeting of the Institution; and then, unless a ballot be demanded by at least five persons entitled to vote, the Candidate shall be declared elected. If a ballot be taken he shall be admitted if three-fifths of the votes are favourable; Members only being entitled to vote. The proposal for transferring any person from the Class of Students to the Classes of Associate Members or Members, or from the Class of Associate Members to the Class of Members, shall be according to Form B contained in the Appendix, and this form shall be subscribed by at least three Members and delivered to the Secretary for the consideration of the Council who shall, if they think fit, make the proposed transfer.

Honorary Members, how elected.

14. The granting of Honorary Membership to any person may be proposed at any Council meeting, and, if the Council, after consideration at their next meeting, approve of the proposal, intimation thereof shall be given by the Secretary in the circular calling the next general meeting of the Institution. At that

meeting unless a ballot be demanded by at least five persons entitled to vote, the person proposed shall be declared elected. If a ballot be taken then the person proposed shall be admitted if four-fifths of the votes are favourable; Members only being entitled to vote.

Members, &c. formally admitted.

15. Every person duly elected or admitted as a Member, Associate Member, Associate, Student, or Honorary Member, shall be notified in writing of his election or admission by the Secretary. At the first meeting of the Institution held thereafter at which he is present, he shall be introduced according to the ensuing form, viz.—The President or the Chairman of the Meeting, addressing him by name, shall say: "As President (or Chairman of this meeting) of the Institution of Engineers and Shipbuilders in Scotland, I introduce you as a Member (or Associate Member or Associate or Student or Honorary Member as the case may be). Thereafter the new Member, Associate Member, Associate, Student or Honorary Member shall sign the Roll of Members, etc., to be kept by the Secretary, and on making payment of any fees or subscriptions due he shall be entitled to receive a diploma. The diploma shall be signed by the President and the Secretary.

Diploma.

Rejected candidates not to be noticed in minutes—wish of Honorary Members to be obtained before being balloted for.

16. If any person proposed for admission into the Institution be not approved by the Council, or be rejected on being balloted for, no notice shall be taken of the proposal in the Minutes of the General Meetings, and such person shall not be proposed again for admission until after the expiry of one year from the date of such disapproval or rejection. Before the meeting of Council for considering any proposal to grant Honorary Membership it shall be ascertained from any person proposed to be made an Honorary Member, whether he will accept the honour, no notice being taken of the proposal in the Minutes unless he is elected.

SECTION III.—MANAGEMENT AND OFFICE-BEARERS.

17. The Direction and Management of the affairs of the Institution shall be confided to a Council, which shall consist of a President, six Vice-Presidents, and eighteen Councillors. Of the eighteen Councillors, not more than three may be Associates, the remainder being Members. Five Members of Council shall constitute a Quorum.

Council, Management by.

Constitution of Council—Five a Quorum.

18. Members only shall be eligible for election as President. The President shall preside over all meetings of the Institution and Council at which he is present, and shall regulate and keep order in the proceedings. The President shall hold office for one year only, but shall be eligible for re-election at the expiry of the year.

Who may be President.

19. Members only shall be eligible for election as Vice-Presidents. In the absence of the President, the Vice-Presidents in rotation shall preside at meetings of the Council and Institution. The Vice-Presidents shall hold office for three years.

Who may be Vice-Presidents.

20. In case of the absence of the President and all the Vice-Presidents, the meeting may elect any one of the Council, or any Member, to preside. In all cases the Chairman of any meeting shall have a Deliberative Vote and a Casting Vote.

Chairman to have casting vote.

21. Members and Associates only shall be eligible for election as Ordinary Members of Council, and shall hold office for three years, and not more than three Associates shall hold office in the Council at any one time.

Who may be Councillors.

22. Past Presidents of the Institution shall be *ex officio* Honorary Members of Council.

23. The Office-Bearers in office at 30th April, 1902, shall continue in office till the First General Meeting of the Institution in October, 1902, when a new Council shall be elected in terms of these Articles. Such Office-

First Council.

Retiral of Members of Council.

Bearers shall be eligible for election for the new Council. Of the new Council, two Vice Presidents shall retire in October of each of the years, 1903, 1904, and 1905, their places being filled by election, and the persons elected shall hold office until the expiry of the terms of office. Similarly of the new Council, six Councillors (being five Members and one Associate) shall retire in October, 1903. and a like number in October, 1904, and the remainder in October, 1905, their places being filled by election at these dates respectively, and their successors retiring at the expiry of the terms of office, and so on thereafter from year to year. The Vice-Presidents to retire in October, 1903, and 1904, shall be determined by lot among the six Vice-Presidents first elected, and the Members of Council to retire in October, 1903 and 1904 shall be determined by lot among the Members of the Council first elected. The Vice-Presidents and the Ordinary Members of Council who fall to retire at the dates mentioned, or who fall to retire at any time on the expiry of their term of office, shall not be eligible for re-election in the same capacity, nor shall a retiring Vice-President be eligible for election as a Member of Council until one year has elapsed from the date of retiral.

Office-Bearers to be elected by Ballot.

24. The Members of Council shall be elected by ballot at the Annual General Meeting, such meeting being the last Ordinary Meeting held in each month of April, but the new Office-Bearers elected at this meeting shall not enter office until 1st October following. In the election of President, Vice-Presidents, and Ordinary Members of Council from the Class of Associates, all Members, Associate Members, and Associates shall be entitled to vote. In the election of the other Members of Council only Members and Associate Members shall be entitled to vote.

Lists for Election.

25. In March of each year the Council shall meet and prepare a list of names for the election of Council for the ensuing year. This list shall be submitted to the

Members at the Monthly Meeting preceding the Annual Meeting, and the Members present may by motion, duly seconded, propose any additional names for any of the offices.

Ballot Lists to be sent to Members.

26. Fourteen days before the General Meeting in April of each year the list as proposed by the Council for the election of Members and others to fill the vacancies in the Council for the ensuing year, with such additions as may have been made thereto under Article 25, shall be printed and sent to all Members, and Associate Members, and the list shall serve as a ballot paper. A similar list shall be printed and sent to all Associates containing the names of those for whom they are entitled to vote. Those persons entitled to vote may vote for as many names on the list as there are vacancies to be filled. In the event of any ballot paper not containing names equal to the number of vacancies to be filled such ballot paper shall be treated as a spoiled paper.

The ballot papers may be sent by post or otherwise to the Secretary so as to reach him before the day and hour named for the Annual General Meeting, or they may be presented personally by those entitled to vote, at the opening of the Meeting.

Vacancies occurring during the Session to be filled up by the Council.

27. A vacancy occurring during any Session in consequence of the resignation or death of any Office-Bearer (except the President) shall be filled up by the Council, until the next Annual General Meeting for electing Office-Bearers. Any vacancy in the office of President shall be filled up at the next General Meeting of the Institution. A person elected to fill a vacancy shall hold office for the period unexpired of the term of office of the Office-Bearer resigning or dying or being removed from office, and he shall not be eligible for re-election.

SECTION IV.—POWERS AND DUTIES OF COUNCIL.

Meetings of Council. 28. The Council shall meet as often as the business of the Institution requires, and during each Session—that is from October till April—the Council shall meet at least once a month.

Committees. 29. The Council may delegate any of their powers to Committees consisting of such Members of the Council as they think fit, and they may appoint Committees to report to them upon special subjects. In particular, they shall appoint a Finance Committee to superintend the finances of the Institution, a Library Committee to superintend Library arrangements, and a Papers Committee to arrange for papers being submitted at meetings of the Institution. The Minutes of all Committees shall not take effect until approved by the Council. The President shall be *ex officio* a member of all Committees. Honorary Treasurer. The Convener of the Finance Committee shall be styled Honorary Treasurer. He shall be elected by the Council from their number, and notwithstanding the provision for retiral in Article 23, he shall be entitled to retain the office of Honorary Treasurer for three years from the date of his appointment.

Bye-Laws, etc. 30. The Council may make Bye-Laws and Regulations for carrying on the business of the Institution, and from time to time, alter, amend, repeal, vary, or add to the same; but any Bye-Law or Regulation, or any alteration or amendment thereon, or addition thereto, shall only come into force after the same has been confirmed at a General Meeting of the Institution, and no Bye-Law or Regulation shall be made under the foregoing which would amount to such an addition to or alteration of these Articles as would only be legally made by a Special Resolution passed and confirmed in accordance with Sections 50 and 51 of the Companies Act, 1862. Investments. The Council shall be entitled to invest the Funds of the Institution as they think fit, on such security, heritable or moveable, as to them shall seem proper, and may alter or vary the investments from time to time. The Council may purchase or sell property, heritable or moveable, for the use of the Institution, and may borrow money on the security of the property of the Institution, subject to confirmation by the Institution at an Extraordinary Meeting called for the purpose.

Council may purchase or sell.

Borrowing.

31. The Council shall appoint a Secretary and a Treasurer, and any other official or servant required to carry on the work of the Institution, and the appointments made by the Council shall be on such terms and conditions as the Council may think fit.

Officials to be appointed.

32. All questions in or before the Council shall be decided by vote, and such vote shall be taken by a show of hands or by ballot; but at the desire of any four Members present the determination of any subject shall be postponed till the next meeting of Council.

Votes at Council Meetings.

SECTION V.—SECRETARY AND TREASURER.

33. Subject to regulation by the Council, the Secretary (who may also act as Treasurer) shall conduct the correspondence of the Institution; attend all Meetings of the Institution, of the Council, and of Committees; take Minutes of the proceedings of such Meetings, and enter them in the proper books provided for the purpose; read at all Meetings of the Institution and Council respectively the Minute of the preceding Meeting, and all communications received by him or ordered to be read; superintend the publication of such papers as the Council may direct; take charge of the Library; issue notices of Meetings; issue Diplomas; keep the Roll and Registers; and perform whatever other duties are indicated in the Regulations of the Institution as appertaining to his department or set forth in the terms of his appointment.

Duties of Secretary.

34. Subject to regulation by the Council, the duties of the Treasurer shall be to take charge of the property

Duties of Treasurer.

of the Institution (excepting books, papers, drawings, models, and specimens of materials, which shall be in the charge of the Secretary); to receive all payments and subscriptions due to the Institution; to direct the collection of subscriptions; to pay into one of the Glasgow Banks, in the joint names of the President, Honorary Treasurer, and himself, the cash in his hands whenever it shall amount to Ten Pounds; to pay all sums due by the Institution, but not without an order signed by two Members of the Finance Committee, and to keep an account of all his intromissions in the General Cash Book of the Institution, which shall upon all occasions be open to inspection of the Finance Committee, and which shall be balanced annually, as at 30th September. The Treasurer shall prepare an Annual Statement of the Funds of the Institution, and of the receipts and payments of each financial year, which shall be audited by the Auditor aftermentioned, and this Statement of the Funds and an Inventory of all the property possessed by the Institution, and a List of the Members, Associate Members, Associates, and Students, whose subscriptions are in arrear, shall be submitted to the First Meeting of the Council, in October.

Annual Report. 35. An Annual report upon the affairs of the Institution shall be drawn up under the direction of the Council at a meeting to be held not less than ten days before the General Meeting of the Institution in October. This report shall embody reports from the representatives elected by the Council to various official bodies.

SECTION VI.—AUDIT OF ACCOUNTS.

Auditor and duties. 36. An Auditor, who must be a Chartered Accountant of at least five years standing, shall be appointed by the Council at their meeting preceding the last General Meeting of each Session, to examine the accounts and books of the Treasurer, and the Annual Financial Statement or Statements of the Funds, and that Statement along with the Audit and Annual Report, shall be printed in the notice calling the First General Meeting of the Institution in October, and shall be read at that meeting.

SECTION VII.—MEETINGS AND PROCEEDINGS OF THE INSTITUTION.

Ordinary General Meetings every four weeks during the Session.

37. The Institution shall hold ordinary meetings for reading papers, and for discussing matters connected with the objects of the Institution; and such meetings shall take place regularly, at least once in every four weeks during each Session; and may be adjourned from time to time. The Sessions shall commence in October, and continue until the month of April next following, inclusive. No business shall be transacted at any Meeting, unless 25 Members shall be present.

At the General Meeting in April of each year for the election of Office-Bearers, the order of business shall be:—

(1) Minutes of last meeting.
(2) To read and consider the reports of the Council and Treasurer.
(3) The meeting shall nominate two Scrutineers who shall be members, and shall hand to them the ballot-box containing the voting papers for the new Office-Bearers.
(4) The Scrutineers shall receive all ballot papers which may have reached the Secretary, and all others which may be presented at the Meeting. The Scrutineers shall then retire and verify the lists and count the votes, and shall, before the close of the meeting, report to the Chairman the names which have obtained the greatest number of votes subject to the conditions of the ballot. The Chairman shall then read the list presented by the Scrutineers, and shall declare the gentlemen named in the list to be duly elected, provided always that the list does

not contain more names than there are vacancies to be filled.

Ordinary Meetings—order of business.

38. At every ordinary meeting of the Institution, the Secretary shall first read the minutes of the preceding meeting, which, on approval, shall then be signed by the Chairman of the meeting at which the minutes are read and approved. The Secretary shall next read any notices which may have to be brought before the meeting; after which any Candidates for admission may, if necessary, be balloted for, and any new Members shall be admitted. Any business of the Institution shall then be disposed of, after which notices of motion may be given. The paper or papers for the evening shall then be read and discussed. Each Member shall have the privilege of introducing one friend to the General Meetings, whose name must be written in the Visitors' Book together with that of the Member introducing him; but if the introducing Member be unable to attend the Meeting he may send with the visitor a card signed by him addressed to the Secretary. During such portions of any of these Meetings as may be devoted to any business connected with the management of the Institution, visitors may be requested by the Chairman to withdraw.

Nature of papers to be read.

39. All papers read at the meetings of the Institution must be connected with the Science or Practice of Engineering or Shipbuilding, and must be accepted by the Papers' Committee before being read.

Proceedings to be published.

40. The papers read, and the discussions held during each Session, or such portion of them as the Council shall select, shall be printed and published forthwith.

Explanatory notes after reading of papers may be published.

41. Explanatory notes communicated after the reading or discussing of papers may be printed in the *Transactions*, if the Council see fit.

Copyright of papers shall be the property of the Institution.

42. The copyright of any paper read at a meeting of the Institution, with its illustrations, shall be the exclusive property of the Institution, unless the publication thereof by the Institution is delayed beyond the commencement

of the Session immediately following that during which it is read; in which case the copyright shall revert to the author of the paper. The Council shall have power, however, to make any arrangement they think proper with an author on first accepting his paper.

43. The printed *Transactions* of each Session of the Institution shall be distributed gratuitously, as soon as ready, to those who shall have been Members, Associate Members, Associates, or Honorary Members of the Institution during such Session, and they shall be sold to the public at such prices as the Council shall fix. Authors of papers shall be entitled to thirty separate copies of their papers, with the discussions, as printed in the *Transactions*.

Members, &c., to receive copies of *Transactions*—Authors 30 copies of their papers.

44. Extraordinary or Special Meetings may be called by the Council when they consider it proper or necessary, and must be called by them on receipt of a requisition from any 25 Members, specifying the business to be brought before such meeting.

Special Meeting may be called by the Council, or on requisition by 25 Members.

45. Any question which, in the opinion of the President or the Chairman of the meeting of Council and Institution, is of a personal nature, shall be decided by ballot; all other questions shall be decided by a show of hands, or by any convenient system of open voting.

Voting.

In all cases, not hereinbefore provided for, only Members, Associate Members, and Associates, shall be entitled to vote. Every Member, Associate Member, and Associate, shall have one vote only, which must be given personally.

Who may Vote.

SECTION VIII.—SUBSCRIPTIONS OF MEMBERS AND OTHERS.

46. Each Member shall, on election, pay an entrance fee of £1, and for the current and for each Session thereafter an annual Subscription of £2.

Annual Subscription payable.

Each Associate Member shall, on election, pay an entrance fee of £1, and for the current Session and each of the two following Sessions an Annual Subscription of £1, and thereafter an Annual Subscription of £1 10s.

Each Associate shall, on election, pay an entrance fee of £1, and for the current Session and each Session thereafter an Annual Subscription of £1 10s.

Each Student shall pay an Annual Subscription of Ten Shillings, but no entrance fee.

In the case of Members, Associate Members, Associates, and Students, elected during March and April no subscription shall be payable for the current Session.

47. Honorary Members shall be liable for no contribution or subscription or entrance fee.

48. The Liability of any Member or Associate for future Annual Subscriptions may be commuted by the following payments, viz., in the case of a Member, by the payment of £25; and in the case of an Associate, by the payment of £20 and, in the event of such payment being made by a Member or Associate on his admission to the Institution, the same shall be in full of Entry Money as well as future Annual Subscriptions.

49. All persons transferred, in terms of Articles 10 and 11, to the Roll of Members, Associates, or Students, to be kept under these Articles, shall not be liable to pay any entrance fee, but for the Session, 1902-3, and thereafter they shall be liable for the Annual Subscription applicable to the Class to which they are transferred. All persons who, as Members or Associates under the former Articles of Association, had commuted their Annual Subscriptions by a capital payment to the Institution shall not be liable for any subscription, notwithstanding the terms of this Article.

When Annual Subscriptions due.

50. Annual Subscriptions shall become due on the first day of October in each year, and must be paid before 1st January following.

Members, etc., not entitled to vote if in arrear.

51. No Member or Associate Member or Associate, whose subscription is in arrear, shall be entitled to vote at any meeting of the Institution nor to receive copies

of papers or proceedings while the subscription remains unpaid.

52. Any Member, Associate Member, Associate or Student, whose subscription is more than three months in arrear shall be notified by the Secretary. Should his subscription become six months in arrear he shall be again notified by the Secretary and all his rights in connection with the Institution shall be suspended. Should his subscription become one year in arrear he shall be removed from the roll of the Institution unless the Council may deem it expedient to extend the time for payment.

Members, etc., retiring from the Institution.

53. Any Member, Associate Member, Associate, or Student retiring from the Institution, shall continue to be liable for annual subscriptions until he shall have given formal notice of his retirement to the Secretary. Contributions payable by Members, Associate Members, Associates or Students, shall be debts due to the Institution, and may be recovered by the Treasurer.

Remission of subscription in certain cases.

54. In the case of any Member or Associate who has been long distinguished in his professional career, but who, from ill health, advanced age, or other sufficient cause, does not continue to carry on a lucrative practice, the Council, if they think fit, may remit the annual subscription of such Member or Associate, and they may remit any arrears due by him. Any such case must be considered and reported upon to the Council by a Committee appointed by the Council for the purpose.

Council may refuse to receive subscriptions in certain cases.

55. The Council may refuse to continue to receive the subscription of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall, in the opinion of the Council, have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution, and may remove his name from the Register, and he shall thereupon cease to be a Member, Associate Member, Associate or Student (as the case may be) of the Institution.

SECTION IX.—GENERAL POWERS AND PROVISIONS.

Powers of Institution in General Meeting.

56. Any Extraordinary or Special Meeting of the Institution, duly called, shall have power, by a majority in number of the persons present thereat entitled to vote, from time to time, to review the decisions or determinations of the Council; to remove Members of Council; to expel Members, Associate Members, Associates, Students, or Honorary Members, from the Institution, and to expunge their names from the Roll; and to delegate to the Council all such further powers as may be considered necessary for efficiently performing the business of the Institution. At any Extraordinary or Special Meeting 50 Members shall be a quorum.

To delegate powers to Council.

Common Seal.

57. The Institution shall have a common seal, which will be under the charge of such of the Office-Bearers as the Council may appoint, and all instruments bearing the seal shall be countersigned as the Council shall direct.

SECTION X.—NOTICES.

Notices.

58. Notices requiring to be served by the Institution upon its Members, Associate Members, Associates, Students, or Honorary Life Members, may be served either personally, or by leaving the same, or by sending them through the post; and notices so posted shall be deemed to have been duly served. No Members, Associate Members, Associates, Students, or Honorary Life Members, who have not a registered address within the United Kingdom, shall be entitled to any notice; and all proceedings may be had and taken without notice to any such.

Induciæ of Notices.

59. Notices for any General or Extraordinary or Special Meeting of the Institution must be given by the Secretary to all Members, Associate Members, Associates, or Honorary Life Members, at least four days before such meeting. Notices of any adjourned meeting shall be given at least two days before the

adjourned meeting is held. Such notices shall specify the nature of the business to be transacted and no other business shall be transacted at that Meeting.

60. Notices for any meeting of Council must be given by the Secretary at least four days before such meeting. Notices for the meetings of Committees shall be given as the Council shall direct. **Notices.**

61. In computing the *induciæ* of any notice the day on which the same is delivered shall be reckoned as an entire day **Computation of Induciæ.**

APPENDIX.

FORM A.

Form of Recommendation and Undertaking.

A. B.............. of...............being upwards of......... years of age and being desirious of belonging to the Institution of Engineers and Shipbuilders in Scotland, I recommend him from personal knowledge as in every respect worthy of that distinction because (here specify distinctly the qualifications of the Candidate according to the spirit of Articles 5, 6, 7, and 8).

On the above grounds I beg leave to propose him to the Council as a proper person to belong to the Institution.

..............................*Member.*

*Dated this............day of............*19

We, the undersigned, from personal knowledge, concur in the above recommendation.

..................................*Member.*

..................................*Member.*

I, the said A B., do hereby promise that in the event of my election I will abide by the Rules and Regulations of the Institution, and that I will promote the objects of the Institution as far as may be in my power.

....

FORM B.

Form for Transfer from one Class to another.

A. B................of..................having been a............ of the Institution of Engineers and Shipbuilders in Scotland for..................years, and being desirous of becoming a...........................of the Institution, we, from personal knowledge, recommend him as in every respect worthy of being elected a.............. of the Institution.

.... *Member.*

.... *Member*

.... *Member.*

I, the said A. B., do hereby promise that in the event of my election I will abide by the Rules and Regulations of the Institution, and that I will promote the objects of the Institution as far as may be in my power.

....

The Council having considered the above recommendation and undertaking approve of the same.

....*President (or Chairman).*

Dated this.........*day of*...........19

BYE-LAWS.

MEDALS AND PREMIUMS.

1. Each of the two Medals founded by subscription, for the best paper in the Marine and Railway Engineering Departments respectively, shall be awarded by the vote of a General Meeting, not oftener than once in each Session.

Marine and Railway Engineering Medals.

2. The Council shall have power to offer annually a Medal for the best paper on any subject not comprehended by the Marine and Railway Engineering Medals. Such additional medal to be called the Institution Medal, and to be paid for out of the Funds of the Institution, until a Special Fund be obtained. This medal also shall be awarded by the vote of a General Meeting.

Institution Medal.

3. If it shall be the opinion of the Council that a paper of sufficient merit has not been read in a particular department during any Session, the Medal shall not be given in that department; and, in the case of the Marine and Railway Engineering Medals, the interest arising from the particular Fund shall be added to the principal.

When Medals may not be awarded.

4. If the Person to whom a Medal may be awarded shall express a wish to receive a Bronze Medal, accompanied with the extra value in Books, in lieu of the ordinary Gold Medal, the award shall be made in that form. The Council may recommend premiums of Books in lieu of, or in addition to, the Gold Medals. The value of such premiums of Books to be determined by the Council.

Medals and Books may be awarded.

MANAGEMENT OF THE LIBRARY.

5. The Council, at their first Meeting each Session, shall appoint eight of their number to form a Library

Appointment of Library Committee.

Committee, one of the eight to be Honorary Librarian and Convener of the Committee. Three Members of the Committee shall form a quorum.

Secretary shall have charge of Library.

6. The Secretary of the Institution shall have charge of the Library, and shall also act as Secretary of the Library Committee.

Powers of Library Committee.

7. The Library Committee, subject to the sanction of the Council, shall expend in Books and Library expenses the sums placed at their disposal, and, subject to the approval of the Council, may make Bye-Laws for the management of the Library, and appoint Assistants. The sum of £30 or thereby shall be expended annually out of the funds of the Institution, in the purchase of Books for the Library, in addition to the ordinary expenditure in binding, &c.

Duties of Library Committee and Annual Report.

8. The Library Committee shall annually make an examination of the property in connection with the Library, and report to the Council, detailing the state of the Library affairs.

LIBRARY BYE-LAWS AS TO USE OF BOOKS.

When Library is to be open.

9. Except during Holidays and Saturdays, the Library shall be open each lawful day from 1st May till 30th September inclusive, from 9.30 a.m. till 5 p.m. On Saturdays the Library shall be open from 9.30 a m. till 1 p.m. On the 1st October and thereafter throughout the Winter Session the Library shall be open each lawful day from 9.30 a.m. till 8 p.m., except on Meeting nights of the Institution and Royal Philosophical Society, when it shall be closed at 10 p.m. The Library shall be closed for the Summer Holidays from the 11th July till 31st July inclusive.

Who may borrow books.

10. Books shall not be lent to any persons except Members, Associate Members, Associates, Students or Honorary Members of the Institution; but a person entitled to borrow books may send a messenger with a signed order.

Books for Consultation only.

11. The books marked with an asterisk in the Catalogue shall be kept for consultation in the Library only, and shall not be lent.

Librarian to keep Accession Book.

12. The Librarian and Assistant Librarian shall take their instructions from the Secretary of the Institution. They shall keep an Accession Book, in which shall be entered the particulars of all books purchased for or donated to the Library.

Register kept of books lent.

13. The Librarian, or Assistant Librarian, shall keep a Register, in which he shall enter the titles of the book or books lent, the date of lending, the name of the borrower, and the date of the return of the book or books to the Library.

Borrower to sign for books.

14. The borrower of the book or books, or, in his absence, the bearer of his order, shall sign his name to the entry of such borrowing in the Librarian's Register.

Librarian to certify return of books.

15. The Librarian, or Assistant Librarian, shall sign his initials to the date of the return of the book or books.

Books damaged to be entered in Register. Intimation to Library Committee, and notice to last borrower.

16. The borrower shall be responsible for the safe return of the book, and if it be damaged or lost he shall make good such damage or loss. Should books be returned in a damaged condition, the Librarian, or Assistant Librarian, shall immediately make an entry of the fact in the Register, and report the same to the Library Committee without delay; and he shall give notice in writing of such entry, and report to the person from whom he last received the book, within three clear days of the receipt of the book, exclusive of the day of receiving the book and the day of giving such notice.

Number of books which may be borrowed at one time.

17. No person shall be entitled to borrow, or have in his possession at one time, more than two complete works belonging to the Library, or two volumes of any periodical.

Persons in Arrears of Subscription not to have use of Library.

18. No person being six months in arrears with his subscription to the Institution shall be at liberty to use the Library or Reading Room.

Time books may be obtained.

19. No borrower shall have the right to retain a book longer than thirteen clear days, exclusive of the days of borrowing and returning; and written notice shall be sent to the borrower one day after the time has expired. In no case shall any book be kept longer than twenty clear days.

Lots to be drawn when two may apply for the same book.

20. In the event of two or more persons applying for the same book at the same time, the applicants shall draw lots for priority.

Introduction of friends to Reading Room.

21. Each Member shall be entitled to introduce a friend to the Reading Room, whose name shall be written in the Visitors' Book, together with that of the Member introducing him.

Annual scrutiny of books.

22. All books belonging to the Library shall be called in for inspection, and the lending out of books shall be suspended in each year for one week, being the last seven clear days of March; and all Members shall be required, by an intimation to be inserted in the notice calling the preceding meeting of the Institution, to return all books in their hands to the Library on or before the day next preceding the period before mentioned.

NOTE.—The Library and Reading Room are open to Members, Associate Members, Associates, and Students; and the Library of the Philosophical Society is open for consultation.

WILLIAM BROWN, *Convener.*
WILLIAM M. ALSTON.
PROF. A. BARR, D.Sc.
W. A. CHAMEN.

E. HALL-BROWN.
WILLIAM MELVILLE.
JOHN STEVEN.
JOHN WARD.
EDWARD H. PARKER,
Secretary.

21*st April*, 1903.

INSTITUTION
OF
ENGINEERS AND SHIPBUILDERS
IN SCOTLAND
(INCORPORATED).

PRESIDENTIAL ADDRESS
OF
MR. JOHN WARD.

22nd October, 1907.

I FEEL greatly honoured in having been elected by my fellow-members to follow in the Presidential Chair such a worthy company of engineers and shipbuilders. It is an honour of which any man may be justly proud.

When I remember the many eminent men who have preceded me in this Chair, beginning with that great genius Macquorn Rankine, I feel both diffident and humble. I know and realise the high aims and ideals with which my predecessors worked for the best interests of this Institution, and how specially this has been the case in the work done by our esteemed retiring President, Mr James Gilchrist. As his successor, I can only say that in discharging the duties devolving upon me, I shall earnestly strive with your co-operation and support to uphold and maintain the high reputation of our Institution in the professional world, and at the end of my term pass on the office to my successor undimmed and untarnished.

The next two sessions are likely to be memorable ones in the history of our Institution. The present one from the fact that it is the last during which we shall meet in this familiar building, and the succeeding one, because we will then meet in our new home. I desire then in your name, to recall our great indebtedness to past presidents and members during our fifty years existence as an Institution, years which to the seniors especially are fraught with the memories of familiar forms and faces—many, alas, long gone to their rest—who as fellow-members right worthily did their part, and of whom in this, our session of severance and departure, we think this evening with affectionate esteem and regard. This is borne in upon us very specially by the report just read, giving a record of our losses by death during last session. In the list are some of the names of our oldest and most esteemed members. Mr Hazelton Robson, Mr Andrew Brown, and Mr Walter Brock represented the grave and reverend fathers of our Institution, who as captains of industry, and outstanding engineers did much for the advancement of their profession, and writ their names large in its history.

Mr James Rowan's sudden death was to many of us a personal loss, as well as a loss to the profession he adorned. We looked upon him as one of the outstanding vigorous men, who would certainly uphold and maintain the best traditions of his profession and our Institution. As a captain of industry he was brimful of enthusiasm and energy, and crowded much professional work into a comparatively short life.

Sir William Robertson Copland, another esteemed member, has gone to his rest. From my close comradeship with him as your representative on the Board of Governors of the Technical College (of which he was the able Chairman) I can truly say that both we and this great city are all the poorer for his loss.

You can quite well believe that the choice of subject matter for a presidential address is generally one of some difficulty. Fortunately, or unfortunately, for you and me, the fact that we have reached our jubilee year, virtually fixed the subject and its nature. A jubilee year, whatever it commemorates, is usually sufficient warrant for a brief retrospect of the events connected with it, and very specially so when it is also the centenary of marine engineering, as applied successfully to ocean navigation.

And so, gentlemen, although I might wish as an individual to speak more freely than I may do as your President, I accept the subject with some measure of satisfaction, while perhaps not with absolute confident hope of meeting expectations.

As an Institution we have, as it were, reached a Mount Pisgah in our history, whence we may look back on the ways we have trodden, then glance through the mists of futurity to our promised land. To the older members, despite difficulties and disappointments of earlier years, the backward glance is full of comfort, if not of complete satisfaction; since retrospect always brings the wisdom of experience after the event. But, best of all thoughts, there is joy in the fact that we can place in the hands of youthful enthusiasts the means of discerning the great things which the forward glance promises.

The temptation came to me to speak a little about the good work done by our Institution, but I rejected it, because there is nothing so harmful to a youth as to have done for him that searching after knowledge which is stimulating and suggestive. The volumes of the Proceedings of the Institution are well worth study, because the future, whatever it may have in store, must be built up on the experience of the past. Errors can only be avoided by a full knowledge of the successes, and it may be the failures, made by preceding generations, and I hope that amidst the great flood of technical literature, which abounds on every hand, our young members will realise that while modern text-books and modern formulæ will provide them with ready reckoners for the future, the surest road to success is discovered by careful analysis of the work of the past. If our Institution has done nothing more than place on record some part of the contemporaneous literature of engineering work during the past fifty years, it can claim to have done a great work. Convinced of this, I hope that one of the commemorative events of our jubilee will be the publication of a complete index to the whole 50 years' transactions of the Institution. The value of such a work is too obvious to require further commendation.

The importance of research among past records was brought home to me when studying the story of the evolution of the marine engine. The fact that this is, as I have already said, not only the jubilee year of our Institution, but the centenary of the successful application of steam to a commercial ship, induced me to study the early efforts to construct a reliable marine steam engine. I do not propose to enter into details of this early work; in the appendix there is given in chronological order a record, so far as I have been able to gather, of the successive proposals, which appendix I trust may be helpful to the student.

The research shows that there were many minds working at the problem, and had they had the advantage of easily accessible records of the past, their work would have been simplified, and success more quickly achieved. It seems surprising, for instance, in view of Blasco de Garry's close approximation to success in paddle wheels, that we had not paddle steamers in the fifteenth century at latest. Papin's idea in 1688, of producing motive power by means of a piston working in a cylinder, ought also to have brought a practical application of steam. And yet Fitch in 1787 applied in his first and second boats mechanically worked oars. It is difficult to say how far the workers up to the time of Patrick Miller of Dalswinton were aware of earlier inventions. The problems of steam navigation were attractive to ingenious minds; the variations of probable solutions were within somewhat restricted limits. Contemporaneous experiments, and even workers in successive generations, arrived at the same results unconscious in many cases of each other's operations. Had there been interchange of thought—one of the incalculably great advantages of modern technical literature and professional institutions—practical success would have come early from the lead of the great workers, notably the Marquis of Worcester, Papin, and Hulls, who respectively disclosed the elasticity of fluids, the condensation of steam and the influence of vacuum thereon, and the use of the piston in giving a reciprocating motion. Towards the close of the eighteenth century there was certainly freer intercommunication, and records were more available and more closely studied.

Watt, whose name must illumine every page of the history of the steam engine, is an early example of research upon original work. His knowledge of French and German, and the facilities he had in our Glasgow University, must have brought him into touch with early works, stimulating mental ingenuity and guiding experimental activity. Without the great and well-known discoveries and improvements due to his work, the marine engine could not have succeeded. He was unfortunate only in not having the financial help which Fulton subsequently got. The inventor without financial support is but a voice crying in the wilderness proclaiming the advent of a new era. May this not be equally the case to-day? It is true that the proportion of useful inventions to the total is not one per 100, some might say not one per 1000, but that single useful invention may go unheeded. Watt had many disappointments before he succeeded in impressing patrons with the worth of his invention. Miller of Dalswinton grew weary of his work; Symington, too, was neglected by his patron; and Fitch died from an overdose of opium. We may similarly miss in our generation great inventions.

Patents are granted by a beneficient Government, because they yield revenue, and the patent agent, being human, encourages the inventor, because of the pending fee; but is it not possible to organise a great laboratory on commercial lines, to give the hall mark, after sufficiently searching experiment, to the practical and commercially valuable invention? This would require money, but the income of each successful invention might be taxed for the general good. The scheme is not one for Government control like the National Physical Laboratories, where purely scientific research is pursued, and with general advantage; it is rather one for millionaires, who by helping the invention of a useful idea could confer greater benefit on mankind than by many philanthropic schemes they now subsidise. For lack of this stimulation, perhaps, also, because of legislative restriction, Britain got behind in electrical work, in chemical science, in the internal combustion engine, and to-day from the same cause she is taking a second place in aerial ships. Fulton's credit as the first to run a commercial steam propelled ship is largely due to such financial support; his credit is none the less, but the lesson should not be ignored. An American of British parentage, Fulton was studying art in England, and becoming enamoured with mechanics, secured the Duke of Bridgwater, the Earl of Stanhope, and the U.S. Minister at Paris, Robert A. Livingston, as patrons. In 1798 Livingston got by legislation a monopoly of the passenger traffic on the waters of the New York State. Fulton was meanwhile working at the steam engine, and had submitted a submarine boat for test to the French Government; it was not a success. He then returned to this country, and there can be no doubt that he went on Mr Symington's boat on the Forth and Clyde Canal in 1801, although perhaps under an assumed name. In the biography of William Symington, published in 1862, there are printed sworn affidavits by all the crew and others to this effect. Even so, Watt built the engines for Fulton's boats, and in the appendix are copies of letters from Fulton to Boulton and Watt in connection with the design and order. The hull was built to suit the engine. Thus the credit for the historic "Clermont" is widespread, and the conception of the idea and its realisation offers further proof of the universality of science, and proves that notwithstanding mechanical genius money generally rules.

The "Clermont," which commenced trading on the River Hudson in August, 1807, was unquestionably the first commercial steamer, and as such was the embodiment of the ideas of many workers of different nationalities, affording a literal fulfilment of the old prophecy, "Many shall run to and fro and knowledge shall be increased."

To members of the Institution, it is a great satisfaction to reflect that the outstanding genius amongst the contributors to this result was our patron saint—James Watt. As ship succeeded ship fitted with Watt engines, and the mercantile marine developed, his genius became more widely recognised, and his services to the nations of the world more fully appreciated. To-day Fulton is being deservedly honoured in the United States. The new largest side-wheel steamer ever built in America is being called after him, and is to run between New York and Albany as did the "Clermont." A bill has been passed by the American Government granting land on the Hudson River front for the erection by his countrymen of a watergate to the city of New York, as a memorial to his work and worth, and a fitting and abiding statue to his memory is also being erected. To accomplish this a fund of $1,000,000 (£200,000) is being raised and the representative citizens whose names figure on the executive and gneral committe are warrant that the memorial will be speedily and successfully completed.

Should we not similarly signalise the centenary by naming the new home of the Institution the James Watt building, or at least the lecture hall of it, the James Watt hall, and by placing in a prominent place in the vestibule a model of this first commercial steamer's engines?

Although it was five years after the advent of the "Clermont" before Henry Bell's "Comet" began a regular service on the Clyde, British enterprise was aroused and the progress of the industry was rapid.

I have extended the chronological table in the appendix to 1840 when regular ocean steamship services were undertaken, and it is unnecessary here to do more than refer to one or two significant incidents.

Up till 1840 the United States were keen competitors and the number of ships built was greater than in this country. America's rich supplies of timber, which was the building material, and the extent of her sea-board and inland waters, account for the early rapid steamship development in the States. But there came a change in the relative positions of Britain and America when economy enabled engines to be used in ocean voyages, and when iron began to replace wood as a constructive material. This was in 1818, in a vessel built for the Monkland Canal trade; then an iron steamer, the "Aaron Manby" built in 1821, at Horsley, under Captain Napier made the trip to France, where she was used for river traffic; next in a vessel built in 1832, at Birkenhead, for the regular coasting trade; and also in the "Great Britain," built at Bristol in 1843.

Wooden vessels, however, continued long in vogue, and the difficulty of getting material in Britain and the consequent high price militated against the progress of the industry. Iron was then much dearer than wood, and there was moreover prejudice against it; it was difficult for a layman to realise that a material which itself sunk like a stone should be superior for a ship's hull to wood, which itself floated. In 1834 the iron steamer "Garry Owen," built at Birkenhead, was driven ashore on her first voyage during a gale, and the satisfactory manner in which she withstood the injury did much to establish confidence in the strength of iron ships. The stranding of the "Great Britain," the first of the Atlantic liners of iron, without the hull being greatly injured, further proved the superior resisting power of the metal hull. Thus iron ultimately won the day, although financial considerations which must ever be dominant had the greatest influence. The iron ship was 25 to 30 per cent. lighter than the wooden ship of the same dimensions, and draught and cargo capacity was increased to a corresponding extent. In wooden vessels again, the limit of length was about 275 feet over all, the "Great Eastern," built in 1858 proved that there was little limit to the length of the iron ship. The effect of the introduction of iron was a redistribution of the seats of the industry. In the early days the larger vessels were built on the Thames, at Bristol, or on the Mersey, because these were the great ports into which timber was brought. When iron became the constructive material, the Clyde, and later, the Tyne, Wear, and Tees, became the great shipbuilding centres by reason of their proximity to the iron and coal fields. This condition has naturally continued through the steel era. Bessemer's converter, and still later Sir William Siemens' open hearth process early in the eighties gave the shipbuilder a material in which there was infinite possibility, and to its adoption is partly due the position in which our mercantile marine stands to-day. On this head the tables in the appendix, compiled by the courtesy of Lloyd's Register of Shipping, are both interesting and up-to-date. The adoption of steel not only enabled the metal hull to be reduced to the extent of about 15 per cent. in weight, but made the naval architect more comfortable because of its greater ductility, and of its resistance to local stresses as well as hogging and sagging stresses, which have increased in amount with the increased dimensions of ships.

The introduction of alloys will bring still further reductions in scantlings, especially in large ships. High tensile steel is, it is true, expensive, but that objection has been applicable to every new departure. With an extension of its use, and with greater experience in manufacture there will come a reduction in price. Moreover, the saving in weight of the hull will augment the proportion of cargo carried to the total displacement, and the resultant increase in the earning power should compensate the shipowner for any small increase in capital expenditure. I do not wish to suggest limitations, but there must come a time when in large ships, as with destroyers and light craft now, the problems of buckling stresses will militate against further reductions of scantlings, but in merchant work we are still far from this. This indication of the influence of metals on our results as marine constructors points to the importance of the young member of the Institution devoting time to what may be termed the collateral branches of his profession.

To continue the historical resume. The "Archimedes," launched in 1838, was, I think, the pioneer commercial steamer fitted with screw propellers, although Stevens of New Jersey had experimented with them away back in 1804. The Inman Line was the first to adopt the screw on the Atlantic service. In 1850 Mr Inman purchased the "City of Glasgow" and sent her on a winter trip across the Atlantic, with the result that a new British line was organised in 1853. The Royal Mail Steam Navigation Company also adopted the system, and quickly the screw propeller, save for light draught craft, became almost universal.

There is here great scope for the young engineer, as few units of marine machinery involve a greater uncertainty than the propeller. The problem has been attacked with a certain degree of success by various patient investigators. It involves the consideration of many factors of hitherto indeterminate value which are usually ignored, but high speed vessels (particularly those driven by turbine engines) have necessitated the most careful consideration of all the factors. For many years designers pinned their faith to a particular pet formula for determining the dimensions of screw propellers. For ordinary vessels, and within certain limits, the results have been usually satisfactory, but experiments with model propellers behind a ship model fitted with shaft bosses and supports, are of much more value than many formulæ. The deduced

H.P. for the ship thus obtained being definitely related to the I.H.P. of the ship on measured mile conditions, so long as cavitation does not take place. Such model tests are more difficult of application, however, in cases where the ship's screws are so small as to cause cavitation, for in such cases the same effect cannot be easily produced with the model screws, and the results cannot, therefore, be directly compared. A complete and infallible formula to deal with cavitation has yet to be evolved by the determination of the exact relative values of the various dynamical factors, and in the absence of such a complete formula, there is need for caution in dealing with the matter.

The necessities of the screw propeller after its general adoption, demanded a much greater increase of engine evolution than constructors in the early days, or for some years after, deemed it prudent to adopt. Thus a great variety of design, including beam, steeple, oscillating and other forms of machines were used, all with gearing between the engine and the propeller. But a few direct-acting engines appeared very early, and gradually, as engineers gained confidence, this latter type became universal, and assumed the form of the inverted cylinder in the so-called steam hammer engine which was the universal type for mercantile purposes until the end of the century.

John Elder we may look upon as the father of multiple-expansion engines. He, together with his partner, Charles Randolph, was trained in the marine school of Mr Robert Napier, Vulcan Foundry, Washington Street, Glasgow. In 1852 they commenced business, and by 1856 had constructed several four-cylinder compound engines. In our own Transactions, Professor Rankine in his Presidential Address (Vol. II., Oct., 1858) states that Randolph, Elder and Company, entered into a contract for a set of engines the coal for which, on trial, would not exceed 3 lbs. per I.H.P. per hour. The trial was reported on by Professor Rankine and worked out at $2\frac{18}{20}$ lbs.

The I.H.P. was given as 744 "including friction." The boiler pressure is not stated, but we may assume it was not more than 80 lbs., very probably less, and the engines were jet condensing. In the same Volume, p. 33, Mr Walter Neilson remarked that a "consumption of 5 lbs. per I.H.P. was considered very economical." A notable reduction indeed by one of the early fathers.

At a meeting of the British Association in 1858 (see "Artizan," Jan. 1859) Mr Elder referred to the "Pride of Erin" burning 4·27 lbs. coal, and the "Valparaiso" with his compound engines burning 2·98 lbs. on the run from Glasgow to Liverpool. "In both cases the surface blows were open."

At the meeting of the British Association the following year, 1859 (see "Artizan," Oct. 1859), Mr Elder read a paper on his engines for the Pacific Steam Navigation Company's steamers "Callao," "Lima," and "Bogota," which had been brought home from the Pacific coast to be re-engined. These vessels all showed a consumption of from 2 to 2½ lbs. per I.H.P. of best Welsh coal. In the "Artizan," Nov. 1859, a reference to the performance of the "Bogota" states that with her old engines the "average speed was 9·75 knots and the coal consumption not less than 38 cwts. per hour." On her voyage out with new engines she "gave a mean speed of 10·47 knots with 19 cwts. of coal per hour." Using Atherton's formula the writer shows "this meant an economy of 59.919 per cwt., the coals in both cases being of exactly the same quality." The steam pressure was 22 lbs., the average coal 19 cwts. per hour, and about 950 I.H.P., giving an average of 2¼ lbs. per I.H.P. per hour.

These early fathers seemed to see into the future. Walter N. Neilson, in his Presidential Address (Vol. III., 1859) refers to "the three grand requirements" (of marine engines) "may be stated as—a safe and suitable boiler for 100 lbs. and upwards; a good arrangement of engine to receive the initial force of the steam without shock or liability to derangement, and carry out expansion to the greatest practical limits; and, lastly, an efficient surface condenser."

John Elder was among the first to adopt the surface condenser, and the cylindrical boiler, and he thus in the "fifties" brought to a successful issue these "three grand requirements." We must go back to these early days to realise what it meant to make a boiler which would "be safe for 100 lbs.;" steel plates of the present day weighing tons were then represented by puddled iron plates weighing hundredweights. This led John Elder to try a water tube boiler, practically the modern Yarrow boiler, also a spiral tube boiler, but probably none of these were successful owing to the salt water difficulty, evaporators not being introduced till many years afterwards. Indeed, John Elder might be looked upon as a Macquorn Rankine among marine engineers, "as a man ahead of his time."

The increase in pressure called for better design and workmanship in the construction of boilers. This necessity stimulated research for the ultimate successful manufacture of the new carbon steel, thus enabling further progress and pressures reaching from 90 to 100 lbs. with the compound engine, to be made, and proportionate economy achieved. Efforts towards higher economy were not relaxed, and as pressures increased it was recognised that the range of expansion afforded by two cylinders was not sufficient, and as far back as 1874, these considerations induced the late Dr. A. C. Kirk, a former President of this Institution, and at that time engineering manager to John Elder and Company, to propose a triple-expansion engine, in which the steam was expanded successively in 3 cylinders, the initial boiler pressure being 160 lbs. The machinery was fitted on the "Propontis" in association with a set of the late Mr Rowan's tubulous boilers. The boilers did not prove quite satisfactory; but when these were replaced with the ordinary type, the machinery worked well. In 1881, he, then being the senior partner in the firm of Robert Napier and Sons, built a second form of triple-expansion engine for the s.s. "Aberdeen," the initial pressure in this case being 125 lbs., and the boilers of the return-tube cylindrical type. The machinery of this vessel proved very economical, the consumption of coal being 1·6 lbs. per I.H.P. per hour, or about one-half the rate in ships thirty years earlier.

Pressures continued to increase, and engines expanding the steam through 4 cylinders were designed by my late senior partner, Mr Walter Brock, and constructed by Denny and Company, pressures up to 200 lbs. being adopted. In a list of the vessels trading from Southampton, Portsmouth, and Weymouth, in 1860, I find that the steam pressures range up to only 20 lbs. per square inch. In 1872 the average was 52 lbs., in 1881 it was 77 lbs., and ten years later 158 lbs. Now it is in many cases over 200 lbs.

The effect of higher pressures is perhaps more readily appreciated by a measure of the economy. In the Cunard "Arcadia," built in 1840, with the old flue boiler working at 6 to 7 lbs. pressure, the consumption of coal per unit of power was 5 lbs. Fifteen years later the "Persia," with tubular boilers working with 20 lbs. pressure, had a coal consumption of 4 lbs. per horse power per hour. The lapse of 20 years brought the compound engine, and the return-tube boiler with 10 lbs. pressure and a coal consumption of about 2 lbs. per horse power per hour. The triple-expansion engine, with 180 lbs. pressure reduced the fuel to 1½ lbs., but since then increased pressure has failed to bring much appreciable reduction, although 1 lb. per horse power per hour has frequently been claimed.

In the early compound engines steam was superheated to a certain extent by the hot gases passing to the funnel, and in some of them the steam, after being exhausted from the high pressure cylinder, was reheated by passing through pipes in the uptakes before being admitted to the low pressure cylinder. The cylinder walls and ends were most carefully jacketed, and in some cases even the interior of the piston was also heated by live steam entering by a telescopic pipe passing through a gland in the bottom of the cylinder. All of these applications were to prevent condensation within the cylinder, and were discarded when pressures were increased. But superheating will be again used, and in combination with the utilisation of exhaust steam for driving low pressure turbines, will result in a material reduction in the coal consumption per unit of power, and in this latter combination, as in the introduction of turbines for commercial steamers, I am pleased to think my firm will probably be again first in the field.

In the gradual and successful development of the steam engine a large share of the practical success is due to the skill of a trade whose name is rarely mentioned. I refer to the iron-founder, who has met successfully every demand upon him, whether for castings light or delicate, or as much oftener the case, of a kind large and complicated, enabling the engineer to experiment and advance stage by stage with his machinery until it has reached its present high water mark of perfection.

While the marked and growing economy in coal consumption is gratifying, yet it does not represent the whole sum of the indebtedness of commerce to constructors of marine engines. The cost of transport has been enormously reduced by the construction of leviathans carrying huge cargoes, and these would have been impossible had not the problems associated with steam machinery and constructional strength been tackled with courage and success. The first cost of our ships per unit of capacity is not more than one-half of what it was fifteen years ago, consequent upon the improved methods in our shipyards and engine works, to which unfortunately I can now but merely call attention to the fact. The cost of working the ship has also been correspondingly reduced, so that if the requirements of the benefactor of the race has not been literally fulfilled by " making two blades of grass to grow where one grew before," the Briton at least has been enabled to take from his productive colonies two bushels of corn at the same cost as one bushel a few years ago.

The comity as well as the commerce of nations has been advanced, because not only has speed and economy been increased, but the seduction of travel has been added to by robbing the ocean voyage of a great part of its terrors. The freeboard of vessels has been increased, and bilge keels added; structural strength has been augmented without increase of scantlings; the rolling has been minimised without affecting the reserve of buoyancy; the movements of ships in a seaway has been reduced by laying down conditions of load suitable for each design; and vibration and noise has also been reduced; thus the ship of to-day resembles the building on shore as nearly as is possible with a structure borne on such a restless element as the sea. But above all, the time between this land and that land has been materially reduced, and commercial and social intercourse encouraged.

The Atlantic service has offered the naval architect the best opportunity for increasing speed. It is not possible in this address to enter at length into this question. The advance has been most striking. On the Atlantic service we have in thirty years increased the rate from 16 to 25 knots; on the South African service from 14 to 19 knots; on the South American service from 14 to 18 knots; on the Australian and far Eastern service from 15½ to 18½ knots; while on the Channel service and Mediterranean and Oceanic seas, the rate has gone up from 14 to 22½ knots.

At the time of the American Civil War, there were built blockade runners, in the design of which speed was the dominant, almost the only consideration, and 17 knots was considered a phenomenal rate—to-day this is a very ordinary speed.

In the British merchant fleet there are 128 vessels exceeding 18 knots, and in foreign fleets 57; of vessels of over 20 knots, we have 52 vessels, and foreign nations 30. In naval ships the increase has been even more remarkable. Of more than 22 knots, Britain now possesses 47; and all foreign navies combined 90 ships. Of torpedo craft of over 30 knots we have 89 vessels, all foreign navies combined 75 vessels.

Marine constructors recognise no insurmountable obstacle to higher speeds even to more than 25 knots. The limits are purely financial; that is why the Atlantic service leads in speed. There you have a great flow east as well as west of passenger traffic at remunerative rates. You can have throughout the greater part of the year, a passenger list of 1000 or 1500 passengers per ship, and do not require to consider cargo.

On the Australian and Eastern service, on the other hand, the passenger traffic has not yet grown to anything like the same proportions, and it is largely outwards, the return passenger lists being limited. Cargo must, therefore, be carried to ensure a satisfactory revenue, and the main financial consideration has reference to the most economical rate of speed for the combined duty of mail, cargo, and passenger carrying. From 10 to 12 knots is undoubtedly the most economical rate for cargo. For a displacement of 16,000 tons, and lengths varying from 480 feet for 12 knots to 600 feet for 22 knots, the I.H.P. for a sea speed of

12	knots	will be	about	4500.
15	,,	,,	,,	8700.
18	,,	,,	,,	16000
20	,,	,,	,,	20000.
22	,,	,,	,,	25000.

For every additional 1000 I.H.P., from 180 to 200 tons has to be added to the weight of machinery, and the space occupied increased by 350 to 400 square feet. The dimensions and strength of the vessel have therefore to be increased to accommodate the machinery. Greater size again means additional motive power to maintain the required speed, and to carry the required supply of coal. The vessel of 12 knots will carry a total deadweight of fully 10,000 tons and only burn 70 tons of fuel per day.

The 22-knot vessel will burn about 400 tons per day, and only have a total deadweight capacity of 3000 tons. And thus it comes that in 30 years the Atlantic liner has advanced in displacement tonnage from 8000 to 38,000 tons, not for the mere glory of size, but to enable the advance of speed from 16 to 25 knots to be made. The coal burned on the voyage has gone up from 850 tons to over 5000 tons—this for a voyage of 2800 miles. If the coal has to be carried for a longer distance this again will involve an increase in load, in capacity, and, consequently, in the dimensions of the ship, to accommodate it.

Warm-hearted and patriotic colonials are bent on having at an early date an "All Red Line" of 22- to 25-knot steamers, to link up the colonies and the mother country. Last week the Canadian Premier, Sir W. Laurier, speaking at Halifax, declared that the "All Red Line" "shall, must, and will succeed." This is the true spirit in which to speak, and one through which our countrymen have built up this great Empire. The President of the Board of Trade, Mr. Lloyd-George, similarly emphasised this spirit in his message to the Toronto paper in which it appeared a week ago, the occasion being the inauguration of commercial wireless telegraphy from this country to America and Canada. He wired—"Every improvement in the communication between the various parts of the British Empire helps to consolidate and to strengthen it. All well-wishers of that Empire will welcome, therefore, every project for facilitating the intercourse between Britain and the great Dominion across the Atlantic."

So say we all. The question of a 22- or 25-knot line of steamers to the colonies, however, has difficulties, by reason of the length of voyage, which most people lose sight of when speaking on this subject. Let me try and state the problem as looked at from a naval architect's point of view:—

An 18-knot liner, sailing from Vancouver to Sydney, calling at one of the Pacific Islands, and New Zealand, will take 18 days actual steaming time to do the journey, and besides carrying bunker coal for the voyage will be able to carry, clear of passengers, from 2250 to 2500 tons of paying deadweight.

Five such vessels can be built for the price of one "Lusitania," steaming 25 knots, and altogether can carry, say, from 11,250 to 12,500 tons of paying deadweight. A "Lusitania" steaming 25 knots will take 13 days, but as this latter vessel has only a total deadweight capacity of about 7500 tons, and the coal consumed on the voyage will be 15,000 tons, the whole or at least a greater part of the 5 days gain will be taken up by coaling en route, leaving absolutely nothing for revenue save passengers and mails.

Or take a vessel with a sea speed of 22 knots, length, say, 650 feet, with a displacement of 23,000 tons (proportionate to that of the 25-knot "Lusitania"). This steamer will do the journey in 15 days nett steaming time, and burn about 600 tons of coal per day. The total deadweight will be about 6000 tons. The vessel, however, will require to coal at least once en route, using up a substantial part of the 3 days less steaming time than that taken by the 19 knot vessel, and at the same time burning fully twice as much coal on the voyage, so that when mails, passengers' baggage, and consumable stores are deducted there is practically nothing left for paying deadweight. It thus becomes a matter for consideration whether these five ships would not do far more towards empire building than one or two phenomenally fast ships. A time will come when we shall have 25-knot Australian liners, but not this year nor next, and the time will be hastened by such inventions as that of Parsons' turbine.

The beginning of the nineteenth century opened a new era in the world's industries by the triumph of steam. I must leave to others, or to a future occasion, a fuller analysis of the significance of the changes which steamers brought, from the mechanical and social standpoint. The work of the century was exclusively evolutionary. Parsons' invention is revolutionary. Ingenuity, careful study of the experience of the past, and patient experiment, enabled him to devise his turbine which much more than any other machine utilises to the fullest extent the expansive properties of steam.

The higher steam economy, at no greater first cost, and the reduction in working expenses, account for the unprecedented development in the application of this new invention. It is only ten years since the pioneer steamer, the "Turbinia," developed a speed undreamt of for a vessel of moderate dimensions, displacement, and deadweight. Two torpedo boat destroyers followed, and in company with two of my partners, Mr James Denny and the late Mr Henry Brock, I attended the trial trip of the "Viper" (on the 20th July, 1900), when she steamed at a mean rate of 37 knots. We were convinced that the experimental stage of the turbine had passed, and my firm readily agreed to associate itself with the first commercial steamer having turbines. When that vessel was built, it was little thought that within five years there would be ordered 65 mercantile turbine driven vessels of a tonnage of 264,535, or with war vessels and yachts added there would be turbine machinery to-day of 1½ million H.P., and that the "King Edward" would develop into a "Lusitania" and her sister the "Mauretania" of over 70,000 H.P. each.

The success of these large turbine vessels is a great triumph and worthy of a great engineer and inventor, who can have claimed for him as truly in his life time, as it is recorded of Watt on his tomb in Westminster Abbey, that by "directing the force of an original genius to the improvement of the steam engine, he has enlarged the resources of his country, increased the power of man, and risen to an eminent place among the real benefactors of the world." Might I suggest, that along with a model of Watt's marine engine for the first commercial steamer, we should place in the new home of the Institution a sectional model of the Parsons' engine for the first turbine driven steamer. The advance of the turbine proves that British engineering still takes first rank in initiative and in courage, and British engineers may look forward to the future, certain of success. From our Mount Pisgah we can descry the dim suggestion of great events. You will find problems awaiting solution, problems which are seductive because of their difficulties.

Gas and oil engines may in time be so improved as to be suitable for ocean propulsion. There is justification for the effort being made by many to evolve a satisfactory design, but the problems, although not insurmountable, are still very difficult. No internal combustion engine is self starting, and trouble is experienced with the reversing gear so far proposed. Some have adopted compressed air for starting and for working the engines during manœuvring, others suggest an electric motor connected with the shaft in such a way that it may be coupled or uncoupled as required for starting or manœuvring. Experimenters are still busy devising reversing gear and clutches, but if you have clutches you must use gear, and it is not easy to transmit high power through gearing; moreover gearing is noisy.

It is true that a large measure of success has attended the heavy oil engine in the latest submarine boats, but withal there is work for the young engineer in the development of the internal combustion motor. But may there not be discoverable some absolutely new source of power. If radium can give practically unlimited energy, other similar, and perhaps, more plentiful materials, may be discovered.

Then, there is the problem of mechanical flight. At present almost all effort to produce an aerial ship seems to be dictated by the war authorities. The story of man's contest with the air is a fascinating one, and so late as this month, in the "London Magazine," an article by Dr. Rudolf Martin, Councillor of the German Government, tells it in masterly and graphic fashion. It is a story (he truly says) "of tragic setbacks, of patient endeavour, of blind persistence in the face of seemingly overwhelming difficulties; of men who have taken up the struggle where other men have laid it down, and inch by inch have battled on, leaving their partial successes as heritage to their successors." I content myself by merely drawing your attention to the article and bespeak for it your careful perusal. That success will come in our efforts to conquer the air is certain, and we may any day see the advent of the "heavier than air" machine capable of flying hundreds of miles with as much certainty as a railway train.

Every day is showing that we are living in an age of marvellous scientific progress, and the march is steadily on with accelerating motion. What is its meaning? Where will it end? Assuredly man has not discovered all that can be brought to light in science, and the years to come will show our successors projects and achievements of which we can now have no idea.

We smile now at the puny efforts of our forefathers creeping along in the first steamers; we wonder at the determined opposition to Stephenson; and it is too much to imagine that the future generations will wonder and have their smile at our efforts.

We may rest assured that they will score success where we have failed, that they will carry on to greater perfection our beginnings. Is it too much to imagine that man will yet explore in safety and comfort the wonders of the deep, or that a new feature will yet be introduced into the holiday circular tours of the future, where the steamers will allow passengers a few hours to explore the phenomena of the deep in some sheltered bay? Or in sweltering days will we clothe ourselves in scientific wings and enjoy the cold breeze above the mountain tops, or when storms arise at sea will vessels of the future be so skilfully contrived, that they will descend for a season below the troubled water and go forward to their destination in comparative quiet, and rise again when the waves thereof are still? What a happy era this will be for sea-sick travellers!

As engineers and shipbuilders there is no finality in our profession, and in all future progress we shall have our share. There is no department in life, from the cradle to the grave, during which mankind does not come directly within the influence of the engineer's work. The air we breathe, the food that sustains us, the clothing that covers us, the home that shelters us, the pleasures that enlighten the burden of life, all are effected by the engineer's work. His influence is universal and ennobling. This was Thackeray's thought when in his ode to the 1851 Exhibition, he wrote—

Look yonder where the engines toil,
These Britain's arms of conquest are
The trophies of her bloodless war,
Brave weapons these!
Victorious over wave and soil,
With these she sails, she weaves, she tills,
Pierces the everlasting hill
And spans the seas.

I thank you for the honour you have done me in electing me your President, and I thank you for your patience to-night.

APPENDIX.

The following chronologically arranged events in the evolution of the marine steam engine are given without any claim to absolute completeness. They are the result of careful research in histories, and, to assist the student, there are given as far as possible, the sources from which the facts are derived, whence further details may be had in most cases. For conciseness a numeral in brackets, thus (1) is given at the close of each entry; these numerals agree with the following authorities:—

(1) Lardner on the Steam Engine (1840).
(2) Report of Steam Navigation in the Tenth Census of the U.S. 1880, Volume IV.
(3) Catalogue of Naval and Marine Engineering Exhibition, Corporation Galleries, Glasgow (1880).
(4) Biography of William Symington, Inventor of Steam Navigation (1862).
(5) Transactions of the Institution of Naval Architects 1889, Volume XXX., page 86.
(6) Transactions of the Institution of Naval Architects Volume XVIII., page 148.
(7) Transactions of the Institution of Naval Architects, Volume XL., page 111.
(8) "Ancient and Modern Ships," by Sir George C. V. Holmes, K.C.V.O., C.B., Part II. (1906).
(9) Morris's "Life of Henry Bell."
(10) The "Clyde Passenger Steamers from 1821 to 1901," by Captain James Williamson (1904).
(11) James Napier's "Life of Robert Napier" (1904) p. 21.
(12) Fincham's "History of Naval Architecture," p. 294.
(13) Lindsay's "History of Merchant Shipping."
(14) Hodder's "Life of Sir George Burns, Bart." (1890).

(15) Proceedings of the British Association (1853) p. 45.

(16) Manuscript loaned by Napier Brothers, Glasgow, in Kelvingrove Museum, Glasgow.

1543. Blasco de Garray, a Spanish sea-captain, proposed to the Emperor Charles V. to propel vessels by a machine which he had invented, and experiments were made on the "Trinity," of 200 tons' burthen, which had discharged a cargo of corn at Barcelona. The Commissioners appointed by the Emperor were not allowed to see the machinery, and the only report extant records that there was a large boiler containing water, and that wheels were attached to each side of the vessel by the revolution of which it was propelled. The engine was probably of the "Hero" type; but the vessel was driven a league in an hour and manœuvred easily. The machine was never brought into practical use. (1).

1578. Bourne patented in this country a system of propelling boats by means of wheels at the sides, but there is no reference as to whether steam was to be used. (2).

1630. David Ramsey patented in England a method of making ships and barges to go against wind and tide. (2).

1632. Patents taken out by Thomas Grant. (2).

1637. Patent by Francis Lin. (2).

1640. Patent by Edward Ford. (2).

1661. Thomas Toogood took out a patent. (2).

1663-7. The Marquis of Worcester made many investigations regarding elastic and inelastic fluids and their properties, and proposed the application of steam for the propulsion of ships. (1).

1682. A horse boat moved by wheels at the side, worked by horses, was tried at Chatham, and was used as a tow boat. (2).

1688. Denis Papin, a native of Blois, France, and professor of mathematics at Marbourg, by his research, threw considerable light on the problems of steam. He conceived the idea of rendering atmospheric pressure available as a mechanical agent. He discovered the principle of condensation of steam, and the method of producing a vacuum by condensation. He designed an engine worked by atmospheric pressure, but abandoned the project, adopting the Marquis of Worcester's principle. He conceived the idea of producing motive power by means of a piston working in cylinders, and advocated the application of this system to the propulsion of ships. (1). In a steamer he ascended the Weser, but the boat was destroyed as an innovation of a doubtful character. (3).

1730. Dr. John Allen proposed in this country to move a boat by pumping in water at the bow and ejecting it from the stern, the origin probably of the system of jet propulsion. (2).

1736. Jonathan Hulls, of Berwick-on-Tweed, obtained a patent for a method of towing ships into and out of harbours against wind and tide. This was a revival of the proposal made by Papin in 1690. The motion was to be communicated to a paddle shaft by a rope passing over a pulley fixed on an axis, and was to be maintained during the return stroke of the piston by the descent of a weight which was elevated during the descending stroke. There is no record, however, of this plan, any more than that of Papin, ever having been reduced to experiment. (1). It was a stern wheel. (2).

1774. Count Aixiron made some experiments on the Seine, and repeated them in the following year with more success. (2).

1782. De Jouffroy moved a boat 140 feet long by a steam engine attached to paddle wheels on the sides. This was on the River Saone. (2).

1784. Joseph Bramah took out a patent in Britain for propellers. ( ).

1784. James Rumsey, Sheperdstown, Virginia, constructed a boat propelled by a series of poles, but the mechanism was not supposed to be driven by steam. (2).

1786. John Fitch of Pennsylvania moved a skiff boat with a 3-inch cylinder in American waters. (2).

1787. John Fitch completed his second boat, which had a 12-inch cylinder, driving six paddle oars on each side, the stroke being 11 feet for each revolution of the engine. The oars worked vertically, but with the action of those in a rowing boat. When the three forward oars on the starboard side were immersed the three forward on the port side were out of the water, and when also the three aft oars on the port side were immersed the three aft on the starboard side were out of the water. (2).

1787. Experiments were made at Hull by Fourness and Ashworth in the propulsion of vessels by steam power. They built and engined a boat which plied on the river between Hull and Beverley, and later they constructed a larger boat, which was sent to London to be put together and finished. It was subjected to severe tests on behalf of the Prince Regent, afterwards George IV., who used it as a pleasure yacht, but it was soon afterwards burned. A pension of £70 a year for life was granted to the builders. The vessel was propelled by paddles operated by a steam engine, steam being generated in a copper boiler. (15).

1787. Patrick Miller of Dalswinton drove a vessel by man power, operating paddles in the centre of the vessel, on the Firth of Forth. (2 and 4).

1787. James Rumsey, on December 3rd, moved a boat on the Potomac River by jet propulsion. (2).

1788. Patrick Miller, in conjunction with Robert Symington, and James Taylor of Cumnock, tried a side-paddle steam-boat, 25 feet long and 7 feet beam, on Dalswinton Loch, and got a speed of 5 miles per hour. (3).

1789. Patrick Miller and two others named, in their second boat, 60 feet in length, constructed at Carron, had steam engines with 18-in. cylinders, and on December 26th succeeded in driving the vessel at a speed of nearly seven miles per hour on the Forth and Clyde Canal. The engines of this boat were taken out and deposited at the Carron Works. The vessel was afterwards used as a pleasure boat by Mr Miller. (4 and 5).

1789. Nathan Read constructed an experimental boat at Salem, Mass., having paddle wheels designed to be worked by steam engines. (2).

1789-90. John Fitch built another boat in 1789, with an 18-in. cylinder, but owing to changes in machinery she was not run until the spring of 1790, when she made 7½ miles per hour between Pennsylvania and Burlington on the Delaware River. This boat was also driven by oar paddles which were placed at the stern, but did not long succeed. (2).

1789-90. Seratti, an Italian, worked at the problem with some result. (2).

1790. Captain Samuel Mowrey propelled a boat by steam on the Connecticut River. (2).

1791. William Longstreet worked a boat by steam on the Savannah River at Augusta, Georgia. (2).

1792. Elijah Ornsbee propelled a boat by "goosefeet paddles" worked by steam at Providence, R.I. (2).

1794. Robert Fulton sent the following letter to Messrs. Boulton and Watt. The original (here reproduced with the original spelling), the property of the late Sir Richard Tangye, was submitted by Sir Frederick Bramwell to the Institution of Naval Architects (without prejudice to copyright)—

Manchester, November 4th, 1794.

"Gentlemen,

"I shall esteem it a favour to be informed of the

" expence of a steam engine with a rotative movement
" of the purchase of 3 or 4 horses, which is designed to
" be placed in a boat. You will be so good as to men-
" tion what sized boat it would occupy, as I wish to
" have it in as little space as possible; and what you
" concive will be the expence when finished compleat
" in the boat; whether you have one ready of the dimen-
" sions specified, or how soon one might be finished
" with the weight of coals which it will consume in
" twelve hours, and what quantity of purchase you allow
" to each horse. As I am anxious to apply some engines
" of the above dimensions as soon as possible, your
" emediate answer will much oblige your

" Most obedient and humble servant,

" Robert Fulton.

" Bridgewater Arms, Manchester." (7).

1794. William Lyttleton took out a patent for propellers. ( ).

1796. John Fitch, on his return from Europe, placed a small boat on the Collect Pond in New York, which was worked by a screw propeller, but it was a very primitive affair. The boiler was a ten- or twelve-gallon pot with a lid. The cylinder was of wood, barrel-shaped on the outside, and strongly hooped. The boat was propelled once or twice round the pond before steam was exhausted. (2).

1799. Edward Shorter took out a patent in Britain for propellers. (16).

1800. Henry Bell laid before the Lords of the Admiralty a scheme showing the workability and great utility of applying steam to the propelling of vessels against winds and tides, and other obstructions on rivers and seas where there was depth of water. (9).

1801. William Symington constructed the "Charlotte Dundas" under the patronage of Lord Dundas, after whose daughter the vessel was named. She was 56 feet long, 18 feet in breadth, and 8 feet in depth, and had an engine with a horizontal cylinder, 22 ins. in diameter by 48 ins. stroke, and a connecting rod with a crank at one end turning a paddle wheel placed in a recess at the stern. She had two rudders, one on each side of the recess in which the wheel worked. This vessel in March, 1802, towed two sloops of 70 tons burthen a distance of 19½ miles in 84 hours against adverse winds. This boat also was withdrawn from service owing to complaints of injury to canal banks. (4).

1801. Robert Fulton proposed to the French Government a diving boat, and made several experiments in the harbour of Brest, blowing up a small vessel by means of a torpedo which he placed in her bottom. With this boat Fulton seems to have employed a screw operated by a crank as a means of propulsion. The French Government, however, would not adopt his invention, and he departed from a consideration of this problem. (6).

1802. Shorter's patent propeller, worked by manual labour through a capstan was tried and reported upon in July of that year by Captain Short of the transport ship "Doncaster," on which the experiment was made. Writing from Gibraltar Bay, Captain Short said:—

"I arrived here on the 1st after a passage of ten days "from England, and at the time of my arrival had a "fresh breeze at S.W., in consequence of which had not "an opportunity of making use of the propeller, but "yesterday, being calm, I got the 'Doncaster' under "way by the desire of some Captains in the Navy and "several others, when it was exhibited, to the great "surprise and satisfaction of every spectator. At the "same time the log was hove, and found the ship, although deep loaded, went one knot and a half through "the water entirely by the use of your newly invented "propeller. The enclosed certificate I have received "from the Captains of His Majesty's ships 'Dragon' "and 'Superb,' in order that the utility of the grand "machine may be made known to all persons concerned "in shipping, especially ships coming up the Mediter- "ranean where we are so much subject to calms."

The certificate is as follows:—"We, the undersigned "Captains of H.M.S. 'Dragon' and 'Superb' have seen "the 'Doncaster' moved in a calm a distance of two "miles in Gibraltar Bay, and with sufficient velocity, "by the use of Mr Shorter's propeller, to give her steer- "age way." (16).

1803. Henry Bell repeated his plea to the Admiralty for the construction of steam vessels, and their Lordships, with the single exception of Lord Nelson, reported that the plan proposed would be of no value. (9).

1803. Robert Fulton constructed a working model of his first steamboat, and built a vessel 66 feet long by 8 feet in width at Paris. (2).

1803. Appended are two of the letters which Fulton wrote to Messrs. Boulton and Watt:—

"Paris, 6th August, 1803.

"Gentlemen,

"If there is not a law which prohibits the ex- "portation of steam engines to the United States of "America, or if you can get a permit to export parts "of an engine, will you be so good as to make me a "cylinder of 24 horse power double effect, the piston "making a four foot stroke; also the piston and piston "rod.

"The valves and movements for opening and shutting "them.

"The air pump piston and rod.

"The condenser with its communications to the "cylinder and air pump.

"The bottom of the cylinder cast in form as in the "drawing (Fig. 1, Plate XXVIa., Proceedings I.N.A. "Vol. XL.) and the dispositions of the parts as near "as possible as they stand in the drawing. The other "parts can be made at New York, and as it will save "the expense of transport, and they require a particular "arrangement which must be done while I am present, "I prefer to have them done there. Therefore if it is "permitted to export the above parts you will confer "on me a great obligation by favouring me with them, "and placing me the next on your list . . . when "finished please to pack them in such a manner as not "to receive injury, and send them to the nearest port, "which I suppose is Liverpool, to be shipped to New "York to the address of Brockhurst Livingston, Esq., "the amount of the expences will be placed to your "order in the hands of George William Erving, American "Consul, Nicholas Lane, Lombard Street, No. 10, "London. The situation for which this engine is de-"signed and the machinery which to be combined with "it will not admit of placing the condenser under the "cylinder as usual, but I hope the communicating tube "to the condenser will not render the condensation less "perfect or injure the making of the engine.

"Should you find a difficulty in getting a permit to "export the parts above mentioned, I hope to be able "to obtain it through our Minister, Mr Monroe. And "as there is some difficulty in passing letters to and "from Paris and Birmingham, which may loose much "time, you will be so good as to furnish me the above "parts as soon as possible without waiting to hear "further from me.

"Please to write as soon as possible under cover to

"Mr Erving as before mentioned. In which I beg you "to answer the following questions:—

"What must be the size of the boiler for such an "engine?

"How much space for the water and how much for "the steam? What is the most improved method of "making the boiler and economic mode of setting it? "How many pounds of coal will such an engine re- "quire per hour, and what is the expence at "Birmingham?

"Can you inform me what is the difference in heating "with coals or wood, as in most cases wood must be "used in America; and must not the furnace be made "different when wood is to be used?

"What will be the consequence of condensing with "water salt, as in places where the engine is to work "the water is brackish?

"What will be the interior and exterior diameter of "the cylinder and its length, and what will be the "velocity of the piston per second? This information "will enable me to combine the other parts of the "machinery.

"When can the engine be finished, and how much "will be the expence? Your favouring me with the "execution of this order, and answering the above "questions will much oblige.

"Your most obedient servant,

"Robert Fulton.

"Rue Vaugirard, No. 50 à Paris.

"Can the position and arrangement of the cylinder, "condenser and air pump be adhered to as in the draw- "ing without injuring the working of the engine?"

" Messrs. Boulton, Watt and Coy.

" Gentlemen,

" I like your mode of placing the air pump in " the condenser, but as my movements confine me to " 3 feet in width, the condensing vat ought not to exceed that width. Could not the condenser be made " like a box about 4 feet long, 20 inches wide, and 2 " feet deep, as in this sketch (Fig. 2 Plate XXVIa.— " Reproduced in the Proceedings of Naval Architects, " Vol. XL.). If so I shall be completely accommodated; " if not, you must use your particular composition of " the parts. I must beg of you, however, to fit me " in this respect; if possible, perhaps a hole at A may " be convenient for a man to pass his arm and draw " any chips or dirt which might get into the, or, rather, " under the valve of the air pump, the hole to be " covered with a plate. In a former letter, I mentioned " that the air pump will have a stroke of 2 feet. I see " by your drawings that you have made it 16 inches " diameter in the interior. I presume this width is " calculated accordingly.

" On Tuesday I go out of town for six weeks or two " months. I shall not trouble you farther about the " combinations; you will have the goodness to proceed " immediately to the construction on the manner you " deem best suited to my purpose.

" I am, with much respect, yours,

" R. Fulton.

" London, the 28th July, 1804."

1804. John Stevens, New Jersey, designed and constructed an engine to which was attached a screw propeller, and this vessel ran successfully on the Hudson. It is preserved in the Museum of the Stevens Institute, Hoboken, New Jersey.

1807. Boulton and Watt, in 1805, made at Birmingham an engine for the "Clermont," constructed in America, and launched in the spring of 1807. This vessel, which had many of the characteristics of the American river steamer, was 133 feet long, 18 feet broad, and 9 feet deep. The engine cylinder was 24 inches in diameter, and 4 feet stroke.* The boiler was 20 feet by 7 feet deep, and 8 feet wide. The vessel with several succeeding boats built in the next few years, was engaged in the river traffic on the Hudson, a Bill having been passed by the Legislature of Pennsylvania, granting Fitch and his patron Livingston—formerly United States Minister at Paris — the exclusive rights of river navigation. (2).

1808. John Steven of New Jersey, who had been working steadily and experimentally at the problem, built in conjunction with his son Robert Steven, the "Phœnix," but as it could not ply on the Hudson on account of the Livingston and Fulton monopoly, it was taken by sea to the Delaware, and was probably the first steamer which made the ocean voyage. As Mr J. Scott Russell put it, "she was undoubtedly the pioneer of steam navigation in the open sea," and again, "Robert L. Stevens is probably the man to whom of all other America owes the greatest share of its present highly improved navigation." (2 and 8).

1809. The "Accommodation," the first steamer on the St. Lawrence, was launched. (8).

1811. The "New Orleans," the first steam boat on Western American rivers, was constructed at Pittsburg. (8).

1812. Henry Bell's "Comet" plied between Glasgow and Greenock in August. She was 42 feet by 11 feet by 5 feet 6 inches, and had a side lever engine with cylinder 11 inches in diameter by 16 inches stroke, driving side paddles. (9 and 10).

1813. A record of subsequent Clyde steamers is to be found in Captain James Williamson's "Clyde Passenger Steamers from 1812 to 1901." (10).

1814. The "Fulton," the first war steamer, was built by Fulton at Brown's shipyard at New York. (8).

1815. A steamer was sent from the Clyde to the Mersey, and was the pioneer of steam navigation in that river. Steam navigation extended from the Clyde to the Thames and to Ireland. (8).

1816. The first steamer, the "Regent," built on the Thames, is specially interesting from the fact that Brunel, the great engineer, supervised her construction, and her builder was Maudslay, the founder of the famous engineering firm of Maudslay and Field. (8). This year also saw the "Hibernia," 77 feet long, inaugurate cross-channel traffic from Holyhead to Howth. (8).

1817. The first steamboat to run from New York to Newport, in the same year the first steam vessel was put in service in Boston Harbour. (8).

1818. The "Rob Roy" was built by Denny of Dumbarton, and was engined by David Napier. She ran regularly between Greenock and Belfast, and afterwards inaugurated the steam service between Dover and Calais. (11).

1818. Steam navigation was inaugurated on Lake Erie. (8).

1819. First steam vessel built for the British Navy—the "Comet," 115 feet long.

1819. Memorable voyage made by the auxiliary steamer "Savannah" to Liverpool. She was a full-rigged ship of 350 tons fitted with inclined direct-acting low pressure engines of 90 H.P., having cylinders 40 inches in diameter by 5 feet stroke. Her passage occupied twenty days, eleven hours, and she was only eighty hours under steam, and had consumed all her fuel by the time she arrived at Cork. (8).

1820. The "Conde de Palmella" sailed from Liverpool to Brazil via Lisbon. This is the first steamer that crossed the Atlantic for the west. (8).

1821. The steamer "Lightning" inaugurated the mail service between Holyhead and Dublin.

1821. First iron steamer built at Horsley, the "Aaron Manby," for river traffic in France, succeeded by others in 1824 and 1829.

1825. The auxiliary steamer "Falcon" made the voyage to India, via the Cape, while in the same year the steamer "Enterprise," 122 feet long by 27 feet beam and of 470 tons, with engines of 120 nominal horse power, constructed by Gordon of Deptford, made the voyage from England to Calcutta in 113 days. Ten days were consumed in taking in coal, the vessel being under steam 103 days, the average speed was 8·79 miles per hour. (12 and 13).

1827. The "Curaçoa" of 400 tons and 100 H.P. made the first voyage to South America, consuming 7·14 lbs. of coal per I.H.P. per hour. (8).

1833. The "Royal William," 176 feet long by 27 feet beam, built at Quebec, and fitted at Montreal with engines by Boulton and Watt, made the run from Nova Scotia to Portsmouth—2500 miles—in seventeen days. (13).

1836. The first successful screw steamer built, the "Francis B. Odgen," designed by John Ericsson.

1838. The first voyage across the Atlantic under continuous steam by the "Sirius," "Great Western," "Royal William," and "Liverpool." The "Sirius" was 208 feet long by 25 feet 6 inches in beam, and had engines of 320 H.P. The "Great Western" was 212 feet long between perpendiculars, with 35 feet 4 inches beam, and had engines of 450 nominal H.P. The "Sirius" took seventeen days for the westward voyage, and sixteen days for the homeward journey. The "Great Western," which proved the faster boat took only 15 days on the outward run and 14 days on the homeward run. The latter was built expressly for the Atlantic service and had 73-inch cylinders suitable for a stroke of 7 feet. The paddle wheels were 28 feet 9 inches in diameter, making from 12 to 15 revolutions per minute. The voyage of 3135 nautical miles was made at a speed of 8·2 knots, and the consumption for the whole run was 665 tons. (8 and 13).

1839. The Cunard line was formed, and with their sailings in 1840, a regular Atlantic mail service was commenced. (14).

I.—STATISTICAL TABLES SHOWING THE PROGRESS OF MERCHANT SHIPPING.

The following table giving the tonnage on the United Kingdom Register at the end of various years from 1807 to 1905, will show the great progress of the merchant navy of this

Year	Steam	Sail	Total
1807	—	2,097,327	2,097,327
1814	69	2,414,101	2,414,170
1820	3,018	2,436,011	2,439,029
1830	30,339	2,171,253	2,201,592
1840	87,928	2,680,334	2,768,262
1850	168,474	3,396,659	3,565,133
1860	454,327	4,204,360	4,658,687
1870	1,112,934	4,577,855	5,690,739
1880	2,733,468	3,851,045	6,574,513
1890	5,042,517	2,936,021	7,978,538
1900	7,207,610	2,096,498	9,304,108
1905	9,064,816	1,670,766	10,735,582

country during the last 100 years; as the official figures, except for the later years, only give the net tonnage, this tonnage is taken right through for the purpose of comparison.

The foregoing figures show not only the great increase which has taken place in the steam tonnage owned, but also the striking decrease in the sailing tonnage from 1870 onwards.

No similar official figures are available for foreign countries for any length of time, and although such figures have been published for recent years, owing to their not being calculated on the same basis, no accurate comparison can be made. The only tables published from which such a comparison can be arrived at, especially as regards the gross tonnage of steamers, are those contained in Lloyd's Register Book, from which publication and from the statistics published by that Society all the following tables are compiled. It should, however, be stated that only seagoing vessels of 100 tons and above are included, with the exception of a number of small sailing vessels, which, although of over 100 tons, have not been included on account of lack of accurate information concerning

II.—United Kingdom Tonnage Entered in Lloyd's Register Book.

Year (End of June)	Steam (Gross)	Sail (Net)	Total
1886	6,162,117	3,248,807	9,410,924
1891	8,167,762	2,417,985	10,585,747
1896	9,968,573	2,324,966	12,293,539
1901	12,053,394	1,602,767	13,656,161
1906	15,207,410	1,174,440	16,381,850
1907	15,930,368	1,069,300	16,999,668

III.—GROSS TONNAGE OF STEAMERS ENTERED IN THE REGISTER BOOK FOR VARIOUS YEARS, ACCORDING TO THEIR NATIONALITY.

FLAG.	1887.	1892.	1897.	1902.	1907.
U.K., ...	6,169,065	8,601,679	10,213,569	12,897,592	15,930,368
Colonial, ...	426,806	515,204	585,877	754,863	1,070,771
British, ...	6,595,871	9,116,883	10,799,446	13,652,455	17,001,139
Dutch, ...	175,476	284,804	340,780	555,047	776,855
French, ...	742,662	853,799	954,916	1.104,893	1,284,368
German, ...	654,814	1,088,830	1,549,961	2,636,338	3,705,700
Italian, ...	230,342	317,197	402,205	691,841	823,325
Japanese, ...	77,936	142,492	404,475	555,230	1,068,747
Norwegian, ...	142,185	335,547	564,533	866,754	1,264,002
United States (seagoing), ...	503,677	572,252	1,105,423	1,095,788	1,503,059
Others, ...	1,408,880	1,850,199	2,484,873	4,701,641	6,542,616
Total, ...	10,531,843	14,562,003	18,606,612	25,859,987	33,969,811

them; on the other hand iron and steel vessels trading on the North American Lakes are inserted in the Register Book.

Although the following tables do not go back further than 1886, they show clearly the changes which have occurred in the merchant navies of the world, as it is specially during this period that such changes have taken place.

The figures in Table II. show since 1886 a decrease of over 64 per cent. of the sailing tonnage, but an increase of no less than 147 per cent. in the steam tonnage. But even these percentages do not show sufficiently the real progress. Taking into consideration the increase of steam tonnage, the speed of vessels and the additional shipping facilities, it may safely be assumed that the carrying capacity of the present mercantile navy of the United Kingdom is not less than three and a half times greater than that of the tonnage registered in 1886.

Table III. shows that notwithstanding the great increase which has taken place in the foreign merchant navies, especially in Germany, Japan and Norway, the increase in the tonnage of British steamers during the last 20 years amounts to 2½

IV.—COMPARATIVE PERCENTAGES FOR THE TOTAL SHIPPING OWNED IN THE WORLD IN 1886, 1896, AND 1907. RESPECTIVELY.

Percentage of	1886	1896	1907
Wood and Composite	43·4	20·8	8·0
Iron	52·6	34·7	13·8
Steel	5·0	44·5	78·2
Sail	52·1	30·7	13·9
Steam	47·9	69·3	86·1

millions tons more than the combined increase in all the principal foreign merchant navies.

In Table IV. figures are given showing the steady and rapid change all over the world from sail to steam and indicates the practical exclusion of wood and iron from shipbuilding in recent years; of the tonnage launched in the world during 1906, 97 per cent. was of steel.

V.—Gross Tonnage of Vessels Launched During the Years 1893, 1896, 1901, and 1906 Respectively.

Year	In the U.K.	Abroad	Total
1892	1,109,950	248,095	1,358,045
1896	1,159,751	408,131	1,567,882
1901	1,524,739	1,092,800	2,617,539
1906	1,828,343	1,091,420	2,919,763

It may be here stated that during the last ten years no less than 10,850,000 tons of *new* vessels have been added to the United Kingdom Register, and that the tonnage of the vessels sold to colonial and foreign owners during the same period amounts to 4,864,000 tons.

It is of course in the construction of very large steamers of great speed that the progress of the last quarter of a century can be best traced. The following two tables take only into account ocean steamers of 5000 tons and upwards and those capable of maintaining a speed of 18 knots and upwards.

Table VII. is limited, as described, to the "fastest ocean steamers." Table VIII., however, takes into account *all* steamers now in existence of 100 tons and upwards, capable of maintaining a speed of 15 knots and above.

VI.—NUMBER OF OCEAN STEAMERS OF 5000 TONS AND UPWARDS IN EXISTENCE IN THE WORLD AT VARIOUS DATES.

Division of Tonnage.	1877			1887			1897			1907		
	Brit.	Foreign	Total	Brit.	Foreign	Total	Brit.	Foreign	Total	Brit.	Foreign	Total
5,000 and under 7,000 ...	3	—	3	33	17	40	142	79	221	331	311	642
7,000 „ 10,000 ...	—	—	—	5	—	5	30	10	40	158	60	218
10,000 „ 15,000 ...	—	—	—	—	—	—	3	10	13	48	42	90
15,000 „ 20,000 ...	1†	—	1	1†	—	1	—	—	—	5	7	12
20,000 and above	—	—	—	—	—	—	—	—	—	6	4	10
Totals	4	—	4	29	17	46	175	99	274	548	424	972

† The "Great Eastern."

VII.—NUMBER AND DESCRIPTION OF FASTEST MERCHANT STEAMERS NOW SAILING

Division of Tonnage	Speed in Knots					
	18 and under 20			20 and above		
	British	Foreign	Total	British	Foreign	Total
5,000 & under 7,000	2	4	6	—	—	—
7,000 ,, 10,000	12	1	13	1	2	3
10,000 ,, 15,000	4	2	6	5	9	14
15,000 ,, 20,000	2	—	2	1	2	3
20,000 and above ...	1	—	1	2	—	—
Totals,... ...	21	7	28	9	13	20

VIII.—FAST MERCHANT STEAMERS NOW IN EXISTENCE.

Nationality.	Speed in knots.			
	16 and under 18	18 and under 20	20 and above	Total
British, ...	263	76	52	391
Foreign. ...	217	27	30	274
Total, ...	480	103	82	665

It may be stated that in 1889 the total number of such vessels was 96 as compared with 665 at present, and 17 of them were capable of a speed of 18 knots and above, whilst now there are not less than 185.

As stated in the address the most striking feature in recent marine developments has been the introduction of the steam turbine method of propulsion. The first vessel fitted with steam turbines was the "Turbinia," a small boat of 39 tons launched in 1896, (Parsons Marine Steam Turbine Co.). The first vessel built for ordinary merchant purposes, however, was only launched in 1901; the "King Edward," 562 tons, intended for navigation on the Clyde, (Turbine Steamers, Ltd.). The largest turbine vessels launched in each of the following years were:—

1902—"Queen Alexandra," 650 tons, Clyde Navigation, (Turbine Steamers, Ltd.).

1903—"The Queen," 1676 tons, Channel steamer, (South-Eastern Railway).

1904—"Virginian," 10,754 tons, North Atlantic steamer, (Allan Line).

1905—"Carmania," 19,524 tons, North Atlantic steamers, (Cunard Line).

1906—"Lusitania" and "Mauretania," 32,000 tons, North Atlantic steamers, (Cunard Line).

Thus showing a marvellous increase of power and tonnage in the short space of six years.

IX.—SHOWING NUMBER, TONNAGE AND PLACE OF BUILD OF ALL THE MERCHANT VESSELS AND YACHTS NOW FITTED WITH TURBINES.

Description.	Built at home.		Built abroad.		Total.	
	No.	Tonnage	No.	Tonnage.	No.	Tonnage.
Merchant vessels launched, ...	41	195,456	5	16,272	46	211,728
Yachts launched,	10	9,717	1	190	11	9,907
Now under construction, ...	2	3,500	6	39,400	8	42,900
Total, ...	53	208.673	12	55,862	65	264,535

It may be stated that 50 per cent. of the merchant vessels fitted with turbines, already launched, are capable of a speed of 20 knots and upwards.

Table X. gives particulars of the largest and fastest vessels at various dates since the construction of the first ocean passenger steamer and shows the steady development of shipbuilding and marine engineering.

Of course, many other fine steamers were built in the years mentioned or at other dates, for instance, taking only more recent years, the " Majestic " in 1889, the rival of the " City of Paris "; the " Oceanic " of 17,274 tons in 1889, the first one to exceed the " Great Eastern " in length; the " Kronprins Wilhelm" of 14,908 tons, one of the three fastest vessels at present sailing, and the " Celtic," the first vessel built of over 20,000 tons, both launched in 1901; the " Carmania " and "Caronia " in 1905; the " Kaiserin Auguste Victoria " in 1905, and the " Adriatic " in 1906, both of over 24,500 tons; but the above list is intended to show only the steamers holding what may be called the blue riband of the ocean after their first voyage, only size and speed being taken into account.

In addition to all the above particulars of British and foreign vessels, the following official figures showing the entrances and clearances in the " Foreign Trade " of the United Kingdom may be of interest. Similar official figures for foreign countries would not be accurate for the purposes of comparison as the definition of " Foreign Trade " varies considerably in several countries.

X.—T

	WEIGHTS.				
	Weight of Hull and Fittings.	Weight of Engines, Boilers, and Water.	Weight of Fuel Carried.	Weight of Cargo.	Passengers Carried.
	Tons.	Tons.	Tons.	Tons.	
830 I.H.					
750		480	About 660	250	
740			640	225	
1,040			740	300	
1,400			840	450	140
3,000			1,400	500	
3,600			1,640	1,100	
Paddle, 5, Screw, 6,	10,000 of hull only	}			800 first, 2,000 second, 1,200 third
4,500 I.H.	3,205	944	1,800	1,400	800
2,250 ,,			1.100	1,050	160
2,800 ,,	2,840		1,180	1,260	180
2,480 ,,			1,160	1,600	180
3,000 ,,		876 17			
4,000 ,,			1,161		1,220
2,780 ,,	3,898		940	1,692	340
5,500 ,,		1,181 6			
4,799 ,,			1,197		200 first, 1,100 third
6,857 ,,	3,817	1,250	1,321	2,436	204 cabin, 138 steerage
4,750 ,,			1,244	1,685	250
10,000 ,,	5,180	1,850	1,847	2,078	397 cabin, 118 steerage
11,890 ,,					260 first, 1,250 third
10,300 ,,	5,733	1,877	2,282	3,080	480
12,500 ,,	5,658	2,250	2,357	1,004	414 cabin, 118 steerage
14,500 ,,	6,274	2,500	2,163	1,000	550 first, 800 third
18,000 I.H.	7,400	2,000	2,600	1,500	
18,000 ,,					300 first, 150 second, 750 third
30,000 ,,	10,610	4,625	3,163	1,062	600 first, 400 second, 700 third
28,000 ,,					944 first and second, and 640 third class
29,000 ,,	12,000				710 cabin & 1,000 third class
10,400 ,,				2,100	775 first, 348 second, 770 third
35,000 ,,				at 31·5 ft. draught.	
45,000 ,,	19,850		5,625		
22,000 ,,	12,000 steel construction only			10,000	300 first, 326 second, 1,000 third, 1,000 steerage
,,	12,000 steel construction only			10,000	300 first, 326 second, 1,000 third, 1,000 steerage
16,000 ,,					
65,000 to 70,000 ,,	30,000				550 first, 500 second, 1,300 third

er all." B. ical. Quad. "Quadruple."

XI.—TONNAGE OF VESSELS ENTERED AND CLEARED IN UNITED KINGDOM PORTS DURING VARIOUS YEARS FROM 1840 TO 1905.

Nationality.	1840	1860	1880	1900	1905
British vessels	6,490,485	13,914,923	53,973,112	64,282,805	70,963,087
Foreign vessels	2,949,182	10,774,369	20,310,757	35,812,857	41,077,647
Totals, -	9,439,667	24,689,229	74,283,869	100,095,662	112,040,734

XII.—PARTICULARS OF THE LOG OF THE CUNARD STEAMER "BRITISH QUEEN."

1840

September 1 - - Left Portsmouth at 7 o'clock p.m.

,, 2 - - Took departure from Scilly Light N.N.E. 15

		Lat.	Long.	Distance.
,,	3	49·15	8·28	100
,,	4	49·41	12·10	142
,,	5	49·25	16·14	160
,,	6	49·2	21·4	194
,,	7	48·32	26·4	195
,,	8	48·7	31·5	200
,,	9	47·30	35·51	190
,,	10	46·38	41·10	220
,,	11	45·28	46·30	240
,,	12	44·30	52·0	245
,,	13	43·56	57·41	251
,,	14	42·12	62·30	240
,,	15	41·36	67·0	210
,,	16	40·27	72·0	240

Sandy Hook West, distance 95′; arrived at New York at 12 o'clock at night.

XIII.—Particulars of the Log of the Cunard Steamer “Acadia.”

1841				Distance.
February	1	Left Boston at 10 minutes past 2 p.m., arrived at Halifax at 7 p.m. of the 3rd		395
,,	4	Left Halifax at 10 a.m.		18
		Lat.	Long.	
,,	5	44·49	58·0	224
,,	6	45·11	52·40	228
,,	7	45·50	46·58	243
,,	8	46·48	41·1	254
,,	9	48·3	35·21	242
,,	10	49·4	29·39	235
,,	11	49·42	23·42	235
,,	12	50·18	17·28	243
,,	13	51·00	11·43	220
,,	14	No observation.		
,,	15	10 o’clock off Tuskar Light.		
,,	16	2 o’clock arrived at Liverpool.		

The Cunard Steamship Company, Limited. Abstract Log of the S.S. "Lusitania."
From Liverpool to New York.

Date, 1907.	Distance.	Latitude.	Longitude.	REMARKS.
Saturday, - - Oct. 5	...			Left Liverpool Stage at 7.48 p.m.
Sunday, - - ,, 6	228	To Q'stown		Arrived Queenstown at 7.45 a.m.
,, - - ,, ,,	41	From Daunt's Rock L'ship		Left Daunt's Rock 10.25 a.m.
Monday, - - ,, 7	590	51·01 N	24.54 W	N W'ly
Tuesday, - - ,, 8	608	48·38 ,,	40.10 ,,	S W'ly W'ly
Wednesday, - - ,, 9	617	44·40 ,,	54.00 ,,	W'ly
Thursday, - - ,, 10	600	41·20 ,,	66.02 ,,	W'ly N E'ly
,, - - ,, ,,	131	To Nantucket Lightship		1.17 a.m, Sandy Hook L'ship abeam
Friday, - - - ,, 11	193	To Sandy Hook L'ship		Average speed, 24·00.
From Daunt's Rock L'ship to Sandy Hook L'ship, - -	2780			4 days, 19 hours, 52 minutes.

THE CUNARD STEAMSHIP COMPANY, LIMITED.
ABSTRACT LOG OF THE S.S. "LUSITANIA" (JAMES B. WATT, *Commander*).
FROM NEW YORK TO LIVERPOOL *via* QUEENSTOWN.

Date. 1907.	Winds.	Courses.	Distances	Lat. N.	Long. W.	REMARKS.
Oct. 19	S W'ly	...	...	...	...	3.30 p.m., left Company's Pier; 4.4 p.m., passed Castle Gardens; 5.21 p.m., Sandy Hook abeam; 5.44 p.m., Sandy Hook Lightship abeam. Light winds; fine weather.
,, 20	S E'ly	S. 84·00, E. 176 N. 76·30, ,, 229	405	41·05	65·06	Light to moderate winds; fine weather; head swell.
,, 21	S'ly	,, 76·30, ,, 236 ,, 67·00, ,, 334	570	44·11	52·59	Strong winds to moderate gale; squally; heavy beam sea.
,, 22	S W'ly	,, 67·00	540	47·42	41·04	Moderate gale; squally; rough confused sea.
,, 23	S'ly NW'ly	,, 73·00	532	50·17 DR.	28·08 DR.	,, ,, to strong wind; frequent squalls; high confused sea.
,, 24	NW'ly SW'ly	,, 83·30	570	51·20 DR	13·11 DR.	Strong winds; hazy; rough sea.
,, ,,	...	East	134	To Fatsnet		—— p.m., passed Fastnet.
,, ,,	Various	...	56	To Daunt's Rk. L.S.		9.37 p.m., Daunt's Rock Lightship; 9.43 p.m., arrived at Queenstown; 10.58 p.m., left Queenstown; 9.36 a.m., passed Bar Lightship; 10.38 p.m., passed Rock Lighthouse; arrived L'pool.
...	...	...	228	To L'pool Bar L.S.		

REPORTS.

Oct. 21	...	8.10 p.m.	...	45·21	48·58	In wireless communication with s.s. "Saxonia," bound west.
,, 22	...	2.45 p.m.	...	48·05	39·33	,, ,, ,, s.s. "Campania," bound west.
,, 23	...	7.0 a.m.	...	49·52	30 50	,, ,, ,, s.s. "Minnehaha," bound west.
,, 24	...	5.50 a.m.	...	51·21	16·52	Passed 1 mile south of s.s. "Carmania."

			Days.	Hrs.	Mins.	
Sandy Hook L. S. to Daunt's Rock,	2,807	—Length of passage, deducting 5 hours:	4	22	53	Average speed 23·61
,, to Liverpool Bar, -	3,035	— ,, ,, ,, 5 ,,	5	10	52	

VOTE OF THANKS.

Professor **ARCHIBALD BARR**, D.Sc., (Member) said he had been asked to propose a formal vote of thanks to their new President for the most interesting and eloquent address to which they had just listened. Mr Ward was a shipbuilder and an engineer, and, therefore, he was peculiarly fitted to speak to all of them, and the story of the development of steam engineering, more especially during the past fifty years, which he had related could not have been told in a more fascinating manner than in the address they had heard that evening. The story was one which had many lessons, and Mr Ward had indicated some of these. One was rather apt sometimes to think that men who were of a particularly inventive turn of mind were likely to go astray or be led away by their own inventions. Mr Ward had quoted from the prophet Daniel, "many shall run to and fro and knowledge shall be increased." A later philosopher quoted these words and added to them, "Surely the plain rule is, let every considerate man have his way and see what it will lead to, for not this man nor that man, but all men make up mankind, and their united tasks the tasks of mankind." If indeed they all persevered on their own lines there was no doubt that it would be found that there were fish in the sea as good as ever came out of it. The age of invention was not past. He was sure that they were delighted to have heard Mr Ward's eloquent address, and to the younger members especially, he thought it would be a great encouragement as showing them what progress had been made in the recent past, and what was expected of them in carrying forward such progress in the future. He proposed that a hearty vote of thanks be given to Mr Ward for his address.

The resolution was carried by acclamation.

The **PRESIDENT** thanked the members for their patient hearing and appreciation of his address.

ON AN APPARATUS FOR EXTINGUISHING THE ROLLING OF SHIPS.

By M. Victor Cremieu, D.Sc.

Read 22nd October, 1907.

It is well known that the angle of inclination which a ship makes in rolling on a wave whose period may or may not synchronise with that of the ship, is inversely proportional to the coefficient N of decrease of rolling in calm water. To diminish that angle it follows that N must be increased. It is further known that $N = K \frac{M_1}{\Sigma m r^2}$.

Where K is a constant,

M_1 the statical moment of resistance of the hull, and

$\Sigma m r^2$ the moment of inertia of the ship.

To increase N it is therefore necessary to increase M_1. For modern ships N varies between ·008 and ·02.

Bilge keels, effective only in rolling of large amplitude, permit the raising of N as high as ·04 or ·05. Their effect is limited, because while they augment M_1 they similarly influence the virtual moment of inertia of the ship. They have thus two effects which partially neutralise each other.

Liquid ballast, but little used, allows N to be raised to ·05 or ·06 for small amplitudes of roll. It acts by causing the ship to impart motions to the liquid mass in the rolling chamber which bring into play the viscosity of the mass. As a consequence a portion of the oscillatory kinetic energy of the ship is dissipated in the form of heat.

For amplitudes somewhat larger (exceeding 5° or 6°) the variations of stability due to the positions taken up by the liquid ballast and to the kinetic energy which it acquires, counterbalance to some extent the effect of the viscosity. These variations may attain to such a value as to endanger the total stability of the ship.

The use of the gyroscope has also been recommended to diminish rolling. The apparatus does not influence the value of N. It supplies to the moment of stability of the ship, a moment of dynamical stability, the energy of which is obtained from an external source. This additional couple is proportional to the angular acceleration of the roll—that is, inversely proportional to the proper period of the ship.

It follows that the gyroscope, already very bulky and awkward for a small ship with the short period of four seconds, would become difficult of application to a large ship of long period.

The new arrangement which I have the honour to present to this Institution, influences the value of N, permitting it to be raised to unity.

Like liquid ballast it adds to the natural resistances to rolling of the ship, a resistance inside the ship which transforms into heat a portion as desired of the oscillatory kinetic energy of the ship. This result is obtained without any change in the statical stability of the ship, of which the dynamical stability is alone augmented.

DESCRIPTION OF THE APPARATUS.

Given a ship of metacentre M, of centre of gravity G, and of displacement P. Let $(\rho - a)$ be the mean value of the metacentric height.

A tube, TT, Fig. 1, of circular section and bent to a circular shape of which the outer radius is equal to the distance l between the centre of gravity, G, and the bottom of the hull, is placed inside on the ship's bottom between the frames.

A sphere, B, of weight π, and of diameter less than that of the tube, is placed within the tube. This sphere is able to roll inside the tube, so is always tending to be at its lowest point. Its oscillations of period t are obviously identical to those of a pendulum of length l, which carries at its extremity a weight equal to that of the sphere, and oscillates about an axis passing through the centre of gravity, G. The directing couple acting on the sphere is equal to πl.

The tube, T T, can be hermetically closed, and filled with a liquid of viscosity, μ. If the sphere is now moved from its position of equilibrium it will oscillate with a pseudo-period $t\rho$ longer than t, and it is easy to give to $t\rho$ any value between t and ∞ by varying μ, or the clearance between B and the sides of the tube.

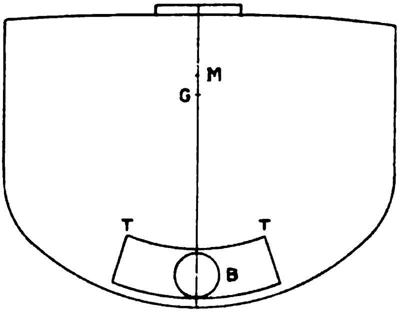


Fig. 1.

ACTION OF THE APPARATUS.

When the ship rolls, it carries with it the tube and the viscous liquid. This liquid tends to carry with it the sphere B. On the other hand, the weight acts in the opposite way, and tends with the couple πl to maintain in the vertical through the metacentre. As a consequence there is an excess of pressure on one of the two portions into which the sphere B divides the viscous liquid. Under the action of this pressure E, the viscous liquid circulates through the clearance space, and on the other hand the sphere partially entrained is displaced from the vertical through an angle, d. The volume, v, of the circulating liquid is proportional to the excess of pressure E, to the size of the clearance space, and inversely as μ.

The work that the ship is obliged to expend on the interior of the tube, T T, for an angle of displacement, α, is represented by two terms—

1st. Mechanical work proportional to the difference between α and α_0; this corresponds to the partial entrainment of the sphere.

2nd. A circulation of the viscous liquid with the transformation of the work done into heat; this term is proportional to volume v, and, consequently to $(\alpha_0 - \alpha)$.

There is a third term which corresponds to the work due to inertia, but the acceleration of the sphere and of the liquid being always very small, this can be neglected.

Now, by varying μ, and the clearance, the angular displacement, α, given to the sphere can be diminished as desired. For a suitable limiting value this angle will become small enough to be negligible, the sphere remaining then practically always in the vertical through the metacentre. Under this condition the volume of the circulating liquid will be a maximum, and all the work delivered to the tube-sphere system by the kinetic energy of the rolling, will be transformed into heat. This work is proportional to the couple πl. Let M_1 be the moment of the statical resistance of the hull. If the condition

$$(1) \quad - \; - \quad (M_1 + \pi l) = P(\rho - a)$$

has been realised, all the mechanical oscillatory energy of the ship will at each instant be transformed into heat, and the ship will be "aperiodic;" the time necessary for it to return to its position of equilibrium will, theoretically, be infinite, and, practically very long. Such a ship would run the greatest danger among waves. It would be, so to speak, synchronous to all waves. It is not necessary then to carry the extinguishing so far as to realise condition (1).

It will be sufficient if the ship when displaced from its position of equilibrium in calm water, returns to it after two or three oscillations, its pseudo-period then differs little from its normal period. The value to be given in this case to the product πl is indeterminate, because one does not know what values to give to the terms representing the passive resistance of the hull and that of the tube-sphere system in the differential equation of the rolling motion. But trials made on models have shown that it is sufficient to take

$$\frac{4}{10} < \frac{\pi l}{P(\rho - a)} < \frac{5}{10}.$$

Under these conditions the co-efficient N takes values which are of the order of ·3 to ·4, that is, 15 to 50 times greater than for a ship not fitted with apparatus of this kind. A roll on a synchronous wave would be accordingly diminished in the ratio of

$$\frac{1}{\sqrt{15}} \text{ or } \frac{1}{\sqrt{50}},$$

and a roll on a non-synchronous wave in a similar proportion.

It is obvious that the amount of work transformed into heat is proportional to πl, so that the smaller the ratio $\frac{\rho - a}{l}$, the smaller will be, for the same efficiency, the ratio $\frac{\pi}{P}$.

Consequently, $\rho - a$ being practically a constant for ships between one and twenty thousand tons displacement, the efficiency of a given weight of the sphere B will be directly proportional to the displacement of the ship on which it is used.

Second Form of Apparatus

The apparatus may have a different form, Figs. 2 and 3. Indeed this was the original design as first conceived. If at the level of the centre of gravity there be fixed an axis, G G, carrying a sheet of metal of length l, and at one extremity of this sheet a weight π be fixed, a pendulum of maximum moment πl is formed analogous to the sphere of the first arrangement. The whole is enclosed in a water-tight compartment, O S, having the form of a circular sector with an angle equal to the mean angle of the rolling expected for the ship under consideration. The compartment has a rectangular section greater in all dimensions by the same increment, e, than the corresponding dimensions of the blade.

The action is identical with that of the sphere, but the arrangement is more bulky; besides, with violent rolling the pendular blade might be distorted; also, the cooling effect, which will be spoken of later, would not be nearly so good.

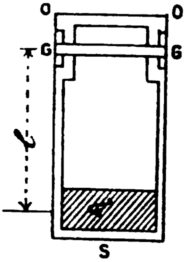


Fig. 2.

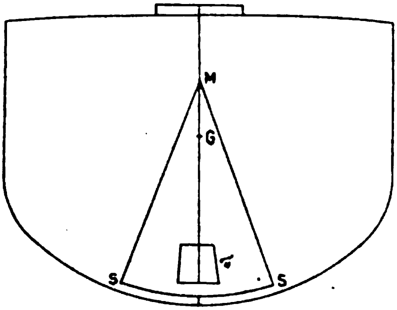


Fig. 3.

Statical Stability of the Ship Controlled.

Such an apparatus gives a very simple means of varying the properties of ships in respect of their statical and dynamical stabilities. In particular, the statical stability will depend on the centre of oscillation chosen for the sphere or for the pendulum.

If this point is the metacentre, the moment of the weight π is always zero about this point in the rolling motions, so that the expression for the statical stability will be in this case.

$$(2) \quad - \quad - \quad (P - \pi)(\rho - a).$$

If a point situated $\pm b$ above or below the point M be taken, the expression (2) will become

$$(3) \quad - \quad - \quad (P - \pi)(\rho - a) \pm b\pi,$$

consequently, if the point of oscillation coincides with G, $b = (\rho - a)$, and the statical stability will have the ordinary value, $P \times (\rho - a)$.

HEATING OF THE APPARATUS.

The action of the apparatus is dependent on a transformation of work into heat in the viscous liquid, which being contained in metallic tubes in contact with the bottom of the ship readily gives up its heat. To calculate the quantity of heat generated per minute a simple example will suffice.

Let there be a ship of a pseudo-period of 20 seconds rolling through 4° on each side of the vertical, and let it be assumed that the distance between the centre of gravity, taken as the centre of oscillation, and the middle of the tube is 10 metres, and the diameter of the section of the tube TT, 1 metre; also, suppose that the tube is constructed for a maximum angle of 20° (10° on each side of the vertical).

Under these conditions the mechanical work on the sphere assumed in the vertical through M, and of weight $\pi = 6{,}600$ kilogrammes, for an angle of 8°, will be

$$2\left[\pi \times l\ (1 - \cos 4^\circ)\right] = 2 \times 6{,}600 \times 10 \times {\cdot}003$$
$$= 39{\cdot}6 \text{ kilogramme-metres.}$$

This work is transformed into heat in 10 seconds, which makes 39·6 kilogramme-metres per second or 0·09 calorie. Now this heat is liberated in the liquid in the tube, which occupies in this example a volume of about 3 cubic metres. If the liquid be a mixture of water and glycerine of specific heat approximately that of water, the rise of temperature per second will be of the order of $\frac{0{\cdot}09}{3{,}000} = {\cdot}00003^\circ$ C. It is evident then whatever may be the conducting properties of the tube or of the sides of the ship on which it rests, that the cooling will always be sufficient.

TESTS MADE.

Some experiments were first made on floating cylinders then on various models, thanks to the courtesy of Prof. Biles.

The model that I have the honour to show this evening is of a

British steamer ($\frac{1}{40}$ full size) which rolls very badly and is difficult to steady because of the small value of the ratio,

$$\frac{l}{\rho - a}.$$

The following are the particulars:—

Period = 2 seconds.
P = 18 kilogrammes.
$\rho - a$ = 8 millimetres.
l = 93 millimetres (from metacentre to bottom of hull).
Length = 1·6 metre.
Breadth = ·19 metre.
Draught = ·10 metre.

A damping pendulum, having a couple equal to

$$\frac{P \times (\rho - a)}{10}$$

may be put into it, or, in place of 12 ballast weights of lead there may be put successively 12 "extinguishers" of the tubular type, each formed of a sector of 45° from a copper tube of 30 millimetres inside diameter, containing a lead-filled copper sphere of 28 millimetres diameter and weighing 100 grammes. For each of these tubes the couple is sensibly equal to

$$\frac{P \times (\rho - a)}{18}.$$

It is to be noted that the value of N, equal to ·02, when there is no extinguishing apparatus, goes through all the values up to unity as the tubes are successively brought into operation.

In conclusion, I may say that I hope shortly to see this apparatus fitted on a full-sized ship, as only by this means can it be demonstrated, in a thoroughly convincing manner, that the system is all that is claimed for it.

Discussion.

Mr J. **Foster King** (Member) observed that Dr. Cremieu's paper had something more than academic interest for all who had to go down to the sea in ships either for business or on pleasure, because they had a practical, and often personal interest in anything which might have the effect of extinguishing those oscillating experiments with more or less solid matter and viscous fluid within the human body, which had been so often and so anxiously observed in a sea-way. It was probably unnecessary to discuss the theoretical basis of the paper, or to analyse Dr. Cremieu's figures with regard to the damping effect of the pendulum, because such practical proof of their accuracy under static conditions must be admitted—at least by those who had the pleasure of seeing the experiments with a ship's model which Dr. Cremieu showed at Bordeaux, and also in this hall, wherein the period of oscillation of the hull in still water was extinguished by the same means and with the same rapidity as with the weighted pendulum shown that evening. The unknown quantity, however, was the effect of the moving weights upon a vessel when in a sea-way under such conditions as having a permanent list, or where the action of the sea might cause weights to rest in unexpected positions and to produce unexpected effects. The solution could only be determined, as it seemed to him, by experiment at sea, and one must await (and he awaited with interest) the results of the trials with a sea-going ship, which Dr. Cremieu expected to make. The structural aspect of the question was, after all, that which concerned him most professionally, and he was glad Dr. Cremieu was present to answer one or two questions on which it seemed to be desirable to have a little more light. If he remembered right, when Dr. Cremieu spoke in London, he referred to a case in which he tried the " pendulum " experiment with a weight which was, roughly speaking, one-half per cent. of the displacement and which had the effect of extinguishing the oscillation of the model. He might be in error, but if he understood the particulars now given by Dr. Cremieu, he spoke of using twelve extinguishers each having a weight equal to one-half per cent. of the displacement.

Dr. Cremieu—Yes.

Mr. J. Foster King—That being so, it would mean, working from the dimensions given for the model, that the 28-millimetre ball would represent an actual ball of over 4 feet in diameter when made for a vessel of 2000 tons displacement, and a weight of more than 10 tons. It would seem to be a very moderate estimate of the weight of the tube to contain this 10-ton ball and of the necessary quantity of viscous fluid, to say that it weighed as much as the ball, so that each extinguisher in a vessel of 2000 tons displacement would weigh about 20 tons, and in one of 20,000 tons displacement, 200 tons. If it should be found that 10 or 12 of these extinguishers would be required to obtain the necessary damping effect, it would mean the permanent abandonment of 10 to 12 per cent. of the vessel's displacement for the purpose, and dealing with a large practical problem. Even with one extinguisher, of the weight mentioned, it seemed to him that the practical considerations involved in handling and controlling such a mass in motion would be very serious, and he would be glad to hear how Dr. Cremieu proposed to provide sufficient strength and space in the hull structure merely to contain such moving masses of lead or iron, whose weight was not diminished by being contained in liquid, and what in his view were the precautions to be taken to guard against these weights "taking charge" and setting up local stresses in the hull structure.

Mr Henry A. Mavor (Member) said that he, like many of the members, knew little about the subject, but he would like even under that disability to say a few words as a personal matter. He had been watching Dr. Cremieu's experiments and had been making a few on the model, and he thought that if Mr Foster King were to see the model he would realise that it was somewhat difficult to make an exact calculation of the

Mr Henry A. Mavor.

weights required. They were a long way from being so great as he had suggested. Dr. Cremieu might explain more scientifically than he could, that while it was possible, as had been seen on the pendulum, to entirely extinguish the oscillation, it would be very unwise to do so on a ship and leave her at the mercy of the next wave to smash her. Roughly speaking, as far as he could calculate, comparing the effect of this apparatus, of about one-hundredth part of the weight of the ship, with bilge keels, it would probably have as good an effect on decreasing the roll. A 2000-ton ship would not require the great weight that Mr. Foster King had described, but only a weight of 20 tons, and although the ball in the tube was a very pretty way of illustrating the method, probably something more easily handled would be used, for example, a truck on wheels in a rectangular chamber would be as free to move as the ball, and be more easily applied. These were points that he had some diffidence in stating, but he wished to say that the Institution was very much indebted to Dr. Cremieu for making two special journeys from Paris to be present at these meetings. To a certain extent these journeys had been made in his own interest, but he was much more of a scientific man than a business man, and a man who had given his life, at his own charges, to the study of gravitation was not quite on the footing of an exploiter of a patent.

Mr John Ward (President) said that Dr. Cremieu's apparatus was an extremely ingenious method of damping down oscillations about the mean position of equilibrium which occurred in free moving bodies, and its application to many cases, such as balances and recording instruments, would be of great value in rendering them dead beat. Its application, however, on the large scale necessary in dealing with ships, introduced a number of factors which were not important in the case of small instruments. The energy of a rolling vessel was often considerable, and its absorption by means of bilge keels (which

Mr John Ward.

was the commonest method of attempting to deal with it) was accomplished by applying a resisting force over a considerable portion of the vessel's length. The forces producing oscillation being also distributed over the vessel's length, there was a partial neutralisation at any cross section which might be considered. The structure of the hull was, therefore, little strained, as it was only called upon to transmit the difference of the forces from a point in the length where one was greater than the other, to another point in the length where the other was greater than the one, which difference would not be very great. If an attempt were made to absorb the energy at what was practically one point in the length of the vessel, there would be very great forces to be dealt with, and the structure would, he feared, be strained in a manner which would necessitate a very considerable increase of scantling in order to keep the stress intensity within practicable limits. That seemed to him a fatal objection to the gyrostatic method of checking rolling, and it would also apply in some part to Dr. Cremieu's apparatus, although its effect would be minimised by fitting several sets of apparatus throughout the length of the vessel. That would necessarily imply a sensible increase in the cost of the vessel, and it would be a matter for the shipowner to consider whether the results justified the expenditure or not. In the case of vessels which were notoriously bad rollers, and, therefore, unpopular with passengers, the investment might be a very profitable one. Rolling, however, was only one of three motions which a vessel in a sea-way might be considered to take. Besides rolling about a longitudinal axis, she pitched about a transverse axis, and this motion, although through a much smaller angle was more rapid and much more unpleasant in its effects, and while, doubtless, it could be dealt with by Dr. Cremieu's apparatus disposed in a plane at right angles to that which dealt with rolling motion, the straining effect on the hull would probably be even more severe than in the case of transverse rolling. In addition to

Mr John Ward.

the angular motions, there was an up and down motion of the ship as a whole, as the static condition of the equilibrium involved equality of displacement and weight, which only obtained for a small fraction of a second, the vessel oscillating about this position of static equilibrium. This was the worst of all motions, both in its effect on the comfort of passengers and in its power to defy treatment by any known means. The effect of any particular sea was naturally less in this respect in large vessels than in small ones, and it might be in the gigantic liners now becoming fashionable that this effect became negligible, but until this was so, it was questionable if shipowners would be willing to increase the capital cost of their ships in order to provide an apparatus which only dealt with the least objectionable of the ship's motions, even although it did deal with it in a most effective manner. He regretted appearing to speak in a manner of destructive criticism, as he had looked upon it from a commercial standpoint, and it was all the more regrettable as he recognised, as everyone must, that scientifically the apparatus was an extremely ingenious one, and that in other directions where it more closely fulfilled all the requirements of the problem it would have a very extended field of usefulness.

Dr. Cremieu, in reply, said that an experiment made by himself with an assistant at the University had proved that the effect of this apparatus was greater than that of bilge keels. A bilge keel only affected great rolling and not small rolling, and only one tube would give better results than a bilge keel.

The President said it was to be regretted that Dr. Cremieu had not been able to give his paper before a meeting of shipowners, because they were really the people who had the power to test it practically, either in vessels already built or to be built later. In the name of the members, he proposed a vote of thanks to the lecturer for the thoroughness with which, from a scientific standpoint, he had gone into the subject, and also for the compliment he had paid them in having made two trips from his home in Paris in order to bring the subject before them. He hoped that as a result they might ere long see a vessel fitted with the apparatus, and the predictions of Dr. Cremieu fulfilled in every particular.

The vote of thanks was carried by acclamation.

Correspondence.

Prof. J. B. **Henderson**, D.Sc. (Member), wrote as follows:—A damper of the oscillations of any body must produce a damping force (or couple) proportional to some power of the velocity. If the force is proportional to the acceleration no damping effect is produced, but simply a loss of stability, that is, the force causing the body to return to its natural position of rest is reduced. Some time ago Dr. Cremieu made the statement at a meeting of the Institution of Naval Architects that in a gyrostatic damper, the damping couple is proportional to the angular *acceleration* of the roll. On that occasion the writer showed that it is proportional to the angular *velocity*, taking as an example the damping of the rolling of a paddle steamer due to the gyrostatic action of the paddles. Dr. Cremieu has evidently not considered that these remarks applied to his statement, for he repeats it in this paper. The writer, therefore, takes the opportunity of again contradicting it, and in proof will take the case of Schlick's gyrostatic damper. In Fig. 4, let OX, OY, OZ, be three mutually perpendicular axes, OX athwartships, OY vertical, and OZ forward in the ship. The rotor has normally its axis along OY and the trunnions of the gimbal ring along OX, the trunnion bearings being fixed to the ship. The hydraulic brake is shown with its connecting rod attached to the bottom of the gimbal ring, the motion of the piston being fore and aft in the ship. I shall represent couples by their axes; the axis of a couple being the axis about which the couple would rotate the body if acting alone, and its direction being the direction of advance of a right-handed screw rotated by the

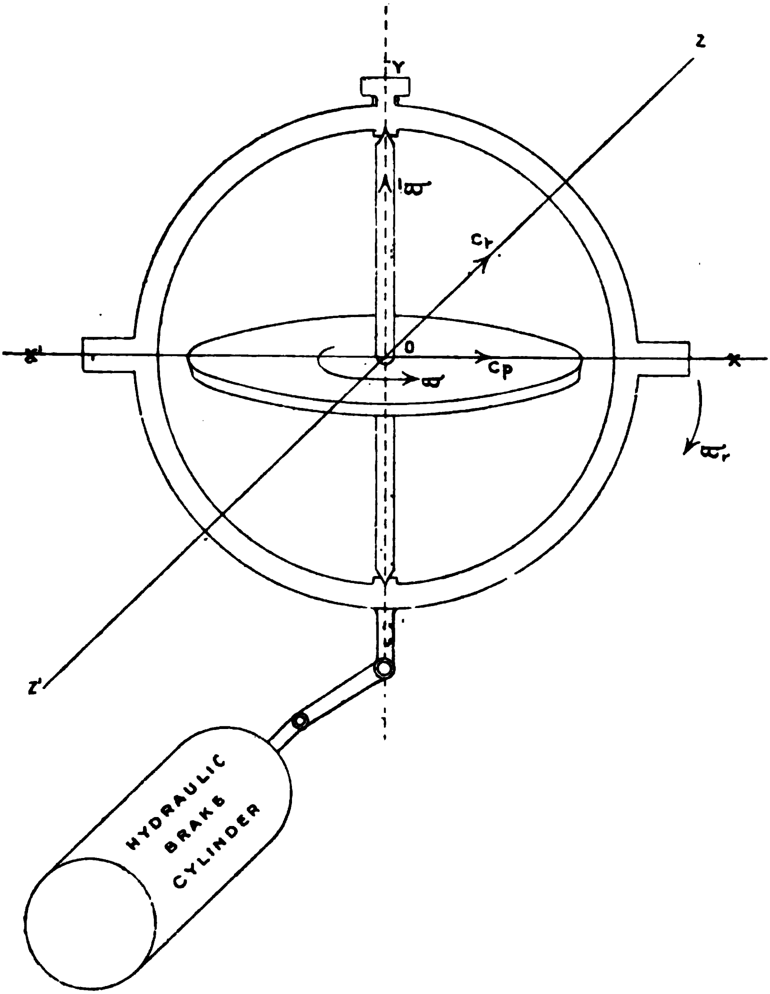


Fig. 4.

couple. Now suppose the ship rolls to starboard with angular velocity ω_r. The "gyro" rolls with her, but the "gyro" can only roll to starboard in virtue of a couple in the plane of pitching. If the rotation of the rotor is positive round OY, then this couple will have OX as axis. (I shall call any motion of the rotor round OX axis pitching of the gyrostat.) Let us denote this couple by C_p. Its value is given by

$$C_p = I\,\omega\,\omega_r,$$

where I is the moment of inertia of the rotor and ω its angular velocity of rotation. This couple C_p can only arise from the action of the hydraulic brake. In such a brake, however, we only get a resistance so long as there is motion of the piston, the force exerted being proportional to some power of the velocity of the piston. Suppose the friction is entirely viscous, say, a very thick liquid in the cylinder and slow motion, the resistance will then be proportional to the velocity. We shall then have C_p proportional to ω_p, or

$$C_p = -k\,\omega_p,$$

where k is a constant. The minus sign simply indicates that C_p is opposed in direction to the motion ω_p. We have seen that if the "gyro" rolls to starboard it must have a couple C_p acting on it, and that in order to have this couple it must pitch with angular velocity ω_p in the direction to depress OZ. The "gyro" can only pitch, however, in virtue of a couple in the plane of rolling and to depress OZ this couple must have its axis along OZ. It is produced by the mutual reactions between the ship and "gyro" at the trunnions. Its magnitude (since the velocity of pitching about OX is ω_p) is

$$\begin{aligned} C_r &= -I\,\omega\,\omega_p \\ &= \frac{I\omega}{k}\,C_p = \frac{(I\omega)^2}{k} \times \omega_r. \end{aligned}$$

This is the couple on the "gyro" in the plane of rolling

Prof. J. B. Henderson, D.Sc.

and has OZ as axis. But action and reaction are equal and opposite, therefore the couple on the ship in the plane of rolling is equal and opposite to C_r, that is, it has OZ^1 as axis and is, therefore, opposing the rolling. We see then that there is on the assumptions made, a damping couple proportional to the velocity of rolling. It is also evident that we only get this couple so long as we allow the "gyro" to pitch under the action of a viscous resistance. If we lock the pitching motion by means of the hand brake, the damping will at once cease. There is theoretically no limit to the damping effect which can be produced by gyrostats. In fact, the damping instead of being passive can be increased until it becomes, as in Brennan's mono-rail, active, and causes the ship to roll in the opposite phase to that in which the sea is trying to make her roll. The practical limit is, of course, fixed by the size of apparatus fitted, and the maximum stresses allowable in the various parts.

Dr. CREMIEU, in reply, agreed that the damping couple of the gyroscope was proportional to the angular velocity; but this did not change a single word in what he said concerning the difficulty that a gyrostatic damper would meet, when applied to ships of long periods of rolling.

THE PLACE OF THE LABORATORY IN THE TRAINING OF ENGINEERS.

By Professor A. L. MELLANBY, D.Sc. (Member).

SEE PLATES I. AND II.

Read 19th November, 1907.

ALTHOUGH many papers on technical education have been read and discussed within recent years, the writer is of the opinion that the subject is not yet exhausted. From conversations with engineers of the district, he has gathered that employers are keenly interested in educational matters, and that many are prepared to make considerable sacrifices to further the advancement of those under their charge. At present, however, there seems to be no unanimous opinion as to the best course of training to be given, and, consequently, a discussion upon this point may be of advantage to all concerned.

It is now generally conceded that the advancement and prosperity of an engineering establishment depends upon the number of well-trained employees it possesses, but much difference of opinion exists upon the point whether the education given in our engineering colleges is of the kind best fitted to produce the type of man who will be of real value to his firm.

It will be well, therefore, to sketch briefly the general course of training given to students in engineering, and to consider seriously whether this training is on right lines, and whether the engineering industry of this country is obtaining the maximum possible amount of benefit for the large sums of money that are being spent on technical education.

In the opinion of the writer the training given in the majority of our engineering schools is far from being what it might be, and he hopes to convince the members of this Institution that with their co-operation a vastly improved scheme might very easily be carried on in this district.

It is the general opinion at the present day that no engineering college is complete without a well equipped laboratory. As to the work that should be done in this laboratory there are many different views, but perhaps the one most general is that students can there obtain in an interesting manner some elementary knowledge of engineering. That the laboratory may be of the greatest use to the engineer in practice is far from being generally recognised, and it is to the importance of this latter consideration that attention is here particularly directed.

The usual laboratory work, so far as mechanical engineering is concerned, is confined to the determination of some of the properties of the materials of construction by breaking a few specimens, and to the making of elementary tests upon engines, boilers, water-turbines, etc. Generally the object in view is to familiarise the young engineer with the subjects that are taught in the lecture room, and to bring before him the fact that practical considerations impose limitations in the design of any engineering structure.

Now although a sound laboratory training upon these lines will be of great use to an intending engineer, it must be obvious that this ought to be merely the beginning and not the sum total of his experimental work. In addition to this he ought to be made familiar with the methods of research work, by attacking some of the numberless problems in engineering that still await solution.

To such a suggestion one of the two following replies is generally given. Thus one may be told that in some laboratories the students are regularly employed upon research work. This research, as a rule, turns out to be the repeating of some simple series of tests upon, say, a steam engine, and the writing of a full report upon the results obtained. Whilst such a course may be of value to the individuals performing the experiments, it can only be called research by a considerable stretching of the meaning of that word. The second reply, and one that is given by the great majority of those who look into this matter, is that the students are altogether unfitted to carry on research work. With this reply the writer in almost all cases agrees, and he considers it to be a most telling argument against the present defective system of training.

In considering the work done in most of the engineering colleges throughout the kingdom, generally speaking the first year course is attended by boys coming straight from school. This course is common to all first year students, and comprises mathematics, physics, chemistry, and drawing. In the second and third year the student specialises in either mechanical, civil, or electrical engineering, and takes lectures dealing with that branch for which he is studying. There are, of course, certain lectures in each subject common to all. In addition he takes laboratory courses where the work done is of the type previously described. When he leaves college at the age of 19 or thereabouts, he has thus a fair theoretical knowledge of engineering, can make a reasonably neat drawing, test specimens of materials, take indicator cards and generally conduct an ordinary engine or boiler trial. As a rule, however, he is incapable of making much practical use of his scientific knowledge, and if compelled to act upon his own responsibility in the case of some mechanical problem, often fails badly. Many employers thus look coldly on a system of education which produces such poor results, and this affords an explanation why the chief draughtsman or foreman who is responsible for getting the work done, so often states that he would rather have a boy straight from school than one who has undergone a college training.

In Glasgow the state of affairs is perhaps somewhat better than this, as with the short winter session many of the students are able to engage in practical engineering work during the summer months. In their third year they are, therefore, in a better position to take advantage of the opportunities afforded them in college, and, consequently, obtain an increased amount of benefit.

The only conclusion to which one who considers the matter impartially, and who is actually acquainted with the type of man desired, can come, is that the average college training is a most absurd one. It is evident that it has grown up because it created least disturbance to the existing state of things, and the writer feels it his duty to state that the development of this fruitless system is chiefly the fault of employers themselves. Anyone who has read the literature dealing with technical education must have been struck by the manner in which all the writers are continually complaining of the lack of support given by employers. The advance in education has been almost altogether due to the fact that the students themselves have felt the necessity for information concerning the principles of engineering, and have attended engineering courses with absolutely no encouragement from outside sources. At the present day this is fortunately changed, and employers are, on the whole, not unwilling to support a scheme of education which they see is advantageous to themselves. When any of those employers who give little or no encouragement to college trained youths are questioned as to their reasons for this line of conduct, they will generally reply that in their opinion the men turned out are not worth the money that has been spent upon them, and they see no reason for sacrificing either money or the efficiency of their workshops for a useless object.

It must be evident that, from their own immediate point of view, these employers are right, for the ordinary college student has had little or no actual engineering experience, and therein it would appear lies the failure of our educational system. To the writer the remedy is obvious, and he feels that the vast sums of money that are now being to a large extent wasted on technical education, might be easily turned to useful purpose if it were made the rule that a considerable amount of workshop practice should precede the final attendance at college courses.

A proposition like this is at once met with the reply that a system which allowed apprentices to leave the works for two or three years after they had reached the age of 19 say, would completely disorganise most businesses. That it would cause some inconvenience is certainly true: a youth of that age is generally becoming of some value to his employer who naturally objects to part with him. Unless, however, the engineers of this country desire to become mere copyists, and to confine themselves to the manufacture, under licence, of foreign inventions, it is necessary that some sacrifice be made. The writer would indeed call it not sacrifice, but an investment, and one sure to produce a big return in a few years.

In support of the above proposal that workshop should precede college, it may be pointed out that if college training is to produce men who are capable of inventing new processes and improving existing methods of manufacture, then the training must not confine itself altogether to principles, but must direct attention to current engineering work. This means that the student should not only have a working acquaintance with engineering practice, but must be prepared with a sufficient knowledge of mathematics and physics to take up his technical studies at the college with profit. It therefore follows that there must be a continuity of theoretical study between school and college. The youth who neglects his education after leaving school, and who after some years with an engineering firm determines to take a college training, generally finds himself in an unenviable position. His knowledge of mathematics and science is usually so small that he cannot take advantage of the higher technical lectures and, consequently, wastes much time in trying to obtain that elementary knowledge which he might easily have acquired had he continued his studies on leaving school.

It becomes then an important point to consider in what way an employer may best help to carry out a scheme which will give the colleges an opportunity to do their share in turning out really valuable engineers. The following proposal is brought forward in the belief that with very little works disorganisation, all that is desired can be accomplished.

The student after leaving school should immediately proceed to college and there take up the first year general course. He will thus get a preliminary grounding in mathematics and science, and since there has been no break between college and school, his mind will be in a sufficiently well-trained condition to benefit by the instruction he receives. At the close of the college session he ought to enter an engineering works where he should remain for at least three years. During these three years he would keep up his studies, especially devoting himself to mathematics and physics. At the end of this time he ought to return to college and take during the winter session the second year's course. The following summer would be again spent in the workshops, and the next winter would be devoted to the third and final course of college work. It will be seen that the scheme proposed bears some resemblance to the oft-discussed sandwich system, but there are sufficient differences between them to ensure that the comparative failure of the old scheme will become the absolute success of the new one. It is essential, however, for its success that there be continuity of theoretical work from the time the student leaves school, and no apprentice ought to be allowed to take up the second year's college course unless he could produce evidence of having made material progress in his mathematics and natural science during the three years spent in the works. How his training during this period ought to be carried out is a point upon which it is hoped some discussion will be raised. Attendance at evening classes would produce least disturbance in the works, and there is no doubt that a hardworking student could get a fair amount of knowledge in this manner. Whatever advantages evening classes have, it is generally acknowledged that the return for the energy and time expended is very small, and for apprentices engaged during the whole of the day the acquisition of advanced mathematics in this manner means trying and exhausting work. The other alternative is that the apprentices be allowed to attend day classes for, say, two afternoons per week. The evenings would then be free for private study, and a considerable amount of mathematics and natural science could be acquired during their three years in the works. There are obvious arguments against such a course, but several firms have already adopted the system of allowing part of the time during the day to be devoted to class work, and their experience seems to be fairly satisfactory.

The advantages arising from the scheme outlined above will on consideration be apparent. The student would take up his second and third year's college work with such a preliminary practical and theoretical training that the whole character of present day college classes could be changed. The elementary descriptive lectures so necessary to schoolboys could be omitted, and in their place lectures of vital importance to every-day engineering practice could be given. The most recent developments could be described and discussed, and the information given in papers to engineering societies such as this—valuable papers so often neglected as soon as printed—might be gone into and thrashed out by men who had sufficient practical information to see their bearing on current engineering work, and sufficient time and knowledge to go into it fully. The laboratories, instead of being places for elementary testing, might develop into schools for real research. Practical problems that had arisen during workshop experience might be settled by direct experiment, and an amount of information gathered that would in a short time lead to an immense improvement in our national engineering

If such an advance could be made in the standard of work done at college the class of investigation that might be performed in the workshop would be still more improved. Although the writer thinks that the college laboratories might be infinitely more useful to the industries of the country if they were made establishments for research, he is also convinced that many problems can only be solved in the works themselves. The great difficulty in the way of carrying on experimental work outside the colleges is the lack of suitable men. Very few even of those who have had a college training can carry out an original investigation in a satisfactory manner. Reference is not being made here to the ordinary work, such as engine testing, of which so much is being done at present. Even for this class of work, the man who can analyse his trial results and from them discover how to improve the next engine to be designed is not easily found. When it comes to the breaking of fresh ground and the devising of means to discover whether some new system is likely to prove efficient, or the best way to make it so, then anyone capable of carrying on this class of work is rarely met with in practice.

It will be seen that this scheme insists upon the great importance of laboratory work in the production of the right type of engineer. At the risk of becoming tedious the writer would again repeat that laboratory work of the proper kind cannot be carried out unless students have had considerable engineering experience. It is well known that very little research work of any value has been done by our engineering colleges, a point to which attention is drawn by an article in *Engineering* entitled, "Original Research," printed in the part issued in September 20th, 1907.

The reason for this is obvious. The schoolboy students, with which our colleges are filled, have neither the capacity nor desire to carry out work of the kind needed, and the professors and lecturers have their whole time taken up in giving text-book lectures and conducting elementary experimental work.

There may be slight difficulties in the way of bringing about such a course as has been outlined, but if only engineering firms will co-operate with the colleges these difficulties will vanish. Nothing can be done, however, without this co-operation, and if only employers are convinced that it is necessary to the prosperity of the engineering industries of this country that men should be educated to the standard indicated in the paper, facilities for carrying on workshop and college training side by side must be provided. There can be no comparison between the value of the ordinary college educated youth and one who has passed through the course here described, and the question of a slight amount of works' disorganisation ought not to stand in the way of its adoption. Modifications of the scheme may be suggested in the discussion, but it is of enormous importance that the present haphazard methods be abandoned and some definite agreement come to between works and the college.

A paper like this would be incomplete without a reference to the work of Professor J. T. Nicolson of the Victoria University of Manchester, in connection with the attempts to bring about a scheme for the rational training of engineers. More than twelve years ago he was emphasising the immense importance of laboratory work at M'Gill University, Montreal, and there is considerable evidence that his ideas are now being gradually accepted by many engineers of this country.

The following extract from a paper read by Professor Nicolson before the Manchester Association of Engineers may well bring this paper to a close:—

> "In conclusion the writer can only reiterate the statement that the proper education of our young engineers

depends upon the attitude of the employers towards it, and upon nothing else; for if *they* do not realise the national significance of such higher scientific training as is here contemplated, it is useless for the Heads of our colleges and schools to thrust forward their projects in their despite.

If they will not be convinced that it may be to their ultimate advantage to make some present sacrifice, then it only remains to hope that we shall pull through by the mere cogency of the fact that we are not foreigners; or to view, with what philosophy we may, the advent of that commercial disaster which our American critic, Mr Brooks Adam, believes must happen to us in order to arouse us from our lethargy."

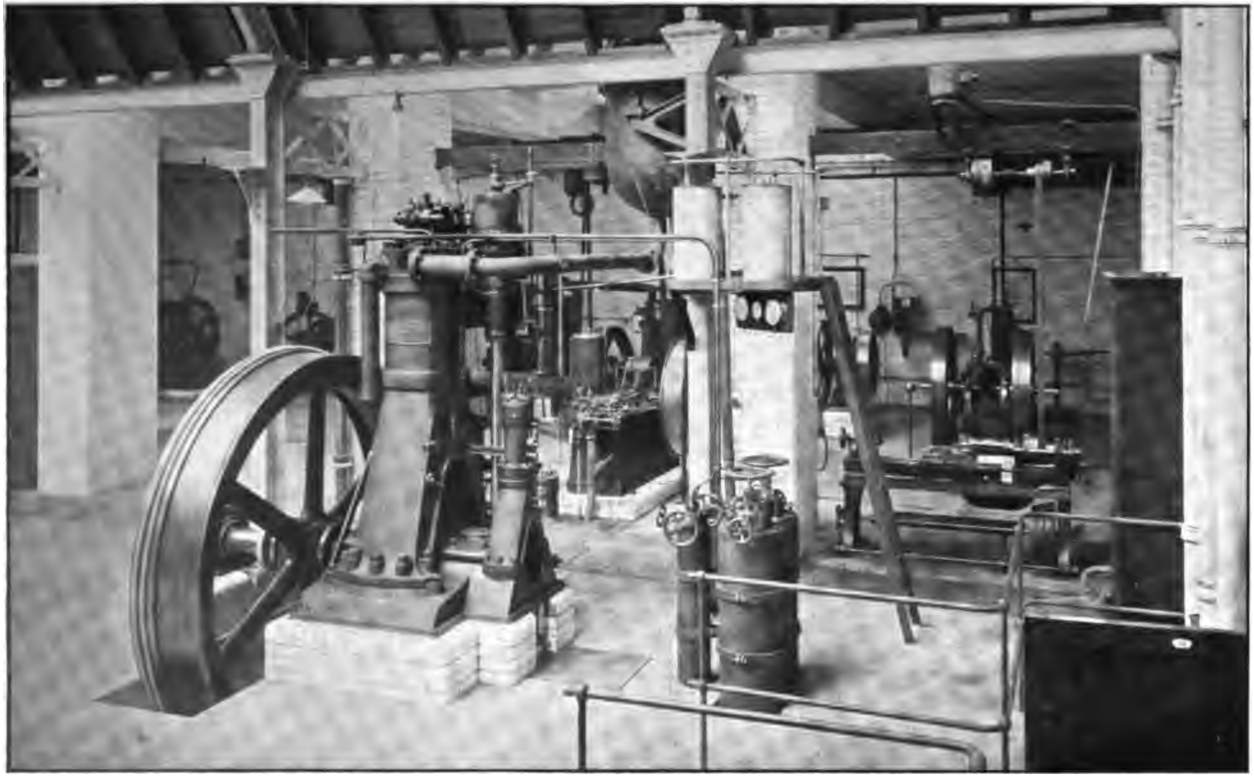
APPENDIX.

A considerable amount of interest has been shown by many engineers in the equipment of the new laboratories of the Glasgow and West of Scotland Technical College, and it was thought that some slight account of them might be of interest to the members of this Institution.

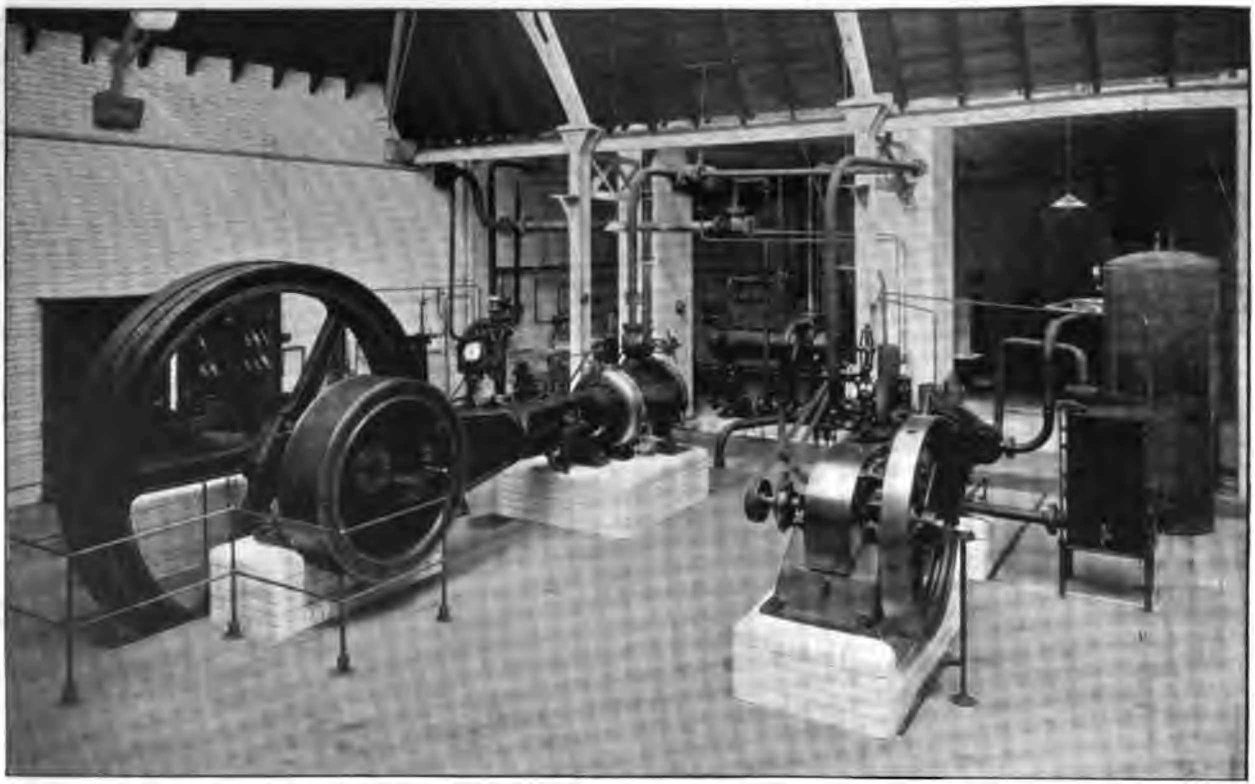
The following illustrations have therefore been prepared, and from these some idea of the laboratory capacity may be obtained.

The first three show general views of the laboratory devoted to motive power engineering, which is under the charge of the Author, and Plate I. is a ground plan of the same. The various pieces of plant have been numbered on the plan, and may be identified from the index provided.

A general view of the dynamo and motor laboratory, in the department of Professor Magnus Maclean, is also shown, and it will be noticed that it contains examples of many modern types of machines.



Motive Power Engineering Laboratory—Oil and Gas Engines.



Motive Power Engineering Laboratory—Steam Engines and Air Compressor.

Motive Power Engineering Laboratory—Motor Car Experimental Plant.

Electrical Engineering Department—Dynamo and Motor Laboratory.

Plate II. shows the ground plan of the mechanics' laboratory. This contains several types of testing machines of novel design, which have been made to the instructions of Professor Longbottom, who is the head of this department.

Much of the plant shown has been either presented or charged at cost price by the manufacturers, and the writer takes advantage of this opportunity to thank them for the interest they have shown in the work and for their generosity.

Discussion.

Prof. ANDREW JAMIESON (Member) said Dr. Mellanby had evidently a very poor opinion of the present and the past methods adopted by colleges where engineering science was and had been taught. For the second paragraph on page 2 stated that "In the opinion of the writer the training given in the majority of our engineering schools is far from being what it might be, and he hopes to convince the members of this Institution that with their co-operation a vastly improved scheme might very easily be carried on in this district." Again, on page 4, the Author said that "The only conclusion to which one who considers the matter impartially, and who is actuated with the type of man desired, can come, is that the average college training is a most absurd one." These were strong statements to make before the members of this Institution, who could point to some of the boldest and most successful engineering results, as carried out by their predecessors and colleagues, who had to be content with the system of training hitherto in vogue in their workshops and the evening classes of the oldest technical college in the world! Dr. Mellanby proposed a remedy for these defects before he had had sufficient time to thoroughly test the results of his own laboratory training and plant at the Glasgow Technical College. His first and best proposal was rather amusing to the speaker, because it was identically the same course of training which he (Prof. Jamieson) went through

Prof. Andrew Jamieson.

at Aberdeen from 1864 to 1870, and which he so strongly advocated from 1880 to 1887, as Principal of the Glasgow College of Science and Arts, and thereafter as the Chairman of the Board of Studies of the present technical college, viz., "the thin and thick sandwich system." This consisted, as they had been told that evening, of attending college day classes for one session immediately after leaving school, then two or three years in works with evening classes or other means of science instruction, and again a course of college, and so on until fairly provided with sufficient knowledge and skill to make successful progress in the engineering world. When the Institution of Civil Engineers distributed questions to its members, in order to ascertain what each one thought was the best system for training young engineers, he (Prof. Jamieson) stated that, in his opinion, the above method had been found by actual experience to produce the best results with those who aimed at the higher positions in the profession. He, however, strongly objected to Dr. Mellanby's proposal "that apprentices be allowed to attend day classes for, say, two afternoons per week," because this would tend to disorganise engineering works which were conducted with the object of earning dividends. Moreover, he had a much higher opinion of the advantages to be gained by apprentices attending evening science classes than that expressed in the paper. Most of the best and highest-paid mechanical engineers who were trained on the Clyde, could only point to evening classes at The Andersonian College or the College of Science and Arts as the main sources from which they gained their knowledge of science. In places where no such science classes existed, or where they were too distant, or when an apprentice felt that he would be better to stay at home during the evenings in order to get to his work regularly by six every morning, then the best alternative was to go in for "tuition by correspondence." Many students had done this after trying the evening classes, and had testified that

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they then made more thorough progress, because they had to really think and study for themselves in order to answer the problems found in their text books or set by the teacher. He refrained from discussing several other statements in the paper, but he would like to ask the Author, Why the present system of teaching at the Glasgow Technical College did not produce a tenth of the number of Whitworth Scholars that were turned out twenty or more years ago in the separate colleges before their amalgamation? Further, he would like to draw attention to the fact that the Author of the paper had omitted to state the necessary and indispensable qualifications of a good "laboratory instructor." No one should be appointed to teach engineering science and to guide students through a laboratory course, unless he had previously undergone at least five complete years in three or four different departments of engineering work, including at least one year in a drawing office and one year in the commercial department, in addition to a college education. Much more depended upon the practical training, mechanical skill, and resourcefulness of the teacher than upon the latest, best, and most expensive laboratory appliances, for stimulating students to work and to devise original methods of carrying out experiments either in connection with preliminary instruction or actual *bona fide* research work. It should not, however, be forgotten that in Glasgow there was a university as well as a technical college, and that the best students from the latter should proceed to the former when they had taken their A.G.T.C. diploma, in order that they might not only obtain the B.Sc. degree in engineering science, but thereafter participate in the privileges of real research work under the patronage and stimulus of the Carnegie research scholarships or bursaries, as some had already done. Dr. Mellanby's two predecessors at the Technical College had no difficulty in interesting the engineers of the Clyde in their work, for they were often asked to test boilers, engines, dynamos, motors, or

Prof. Andrew Jamieson.

devise installations, or carry out practical investigations and research work. In doing these things they always did their best to engage the assistance of senior students, so that they could benefit by such knowledge and experience. There was one thing, however, which had been found by experience, namely, that no firm or person would ask a professor to carry out researches upon special private work if the students were permitted to note all the results. Finally, research work could only be well and thoroughly done at the Technical College during the summer months, if the professor and his assistants were to give the requisite attention to the ordinary routine of lecturing and conducting elementary laboratory work to such large numbers of day and evening students.

Mr Harry Bamford, M.Sc. (Member), considered that Dr. Mellanby had dealt with a subject of very great importance, and in his paper sought the co-operation of employers in the education of engineers, and the question to be considered was the best way in which employers could assist in the matter. He would like to ask Dr. Mellanby in the first place whether he confined his suggestions and remarks to the training of mechanical engineers, or whether they were intended to apply to engineering students in general?

Dr. Mellanby—He was thinking more about mechanical engineers.

Mr Bamford—So far as the education and training of mechanical engineers were concerned he agreed with the suggestions made by Dr. Mellanby to a very large extent, but as the practical training of a civil engineer was so different in character to that of a mechanical engineer, the scheme of his education should be different also. He quite agreed with Dr. Mellanby that an intending student, whatever branch of engineering he intended to follow, should be encouraged to go direct from the school to the college and remain for one session, or until he had completed his first general science course. For mechanical engineers, he thought, the student would then do well to enter the workshop as a regular apprentice, and after remaining for two or three years return to the college or the university to finish his scientific studies. In the case of civil engineers a student might with advantage—especially where the college session was so short as it was in this country—after taking his first general course in a university or college, spend a summer (or a year) in the works of a mechanical engineer and then follow out, where possible, the sandwich system adopted in this country. He would thus—whether the sandwich system were adopted or not—require to spend two or three years in the works or in the office of a civil engineer after completing his college course. With the Author's sweeping assertion that "the average college training is a most absurd one," he did not agree at all. Neither did he altogether agree with the somewhat disparaging remark that "evening classes yield very small returns for the energy and time expended." College-trained engineers, he thought, were becoming more fully appreciated by employers, and he knew of cases where young college-trained engineers had obtained employment with firms prejudiced against this type of man, with the result that the firms not only speedily lost their prejudices, but rewarded them for their services in such a way as to indicate that there had been nothing very absurd about their college training. In conclusion he would like to say, that in his opinion, evening classes served a very useful purpose; and, if not too large, the apprentice, after his daily labours in the shops, would find them more stimulating, and, for the same rate of progress made, less exhausting than private study.

Prof. **George A. Gibson**, M.A., LL.D., observed that the essence of Dr. Mellanby's paper was to be found in the contention that a college training should produce an engineer who could so conduct research that he would be able to improve on the designs of engines and of engineering processes generally. For example, at the foot of page 75 Dr. Mellanby said, "The most recent developments could be described and

Prof. Geo. A. Gibson, M.A., LL.D.

discussed, and the information given in papers to engineering societies such as this—valuable papers so often neglected as soon as printed—might be gone into and thrashed out by men who had sufficient practical information to see their bearing on current engineering work, and sufficient time and knowledge to go into it fully." The other sentence was near the end of the second paragraph on page 76, "Even for this class of work, the man who can analyse his trial results and from them discover how to improve the next engine to be designed is not easily found." It was upon these two sentences that the following remarks were based. That the aim was good, might be at once and cordially granted, but the chief factor that seemed to be forgotten was the student's capacity; the power to devise improvements, though it could be to a certain extent cultivated, would always depend essentially on the native capacity of the student. They had there the counterpart in science to the idea expressed as regards literature in the saying "The poet is born, not made." It seemed to him to be against all experience to assume that, there was sufficient originality in the average student or workman to make it even probable that any training whatsoever would enable him to be so proficient that he would always, or even generally, be able to devise improvements that were of outstanding importance. The great discoveries would always be made, in a way no one could explain, by the man who had that indefinable possession called "genius." At the same time, there was a very considerable element of truth in the contention contained in the sentences at the foot of page 75; there should be (probably there was at present, but he did not know) such a type of student that it was possible to discuss in the lecture-room—by discussion carried on under the guidance of the professor, and by home exercises—the more important of recent designs, such as formed the topic of discussion at scientific societies or in engineering journals. The amount of lecture work might be diminished, and he thought should be diminished. But this could only be done if the students were willing to take full advantage of the books that their professor recommended to them, and so far as his experience went, this was just the course they would not take; they seemed to find it so much easier to assimilate the oral instruction than the written word. But even granting that the lecture occupied a less prominent place, there must still be a considerable training of a purely theoretical kind before anything in the nature of real research could be overtaken, and when was this training to be obtained? The knowledge of mathematics, physics, mechanics and drawing that was presupposed as a preliminary to Dr. Mellanby's training in research was very considerable, and was generally assumed to be much less in this country than on the Continent. One was almost led to the conclusion that such work as Dr. Mellanby desired could only be effectively done by a few students who could take post-graduate courses, or who could be attached to the works of large firms for the special purpose of research. He did not see how any college could keep its laboratories supplied with all the material necessary for research work of this kind. The laboratories might still, however, give a student a kind of training that, combined with his own inventive powers, might enable him in later life to do really valuable work. The college could not assume that all great improvements would have their origin within its walls; it could, however, and ought to train its students so that they could follow independently all the movements in the particular branches in which they were interested, and could see the leading principles that were called into play in any special process or design. The further power to improve in any material respect on the process or design was largely a matter of long experience and native genius. To attain even this modest aim, it would be necessary to insist on having students who had made the most of their school work and had advanced so far in theoretical studies that they could be trusted to master books

Prof. Geo. A. Gibson, M.A., LL.D.
with the help of their professors rather than to trust to their teachers for every item of information. Much more could then be done than was done at present to help the student to get a real grip of his theoretical work, so that when he went to the laboratory or to the shop he might readily recognise what general principles were in question, and apply his knowledge to the translation of these into the particular case. The grasp that the ordinary student had of the principles of dynamics was usually very feeble, and it could only be strengthened by exercises that involved a fair knowledge of mathematics, a quick and accurate arithmetic, and a sustained power of concentration; but these qualities demanded time for their development, and by the time a student had gained them he should be out in the world. Opportunities for real research would be open to him all his life. To sum up, Dr. Mellanby's ideas of what a college should be able to do were in no way applicable to the technical schools of this country, as matters were likely to stand for many a day. The research he desiderated could only be done either by a small number of post-graduate students, or by men attached to private engineering establishments. On the other hand, he was right in laying stress on the need for diminishing the amount of lecture and "copy research," but to secure even this diminution the students must come more thoroughly trained; they must be able to think for themselves and not merely reproduce a text book or a professor's notes, and they could be aided in this direction by a less formal system of lecturing, which would often take the shape of a series of questions and answers, or informal discussion of the subject matter of books or papers, or formal lectures. Problems could constantly be set which would develop the student's power of applying principles, which would strengthen his grasp of them, and which would to a certain extent prepare him for the daily work of his profession, in so far as that was determined by general scientific principles.

Mr Henry A. Mavor.

Mr HENRY A. MAVOR (Member) wished to express very strongly his opinion that this paper was a bad one. It was most confused in its statements, and altogether unsatisfactory from his point of view, which was, that Dr. Mellanby asked employers for their co-operation in sending students to an institution where the work was being carried out in a futile and absurd manner—an institution which was founded for the purpose of technically training engineers and others engaged in the practical industries of the district, and which, from Dr. Mellanby's statements, was not fulfilling its object. He thought Professor Gibson had stated the case very well indeed. It was not to be expected that a student emerging from the college was going to be immediately entrusted with important work. No wise employer would ever suggest such a thing. Take a lad at the age of 19 or 23 years, who had no practical experience, except from a haphazard attendance in the workshop: to expect such a youth to carry out important work was absurd. There was the same absurdity if he was expected to carry out research work during the course of his studies. Dr. Mellanby must realise that the drudgery work had to be done. A prize flower could not be got from every stem. The wastage from education must be enormous. He visited a school in Dundee the other day where he was sure there was not one in 500 who had a fair chance of making his living. Many of them would do it, but they would do it against the most unfair chances, and against improbabilities. The death rate among them was very high. He believed it was about 30 per 1000 among the children of that class, and they were dealing with a similar class in Glasgow in the elementary schools and in the Technical College. As an antidote to the pessimistic point of view that Dr. Mellanby had put before them, he could not offer a better course than a visit to some of the board schools in Glasgow any night of the week. There would be found in each school lads who were working all day and attending classes at night, and receiving instruction in elementary

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mathematics and geometry. He had often looked at these classes and wondered what the sense of it all was, but if they could see the development that was taking place in the intelligence of these people, it would be evident that it was bound to result in a better brain and a better hand for the workmen of this country; but anything in the way of finished geniuses at the end of a college course could not be expected. They were not aiming at that at all. He thought he had said enough on that point, and, having said so, he wished to give Dr. Mellanby his cordial support in some of his suggestions. He thought it was most important that employers should realise that it was their duty to give the apprentices who wished to study every opportunity of doing so, and the number of apprentices was gradually increasing. He was very much interested in an investigation recently made in his own works. There were about a hundred apprentices in the works, and every boy under the age of 19 was attending evening classes, and there was not one per cent. over the age of 25 who were attending classes. He was sure that his successor in his business would find the percentage quite different. They would go on attending later. A great change had been taking place during the last ten years. During that time Glasgow had been revolutionised in educational matters in regard to instructing engineers. The Scotch Education Department had set itself against the haphazard way of giving education in evening classes, and had made up its mind that the student must be told that there was only one way of acquiring a knowledge of the academic or book side of engineering, with which alone technical colleges were concerned, and that was by a thorough grounding in arithmetic, elementary mathematics, and geometry. Without that he could get a certain practical knowledge of engineering, and the average boy would pick up more in the shop than he would from books, but he would get his brains developed, his intellect strengthened, and his chances in life improved by attending the evening classes in board schools, afterwards

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coming forward to the Technical College and receiving instruction in the science of his business. Everyone of these boys had his chances of life improved, and a small percentage of them had their chances in life very much improved indeed. He thought that the result of the whole was such as to encourage employers to co-operate with the Technical College. He thought it was quite wrong to say that the employers in the Clyde district did not take an interest in technical education, because these very classes were under the management of the employers of labour in this district. The curricula in the Technical College were all approved individually by gentlemen who were at the head of engineering, such gentlemen as Mr Cleghorn of Fairfield, and Mr Ward, who was Chairman of the Engineering Committee, and there was not anything done in the way of technical instruction in engineering that did not come before them. One had a feeling in speaking so strongly as he had done with regard to the point of view that Dr. Mellanby had taken up, but he thought one might follow that up by offering sympathy, in the very discouraging kind of work that a professor in the Technical College had to face who had to take a course of work with day students and night students, a very small proportion of whom were worth troubling about, from the point of view of immediate results. They did not work, and they did not think, and they did not reason, and he was sure that if Dr. Mellanby had his views carried out, and they had to spend three years at work before they came to his class—coming in at 23 instead of coming in at 19—he would have more encouraging work, and he thought that that situation would gradually develop in Glasgow.

Mr Alexander Cleghorn (Vice-President) heartily concurred with Dr. Mellanby in his appeal to employers to co-operate with technical and other colleges in their endeavour to raise the standard of technical education, and thereby the efficiency of the younger generation of engineers. Their President, Mr Ward, as convener of the Committee of Engineering Education of

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the Glasgow and West of Scotland Technical College, had asked him as the convener of a sub-committee appointed to consider the training of engineers, to read the draft of a letter which was about to be issued by the Engineering Committee of the Technical College to employers in the Clyde district, asking their hearty co-operation with the College in the matter of the training of apprentices. The letter only referred to apprentices who were able to attend a day course of study at college, and without further introduction he would read the letter, which was as follows:—

THE GLASGOW AND WEST OF SCOTLAND TECHNICAL COLLEGE.

Dear Sir,

COMMITTEE ON ENGINEERING.

This Committee, being impressed with the great desirability of more advantageously employing the time of students attending the day courses of studies at the College, have appointed a Sub-Committee to carefully consider the matter, with a view to the best interests of the students and those who may afterwards employ them, and, as Convener of this Sub-Committee, I take the liberty of addressing you in the hope that the Committee may be favoured with your views.

In accord with the recommendation of the Committee appointed by the Institution of Civil Engineers to consider the training of engineers, the greater number of students who attend these classes have either not commenced or have only served a short period of their apprenticeship, and since the College Session, in common with that of the University, extends during the winter six months, October to March, the time of lads, who cannot obtain suitable employment in engineering works during the summer months, is, in the knowledge of the Committee, often unprofitably spent. To obviate this waste, two alternatives may be suggested, viz.:—

(1) To make the College session of nine months' duration, with spring, autumn, and winter recesses.

(3) To come to an understanding with the Employers of the Glasgow and West of Scotland District as to their granting permission to eligible apprentices to attend the College during the necessary winter sessions and to resume attendance at the works during the summer.

The objections to the first proposal are that it would throw the Technical College out of harmony with the Universities and all other Engineering and Technical Colleges in Scotland, and that, as it would

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not be possible to shorten the College Course to two sessions, an attendance of two-and-a-half years, and an apprenticeship of five years (seven-and-a-half years in all), might still be required. The adoption of the second proposal therefore seems to be the more satisfactory course.

In putting forward this proposal it is not intended to ask any Firm to receive students from the Technical College as apprentices during the summer months, except in cases where Firms voluntarily offer to do so. The intention is that, if lads of the necessary standing and ability offer themselves to Firms as Engineering apprentices desirous of being allowed to attend the day course of the Technical College, no objection would be raised to the granting or the continuing of this permission, provided that such applications are not too numerous, and that each student apprentice proves by the certificates gained or rank taken at the end of each session that he is himself capable of profiting by his scholastic training, and in this way of becoming a more efficient apprentice.

The courses of study would usually be taken in the following order:—A lad, having gained the leaving certificate of his school or passed the entrance examination of the College, would attend College during the winter following his last session at school. He would commence his apprenticeship in the spring of the following year, again attend classes during the following winter, work during a second summer, and then attend classes during the third and final winter session, and on returning to work in the spring would serve for four continuous years, and thus complete a five years' apprenticeship. As the course of study at College during the first session is confined to pure science, it will be observed that the apprentice will have spent the summer term in the workshop before technical subjects are entered upon; and it is hoped that by serving four years without a break to complete apprenticeship the principle of a continuous apprenticeship is sufficiently conserved.

In submitting this proposal it is not intended thereby to shorten the practical part of the training, and I shall be glad to know that your Firm are prepared to afford it their valuable support.

Further, as it is becoming recognised that the apprentice who undergoes, with success, this training must be more profitable than one who has not studied, would your Firm be inclined to take into favourable consideration the time spent in College as contributing to shorten the period of five years for apprenticeship, particularly in view of the fact that a considerable portion of the College time is spent in laboratories. Alternatively, would you consider it better to grant such a youth a higher rate of wage during the latter part of his apprenticeship, and thus not interfere with the generally accepted period of apprenticeship?

Any answers or suggestions you may feel disposed to make for the guidance of my Committee will receive its earnest consideration, and for this purpose a form for reply is enclosed herewith, which I shall be glad to receive, filled in, at your earliest convenience.

I am, Sir, Your obedient Servant,

Mr Alexander Cleghorn.

(Extracted from the Calendar of the Armstrong College, Newcastle-on-Tyne.)

The following engineers and shipbuilders have promised to co-operate with the College by receiving pupils in the several departments of their works and in their drawing offices, and by permitting them to exclusively devote themselves during two or three sessions (as may be arranged) to their College studies. Parents and Guardians will make their own arrangements with Firms.

1. John Abbot & Co., Ltd., Gateshead-on-Tyne.
2. George Clark, Ltd., Sunderland.
3. William Doxford & Sons, Ltd., Sunderland.
4. J. H. Holmes & Co., Newcastle-on-Tyne.
5. R. & W. Hawthorn, Leslie, & Co., Ltd., Newcastle-on Tyne.
6. North-Eastern Marine Engineering Co., Ltd., Wallsend-on-Tyne.
7. C. A. Parsons & Co., Newcastle-on-Tyne.
8. Palmer's Shipbuilding and Iron Co., Ltd., Jarrow-on-Tyne.
9. John Readhead & Sons, South Shields.
10. Ernest Scott & Mountain, Ltd., Newcastle-on-Tyne.
11. Wigham Richardson & Co., Walker-on-Tyne.
12. Wallsend Slipway and Engineering Co., Ltd., Wallsend-on-Tyne.
13. Clarke, Chapman, & Co., Gateshead.

In Dr. Mellanby's paper and in this letter the need was set forth for the hearty co-operation of employers and colleges in order to secure a supply of men well trained in engineering science to meet the requirements which modern practice and competition demanded. It would also be noticed, although the letter did not emphasise it, that the course suggested was to take the college training towards the commencement of apprenticeship. This was the main point of difference, he thought, between the schemes now generally adopted and that proposed by Dr. Mellanby, who recommended that the period of college training should be reserved till towards the end of the apprenticeship. A comprehensive discussion of this point would certainly be of considerable advantage to those who were guiding the technical education, not only of the district, but of the country. He was in favour of the college course being taken towards the commencement of apprenticeship for the following, amongst other, reasons:—

1. That students came fresh from school to continue, with-

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out a break, their studies in pure science—mathematics, physics, chemistry, etc.

2. That it was difficult for a boy to keep up his knowledge of pure science subjects till some later period of his apprenticeship as, in the interval, his mind and attention would certainly be turned to subjects of a more practical nature.

3. That the last four years of apprenticeship might be served without a break, which arrangement allowed the apprentice to settle down to his work, and interfered least with the established order of the workshops.

4. That, from the increased scientific knowledge of the apprentice, he would profit more fully by the later years of his apprenticeship than one who was only gaining that knowledge during these later years. He, therefore, became a more profitable apprentice to his employer.

5. That, as expected, these better educated lads would be more eligible for admission to the drawing office (through competitive examination or other method of election from amongst the general body of apprentices), and it was considered that attendance in the drawing office, which almost invariably took place towards the end of apprenticeship, if intermittent, would much interfere with the order of the office and put the apprentice out of touch both with the work of the office and with his employer.

He considered it most advantageous to the young engineer to be retained by his employer for a longer or shorter period after his term of apprenticeship had expired, as thereby a start in life was secured which otherwise would generally be lost if the college course remained incomplete and attendance at classes still necessary. With regard to the advantages of evening classes, he could not agree with Dr. Mellanby's remark that "it is generally acknowledged that the return for the energy and time expended is very small, etc." In his opinion the return was very great, as evening classes had been the only means of scientific training which many of the most

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prominent engineers of the day possessed, and he believed that, at the present time, a large number of men, to whom the evening classes of the Technical College were the only means of scientific instruction available, would yet rise to positions of eminence in their profession. The training given at these classes were never more systematic and thorough or more adapted to the needs of the students and progress of the times than at the present, and all interested in the industrial progress of the community looked, in large measure, to the evening courses of the Technical College, both in class-room and laboratory, for not only its continuance, but for that advancement which should elevate its industries to a foremost place in the land and amongst the nations.

Mr E. Hall-Brown (Member of Council) said there was no doubt that all were in sympathy with the objects aimed at in Dr. Mellanby's paper, even if there was a considerable diversity of opinion regarding the methods by which these ends were to be obtained. The object aimed at was the improved education of engineers, and it might clear the air if he pointed out one or two fallacies which were continually put forward by professors and others upon this point. It was continually stated that it would be a great gain to employers if their workmen were technically educated, inasmuch as they would thereby be better workmen. He could not agree with this, and he did not think that any employer favoured technical education from any hope that he had of any direct benefit from it. For himself, he might say that in no single instance had he expected any direct benefit, and he did not think that he had in any case obtained any direct benefit from facilities given to any of the young men towards obtaining technical education. The point was that he recognised that the young men themselves had benefited, and, therefore, he had been quite willing that they should take advantage of every means provided by technical institutions, and he tried to give them facilities for so doing. He would further impress upon pro-

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fessors and others that the attendance at technical colleges, especially during the day-time, was at a very great sacrifice, both on the part of the student and on the part of the employer. On the part of the student because the continuity of his work within the workshops was thereby interfered with, and a valuable part of his education was in danger of being interfered with, namely, that which was obtained during one of the good old-fashioned apprenticeships. Then, on the part of the employer, because the discipline of the workshop was seriously interfered with, and the foremen were to a very great extent uncertain as to when and how work could be finished by apprentices, and, consequently, as a rule, only less important work was entrusted to apprentices who were attending technical colleges. If, therefore, day classes at technical colleges were attended in spite of these very considerable sacrifices, he thought that a heavy responsibility lay upon the professors and teachers to see that the best use was made of the time so devoted to college classes. He feared that it would be impossible for young men to be allowed, as Dr. Mellanby suggested, to remain away from the works certain hours each week during the first years of their apprenticeship, and also to attend classes upon the "sandwich" system later on. This was a greater sacrifice than he thought possible to expect, either from the student or from his employer, and because of this, he was inclined to favour the solution contained in the letter read by Mr Cleghorn; while he at the same time sympathised with the object for which Dr. Mellanby wished more advanced students. He would like again to call attention to the fact that the future of technical education, in his opinion, rested much more with the technical colleges than with the employers, and he was strongly of the opinion, although he had no doubt it was an unpopular one, that there were too many students at technical colleges; that the standard of education should be raised, the lower classes being taken at

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other educational institutions outside technical colleges, and only higher class work done with fewer students within the college. With regard to laboratories, he thought that the position had considerably improved in later years, as he had found in some of the old laboratories models which ought not to have been required by students attending any technical college, inasmuch as they were intended to illustrate almost self-obvious elementary facts in mechanics. He had no doubt that good work and efficient training could be given in an engineering laboratory provided that the standard of work set was fairly high, and that the number of students passing through the laboratory was not too great for individual attention. Up to the present, he regretted to say that he was far from satisfied with the education in any of the engineering institutions in this country. It seemed to him to be lacking on the side of real education and consisted more in instruction or even cramming, without any regard to the mental requirements of the various students. In this way, he feared that a good number of engineering students were suffering from mental indigestion. He was sorry that he was not able to give unqualified adherence to any plan for technical education which had yet been formulated, but it seemed to him that the arrangement advocated by Mr. Cleghorn gave a minimum of disturbance during the period of apprenticeship, and he would be inclined to say that it ought to have a fair trial. In matters educational, as in other matters, he feared that there was no hard and fast rule, and that what might be the best system for one student might not be the best for another.

Mr ROBERT ROYDS, M.Sc. (Member) said that Dr. Mellanby had emphasised the need of a sound laboratory training for engineers and also the necessity for greater facilities for research work. Engineers generally did not seem to realise the importance of research work. Perhaps they were too much involved in business considerations to appreciate this matter fully.

Mr Robert Royds, M.Sc.

Dr. Mellanby had given a summary of the usual laboratory course for engineers, where ordinary tests were made merely with the object of showing students how to make them. This, of course, was an important function of the ordinary engineering laboratory, but by careful organisation a considerable amount of research work could be carried out without any sacrifice of the ordinary training. During their first year in the engineering laboratory students should be made familiar with the methods used in making ordinary tests. In the final year, generally the second year, the work of the laboratory should be pre-arranged, more or less completely, by the staff at the beginning of the session. Instead of making tests haphazard, as was often the case, they should be so conducted that, by varying the conditions, an attempt would be made to throw light upon some problem which had not been treated previously. For example, in making steam engine tests, the students should make them under certain pre-arranged conditions. The same or another group of students should afterwards make tests under other pre-arranged conditions. Before such tests were commenced, the senior students should be given a preliminary lecture regarding the subject for research and the methods it was proposed to adopt. Under efficient guidance senior students usually made good observers, and this system was calculated to develop their capacity for dealing with new problems. Such a method involved a large amount of extra work by members of the staff, but they were repaid by the information resulting from working on these lines. Although this system could not always be carried out to the fullest extent, the fact remained that by careful organisation a certain amount of real research work could be accomplished. He would like to draw attention to an announcement which had appeared within the last few days, and which, he thought, showed the interest which some employers were taking in technical education. The announcement was summarised in *Engineering* of December 22nd, 1907. It was contained in a circular sent out by the Daimler Motor Company, Ltd., offering five "Daimler Scholarships" to be awarded in July, 1908. Anyone interested in this matter could obtain full particulars and conditions from the aforementioned Company. One of the conditions stated that the candidate should present evidence of an adequate knowledge of English, mathematics, physics, chemistry and mechanics.

Mr J. **Foster King** (Member) said that, being neither a professor nor an employer of labour, he had not intended to intervene in this discussion, but in spite of these disqualifications he was provoked to speak by a desire for further information on a question of first importance. What was the real subject under discussion? Was it Dr. Mellanby's condemnation of present methods of technical education; the particular cure recommended in the paper; the Professor's contention that the laboratory had no place in the preliminary training of an engineer, or was it—technical education? In a prolonged discussion he had heard vigorous criticism from professors and laymen, and a very practical scheme of training from Mr Cleghorn; but it seemed to him a little like beating the air, to discuss methods before the parties had met upon common ground—until it was clearly defined what was meant by technical education, and for whom it was intended. He wondered if he were right in thinking that the professorial standard of education, as expressed in existing systems, included the assumptions that the ordinary apprentice of all classes, all qualities of brain and education, and all social positions, could and should be educated up to the high level in mathematics and sciences which professors themselves possessed, even if it were at the cost of business unlearnt; that an apprenticeship was but a prelude to elaborate laboratory experiments, and that research work was natural or necessary to all engineers? If such should in any degree be the standard, then curiosity as to the cause of its relative failure was satisfied; but why was it not vigorously amended? Employers on the other hand evidently recognised, Mr J. Foster King.

as Mr. Cleghorn had pointed out, that the majority of boys went to learn their business primarily as a means of earning a living; while the majority of masters employed them from motives of a somewhat similar character. Employers might possibly think that the higher education was only for the special few, and that the acquirement of a degree might not be an unmixed blessing. In any case, even if it were granted that it was desirable, it seemed to be commercially impossible for employers to be at the expense of teaching apprentices their trades, if they were to stop work when they begun to be of some use in order to learn higher science subjects. He ventured to ask, therefore, if the course proposed by Dr. Mellanby was not rather that desirable for an apprentice professor than an apprentice engineer? It appeared to be obvious that no single system of class work could apply equally to the various degrees of education and capacity to be found amongst apprentices. Assuming that technical education for the average apprentice really meant such education in book work as would enable him to understand the principles applied in his daily practice, ought that not to mean for the boy of the better or middle class—who was at school up to the age of 17 or 18—if school education approached the standard which it ought to possess in these modern days, if the system of teaching were as efficient as it ought to be, and if Latin, Greek, and ancient learning were supplanted by mathematics, mechanics, drawing, chemistry, and the modern arts and sciences, that such a boy should leave school so trained that he would need no technical college or laboratory other than the works, to teach him to be an engineer? Steps should be taken to see that the education provided in the higher schools was of such a practical nature that, a boy would commence his apprenticeship with such an education as would have trained his brain to the point of being able to learn his business and to develop initiative. Even if he were a clever boy who was going to get on top, he would find that, with such a foundation, all his energies and capacities were probably required to learn

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thoroughly the arts that were practised in engineering shops, shipyards, and drawing offices, to handle his tools and to acquire the intelligence which would give him the power of constructing and designing. Was it possible even for a clever boy to do more in the short five years of his apprenticeship, without overworking himself, than get such a grasp of technical knowledge by actual contact with his trade as would convince him that art was long and life short? Would it be for the advantage of his brain to add to the hard work of his business education more than was represented by the occasional evening class which was needed to keep brain cells not in daily use from becoming atrophied? To repeat the main question in another form, should professors and employers not take alarm at what had been freely described as the futility of existing methods—should they not satisfy themselves that the evil was not from the beginning of school life, and have a clear understanding of the precise end in view before they could hope for the success of any means whatever?

Mr JAMES DEWAR (Associate) considered that technical colleges at present were turning out all masters and no men, and no amount of education would convert a healthy, accomplished youth into a useful mechanic. Dr. Mellanby had certainly dealt with an important subject, and had stated his case in a fair, clear, and able manner. The prosperity of an engineering establishment depended upon the number of well-trained employees it possessed, and the first duty of an employer or general manager of works was to earn a dividend. The manager of a works should be thoroughly up-to-date in all technical matters relating to his business, and should have a thorough knowledge of formulæ based on trial and error. He should keep abreast of the times with respect to practical data, and at critical moments should be able to direct his men under any circumstances. Sub-managers should feel that nothing connected with their business was menial or common, and that there was no degradation in being called a six o'clock

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man. Foremen, whose province was necessarily restricted, should be bound up with the very material and the work of construction under their care, and should endeavour to turn out the best work possible under their supervisor's direction. In the workshop the youth should be taught the nobility and utility of handling materials and to take part in work of whatever kind. He should be encouraged to sweat cheerfully, and taught that character was his only private property; accomplishments he might add at his leisure and inclination. On the assumption that a youth had had no practical training, he felt that it was almost impossible to transform scientific knowledge into practical usefulness, but whether this was the case or not, it was a bad feature to encourage that youth to attempt it, unless at his own expense. The idea of the engineers of this country becoming mere copyists and working under a license seemed to him a trifle ridiculous. The student attending evening classes should be taught moderation in all things, and the pace of a teacher should be regulated by the abilities of his dullest pupil. With respect to facilities for carrying on workshop and college training side by side, he thought it would be better to take the college to the workshop rather than to take the workshop to the college. The professors should demonstrate the work on the ground, using the plant and resources that the employer had at hand, and there show the youth the methods to adopt in connection with the work to be accomplished. The youth should be put in the best position, by the professor, to overcome difficulties, and shown the manner in which tools should be handled to acquire the best results. To encourage the youth to exercise his faculties, he might be called upon to locate defects, purposely created, and repair the same, on an old engine, and in this manner he would gather more knowledge in a short time than he would in any other way. After all, was there so much need, as had been expressed, for technical education, for had not all the outstanding mechanical inventions been discovered and carried

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out by working mechanics, such as Watt, Stephenson, Murdoch, Arkwright, and Edison?

Mr JOHN H. A. M'INTYRE (Member) in referring to the general training of the mechanical engineer, agreed, in the first place, with Dr. Mellanby's remarks that a practical training should precede the theoretical one. He did not agree with the amount of apprenticeship time that the Author proposed should come in front of the theoretical work, because he saw from what Mr Cleghorn and other speakers had said that that would necessarily involve serious difficulties in the workshop, and seriously handicap the apprentice in his practical life. He would like to suggest an increment on the time which Mr Cleghorn had put in his letter. Mr Cleghorn asked for a six months' period of practical work, but as the student spent six months in college on purely theoretical training and six months in the works, this seemed to him to be little enough time for an apprentice to get a grasp of the practical side so that he might appreciate the work to be done in college in the following winter session. Again the six months would hardly give an employer a sufficient knowledge of the apprentice to say whether he was ever likely to be of very much use to him afterwards, and he thought that the employer ought to have some knowledge of the apprentice before he was sent to college. He thought a year-and-a-half would be a better time. In that time the student would have some knowledge of the works, and go forward to college quite able to appreciate what would be said to him. During these eighteen months, in the winter period he should attend the evening classes. He did not agree with Dr. Mellanby in his remarks with regard to these evening classes. He thought the evening classes had sent forward men into the world who were quite able to hold their own with any student who had undergone a day training. In the next winter the apprentice would come back to carry through the final session at college, as suggested by Mr Cleghorn, and this

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arrangement would leave him three full years in the works to finish his apprenticeship. That would probably be one year spent in the works and two years in the drawing office. He did not mean to suggest any reduction of apprenticeship, because the employer should be fully repaid for the time given the apprentice to attend college. He could not agree with Dr. Mellanby that an apprentice who had served three years, which should be really two-and-a-half years, and then a winter at college and another six months in the works, would be able to carry out first-class research work, at least connected with his business. He rather doubted if an apprentice of three-and-a-half years' standing would ever be given the opportunity of carrying out a full trial trip, to obtain the knowledge whereby he could in the following session carry out original research connected therewith. He might be wrong there, but that was his opinion. His feeling was that that apprentice afterwards, when he had gained the confidence of his employers and had carried out a complete trial trip, would be in a position to see where improvements might be made, and his employer might be willing to allow him to go to college and carry out some special research work. That was quite possible. All the discussion that evening had been more or less on the general training of the engineer with regard to the day student, and the aim was to give the better men an opportunity of rising in their profession and not merely to remain practical men all their lives. Some men must be at the head of a business and it was these men they wanted to get, and it was these men they wanted to encourage, to enable them to rise to a first-class position in their profession. Might he make one appeal with regard to evening students? The evening student was sometimes seriously handicapped by overtime. Might he ask the firms represented there that evening if they could offer facilities for the apprentices who were in attendance at the evening classes, to be let off on the evenings that their classes met? Might he further appeal

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to employers to take some interest in their apprentices by keeping a record of the work which they had done in their technical studies during the winter, and thus let them feel that they were being looked after both in the works and at college.

Mr John Alexander (Member) considered it very desirable that intending engineers should attack some of the unsolved problems, and conduct original research on their own initiative, but owing to the short term of three years, the usual college course in which to learn principles and get familiar with machines and their efficiencies, research work was almost entirely crowded out. The student might in his third year take a part in research work arranged by the professor, but such work, if it were to be of any real value, required men of considerable engineering training and scientific knowledge to carry it through with accuracy. The student who conducted research work under the guidance of a professor arrived at a result of little value to the profession as a whole, and to the student it was of less value than that obtained by carrying out some other engineering experiment or engine test. As Dr. Mellanby had said, an engine test could not be called research work; but such tests were of considerable service to the young engineer, for in his future career he would probably have to do a similar kind of thing. To attempt to get research work done during the ordinary career at college was, he thought, beyond the student, and he suggested that in the Technical College an honours course in the laboratory should be established when research or other special work could be carried out. A student must first get a thorough grounding in ordinary principles, and research work might follow afterwards. He did not agree with Dr. Mellanby when he said that there was great difficulty in getting men in the offices of engineering concerns who could carry out original work. They did not often get the chance. Many firms did not tabulate their own scientific data, and in this connection their records were in a most deplorable condition. Such firms could

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not train their own scientific staff, but generally had to secure men from other establishments who were more up-to-date, which proceeding was somewhat unfair. Were it not for the trouble which men took themselves, often against great discouragement, to digest the results of experiments and tests conducted by firms, the engineering profession in this country would not be what it was to-day. With regard to the sandwich system of apprenticeship, he did not quite see the reason why employers should suddenly object to that arrangement, as it was nothing new; for a modified system actually prevailed in most workshops at the present time—the essence of which was the opportunity given to likely lads of getting a shift to various departments of an engineering concern, such as fitting, pattern-making, turning, etc., and finally, after having been in one, two, or even three of these departments, to finish their apprenticeship in the drawing office. There were very few establishments, he was pleased to say, in which bright lads were not allowed to serve a part of their apprenticeship in more than one department if they so desired. It seemed to him that it would not matter much if, instead of taking one of these departments, a lad spent a session or two at a technical college where there was a good laboratory, such course to count as time served.

Mr James Anderson (Associate Member) remarked that the laboratory was a very useful institution, provided the tests carried on were such as would be of benefit to the students who were attending them. In the majority of engineering works, if a lad showed any extra ability he got an opportunity of entering the drawing office, and unless he intended to go there, the laboratory was of very little service in his case; for if he was only going to be a fitter the testing of engines was not of much importance to him. While serving in the drawing office, the lad might be sent on a trial trip, but if he never saw an indicator before, it meant that the draughtsman in charge had to instruct him regarding its use. It seemed that the function of the laboratory was primarily to teach the young

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engineer how to make simple tests upon engines and boilers, and after that it might with advantage be used by senior students to carry out original research work. But what was original research work? Was it merely to copy tests which had been made time and time again with superheated steam or with jacketed cylinders, or the consideration of something absolutely new? If the latter, it meant that the investigator must be a man of originality, and, if original, the chances were that he would probably find means of experimenting on his own account without going to a technical college to carry on his experiments. He considered that evening classes formed the best means of educating engineers for average work. Unless born with a silver spoon in one's mouth, it was impossible to spare the time necessary for attending day classes. It seemed to him that the Author had referred too much to the exceptional and not the ordinary student. There was no doubt that a student who intended to get an education in technical matters would acquire it, no matter what opposition he had to encounter. In that case the best man came out on top. He held that young engineers ought to get a certain amount of commercial training. How was a manager to conduct a large works, no matter how well he was trained, unless he knew something about the elements of book-keeping? In no technical college prospectus which he had seen was there any provision made for an engineer to get a commercial education unless he took it out with his engineering course. The discussion had brought out many important points, and one which had struck him was that there were difficulties with the sandwich system, as well as with Dr. Mellanby's system. If every apprentice were to attend day classes for the period Mr Cleghorn had suggested, it might happen that when an important mail steamer was at the quay, having her engines put in, all the apprentices would have to go to a technical college in the middle of the work, and he was not quite sure what the foreman would say to that.

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Professor **Mellanby**, in reply, said that at the beginning of the paper he had expressed the hope that, although much had been said on technical education, there was still some room for further discussion. All would agree that this hope had been realised, and the keen criticism to which the paper had been submitted was evidence that there was, at least, a large amount of theoretical interest in the education of engineers. He would consider that the paper had achieved its main object if it did anything to turn that interest into something practical and applied. Many differences of opinion upon the details of the scheme proposed had been expressed, but it had to be remembered that the important point aimed at was co-operation between employers and colleges. Let that co-operation be once obtained and he was certain that it was only a matter of time for the scheme, at all events in its main outlines, to be adopted. There was no doubt that improvements in manufactures could only be obtained by a large amount of careful and painstaking research. If it were desired to produce men fit to do this work, then they must be given a first-class laboratory training. It was useless to attempt to give this training to men who had not a good practical knowledge of engineering, and few of the speakers had taken the trouble to consider this point at all seriously. Professor Jamieson opened the discussion by quoting two paragraphs from the paper, and gave his idea of the inferences to be drawn from them. He was quite correct in his suggestion that the Author had a poor opinion of both past and present usual methods of engineering education. It was disappointing, however, to find that the paper had not lessened the evident satisfaction with which Professor Jamieson regarded these methods. He also brought forward the usual statement that many men in highly-paid positions had obtained their engineering education in evening classes, suggesting thereby immense importance to this class of work. He forgot that, when these men were serving their apprenticeship, evening classes were the only means by which they could get any

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training in the theory of engineering. There was no doubt that in the immediate future, a continually increasing number of these remunerative posts would be held by college-trained men. He was pleased to find that Mr Bamford supported the scheme in its main outlines, and would have been still more gratified if he could have brought him so far as to see the inefficiency of the present system of training. He protested, however, against Mr Bamford's statement that an apprentice would find evening classes more stimulating and less exhausting than private study. This was exactly the feeling with which the greater proportion of evening students entered college, and many of them seemed to take it as a personal injury that they could not acquire a large amount of knowledge by simply sitting and listening, more or less attentively, to what any lecturer was saying. Surely the chief value of any lecture was to induce men to study for themselves, and to make that work somewhat easier for them by pointing out and explaining any difficulties. At all events, any student whose stimulation died down after leaving the lecture, only to be revived the following week, did very little good for himself. Professor Gibson was one of the few who had really studied the paper, and he was gratified to have his reasonable and able criticism. Professor Gibson asserted that the possession of genius was essential to any man who made a great discovery; but the science of mechanical engineering was in such a backward condition that, for many years they would be satisfied with much less than anything requiring great inventive power. The reason for this backwardness was obviously the small amount of research work that had been done in this line. On the other hand, it was perfectly clear that the vast strides made in electrical engineering were mainly due to the fact that, when any difficulty cropped up, it was at once attacked by large numbers of experimenters and mathematicians. Not all of these men were possessed of great genius, yet they had done their share to bring electrical engineering to the high pitch of development it now enjoyed.

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The scheme proposed in the paper would bring forward, it was hoped, a body of men who would raise up mechanical engineering from its present depths of empiricism, to a correspondingly high position of scientific exactitude. Professor Gibson's opinion of the intellect of the majority of engineering students was fairly low, but none knew better than he that only a small proportion of youths with the best brains came to college. By a system of co-operation with the employers, it ought to be possible for every boy who was worth it to obtain a college training. The tests proposed before admission to the second and third years would eliminate those who could not profit by the work. Mr Mavor commenced his remarks in such an unusual fashion that he had expected, at least, some reasoned criticism of the main points of the paper. Instead of that it was quite evident that he had only glanced over the paper, and had not more than a very hazy idea of what it was about. Mr Mavor said that the Author was asking employers to co-operate in carrying out a futile scheme. This was exactly the opposite to what he was doing. The object of the paper was to obtain that co-operation, and so to introduce a scheme which would be infinitely more efficient than the one now in vogue. Neither had he stated that the employers in the Clyde district had no interest in technical education. At the commencement of the paper, it was mentioned that one reason for writing the paper was the interest many employers were taking in the education of their employees. He was quite certain from Mr Mavor's concluding sentences that if he had devoted some time to the paper, he would have given the scheme proposed his cordial support. If the present educational system was in the main being carried out for those who—to use Mr Mavor's own words—neither worked, thought, nor reasoned, he would leave it to the members to decide whether such a system was worth the vast amount of time and money that was spent upon it. It was gratifying to learn from Mr Cleghorn that an independent movement was being made, by some of the foremost employers,

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to obtain co-operation between works and college in the Clyde district. He only hoped that success would attend the efforts of the committee, and he was quite sure that when co-operation was assured, the best scheme would soon be adopted. Mr Cleghorn thought that the scheme suggested in the paper would be difficult to carry out, but the difficulties connected with it were very slight indeed. They both agreed in the first place that the college work should start immediately after leaving school. This seemed to be the general wish of those teachers who were responsible for the first year's training in mathematics and general science. Mr Cleghorn then stated that it was difficult for an apprentice to keep up his knowledge of pure science till some later part of his apprenticeship. It was not obvious why there should be more difficulty in preserving this knowledge for one part of an apprenticeship more than another. Certainly, if evening classes were all that some members claimed for them, many apprentices not only did this, but, in addition, gained vast stores of new information. It was, however, quite certain that when once it was known that a man could not get back to college unless he did keep up this knowledge, and make some further advance, the difficulty would not prevent the really good men from doing it. The drawing-office difficulty mentioned by Mr Cleghorn was more apparent than real. No apprentice would be taken, as a general rule, into the office unless he had been for at least three years in the shops. A youth, then, who followed the scheme proposed in the paper, might enter the drawing office after he had spent the three years in the works and gone through his second year's course at college. He would be six months in the office and then have another and last six months at college. After that he would return to the works, and ought to be capable of undertaking, when once he had got into the office methods, reasonably responsible work. There seemed to be no reason why such a division of time should cause any more inconvenience than the one advocated by Mr Cleghorn. At all events, the Author's scheme would produce so much the better man that it would be quite worth facing some trouble if it did arise. Mr Hall-Brown's remarks were especially acceptable. When the Author was serving his apprenticeship on the north-east coast, Mr Hall-Brown was one of his first evening class teachers, and he now welcomed this opportunity of expressing his indebtedness to him. He was quite in sympathy with Mr Hall-Brown's suggestion that the standard of education in the colleges should be raised. This was one thing that the scheme would do. He did not expect it would have the effect of reducing the numbers in the day classes, because, once a scheme of co-operation between employers and colleges was in practice, the number of more intelligent boys willing to take up engineering would increase. Mr Royds had had experience in research and, therefore, supported a scheme which recognised the importance of this class of work. Mr Royds pointed out how a considerable amount of research might be done if the students' work were properly organised. He was in entire agreement with him on this point, although many teachers said it was impossible for any laboratory superintendent to carry out research work with only the help of junior students for taking observations. It was altogether a case of laboratory organisation. He was pleased that Mr Royds had brought before the Institution the scholarship scheme of the Daimler Motor Company. This was a striking example of an up-to-date firm which saw the necessity for having a number of first-class employees, and which was prepared to invest a considerable sum of money to obtain the proper type of man. Mr Foster King rightly pointed out that the discussion was in many instances altogether away from the points raised in the paper. His remarks upon a professorial standard of education were distinctly amusing. If anyone could speak feelingly upon the varying intelligences of different classes of students, it was one engaged in teaching. So far as the paper was concerned it was quite obvious that, in the scheme proposed, only the best men were provided for. A first year's course meant a stiff entrance examination, and the necessity for showing fitness before taking up the second and third years' courses, implied that none but the men worth spending time and money upon were being considered. If Mr Foster King's estimate of the capacity of students was anything like correct, the future of British engineering was indeed a dismal one. Mr Dewar had original ideas, and did not hesitate to draw up a list of the qualifications necessary for all grades of engineers, as well as for professors and lecturers. His ideas upon college training and laboratory work were so far removed from those of the Author that, it did not seem profitable to enter into a detailed discussion on the points raised. Mr M'Intyre agreed that a certain amount of practical work should precede college training, but was of the opinion that practical difficulties would prevent the Author's scheme from being carried out. A reference to the reply to Mr Cleghorn's remarks would, it was hoped, convince him that these difficulties were very trifling. Mr M'Intyre appeared to be in favour of a system of post-graduate research. With this the Author was in sympathy, and it was quite probable that when mechanical engineering was put on a more scientific basis, it would become a usual thing for a firm to depute picked men to carry out investigations upon some new design or process. Mr Alexander was one of the few taking part in the discussion who recognised that there were still unsolved problems connected with engineering. He also pointed out that the difficulties put in the way of sandwich systems were greatly exaggerated, and were really being met and overcome continually in all works. It was hoped that the members would specially note this. Mr Alexander seemed to think that there should be no difficulty in finding men capable of carrying out original investigations, but that was certainly not the experience of the Author. It was curious it should be universally admitted that, to become a professional golfer or cricketer, a man must go through a

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long and arduous training, and yet apprentices were expected to develop into first-class engineers by the possession of some peculiar kind of instinct. The points raised by Mr Anderson had either been referred to in the paper or in the replies to previous speakers, and it was not necessary to make any further comments upon them. Taking the discussion as a whole, there were several points that had been referred to by a majority of the speakers, and it seemed advisable to reply to them in common. Almost every one had taken up the defence of evening classes, and few had realised that the worst said about these classes in the paper was, that the return for the time and energy expended upon them was very small. Seeing that this subject had been raised so often, he would now say, he was quite convinced that most people had a very exaggerated idea of the usefulness of evening work. Whilst it was a means of giving some elementary knowledge to young engineers, without interfering with the organisation of a works, to think of it as being the only training for those destined to hold responsible positions was simply preposterous. Unless the employers of this country recognised this they were only courting disaster. No other nation expected to obtain trained men from the ranks of those able to devote only a few hours per week to theoretical work, and to all foreigners it was quite incomprehensible why this evening class fetish should be worshipped in this country. As the Author had attended evening classes for five years before taking up his college course, and had since then lectured to these classes in London, Manchester, and Glasgow, he thought he was in as good a position as anyone to judge of their value. For a man who had no desire to become anything beyond a mechanic, or ordinary draughtsman, they might be of some value. Let engineers once see the necessity of a proper training for the best men, and their ideas about the value of the much-belauded evening work would undergo a change. The question of attending classes during the day had also been referred to, and each speaker

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seemed to think that such a proposal would be impossible to carry out. A reference to the articles now appearing in *The Engineer*, upon the training of apprentices, would show them that such an arrangement was now being tried in several well-known engineering works in England. The Author did not, however, press this proposal at present, and would be content with the co-operation asked for to carry out the main scheme. The subject of research had been mentioned in such ways, as to show that the speakers imagined the research work alluded to by himself was something of a purely theoretical nature, altogether removed from practical work. This showed that they had very little conception of the extent of present-day ignorance upon most engineering problems. To take as an illustration the subject of the steam engine. Everyone knew that an engine used more steam than was necessary, and yet there was not an engineer in the room who could tell exactly why it did so. To an outsider, it must seem quite ludicrous that engineers should have been trying for many years to improve the economy of steam engines, without first discovering the reason for their wastefulness. Engineers were even to a great extent ignorant of the properties of steam. Every experimenter gave a different value for the specific heat of superheated steam, and concerning many of the phenomena attending its evaporation and condensation practically nothing was known. The rate at which heat was transmitted from one fluid to another across metal plates was another subject upon which engineers had much to learn, yet the rational design of boilers and condensers depended upon this knowledge. As it was, the design of these plants was to a great extent a matter of guess work, although the experience of more than a century had yielded some rough rules which enabled engineers to make their guesses big enough. Numerous other illustrations could be given, but sufficient had been said to show that a firm desiring to be in the front ranks had plenty of scope for practical research. This was well recognised upon the Continent, and several of the most renowned firms there had a staff engaged upon nothing else but experimental and research work. His suggestion that they might develop into copyists and licencees of foreign inventions had been ridiculed, and yet a mere inspection of the advertisements in the engineering press would show that this was the direction in which they were marching. There was scarcely a branch of mechanical engineering in which they were not almost altogether indebted to American and Continental designers. In the matter of large gas engines, it would be found that the largest plants in this country were manufactured under the Körting and Oechelhäuser patents. In fact, one firm went so far as to advertise that it was in intimate connection with the Continental designers, and was, therefore, in a position to obtain the best advice possible. In the steam turbine branch Mr Parsons had led the way, but the national invention seemed to have exhausted itself with this effort, and engineering works in this country were now manufacturing turbines under the de Laval, Curtis, Rateau, Zoelly, and various other patents. Even the most rabid patriot would acknowledge that British motor-car work was altogether based on Continental design and experience, and the great value of the imports in cars and their machinery showed that many people still looked abroad for the best productions. Further illustrations could be taken from the latest improvements in stationary engines, locomotives, artillery, and flying machines, but a sufficient number had been given to show that there was some basis of truth in the Author's suggestion. It was quite evident that they were altogether relying for their success upon their superior business methods, natural advantages, and skill of their mechanics. Due to the continued introduction of automatic machinery, the advantage gained by the possession of skilled workmen was becoming less marked, and it now became necessary for them to train up capable designers if they wished to keep a pre-eminent position. This again brought them back to the original statement that the future

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training of engineers was in the hands of the employers, and unless they were willing to make some sacrifices for, and take some trouble with, the training of their apprentices, the colleges were practically helpless.

The PRESIDENT (Mr John Ward) before calling upon the Members to award a vote of thanks to Dr. Mellanby, said they were all, or nearly all, interested in this subject, and all more or less anxious for the advancement of their profession of engineering. While they agreed to differ as to the best method of training, he was quite sure they were all at one in the great importance and benefit of a paper such as Dr. Mellanby had written. The Author had had to suffer the penalties of originality, and to run the gauntlet of many competent critics, but if his scheme in all its details had found favour with few, there was one feature which commended itself to all, and that was that Dr. Mellanby showed very clearly his desire to make the best possible use of his position, as Professor of motive power engineering in the Technical College, to advance the interests of the engineering industry. If, in his anxiety to utilise to the utmost the already ample but growing resources of his laboratories, he had produced a scheme in which the dominant note was research rather than the inculcation of principles, he could not be blamed, for the professor whose ideas of the functions of his Chair did not include the advancement as well as the dissemination of knowledge was, in his opinion, not worthy of his title. Perhaps Dr. Mellanby's greatest fault was that he was a little ahead of his time. The active co-operation of employers with colleges generally, in this country at least, was a plant of recent growth, and for this it was probable that the colleges were not altogether free from blame. It was only lately that the colleges had begun to realise that co-operation with the employer meant a much more sympathetic view of his position than some had held in the past. To his mind the most satisfactory feature of the general discussion, was the unanimous opinion that employers and colleges could and should work hand in hand for the benefit of the coming engineer. Many employers now saw that it was to their own personal advantage to help the budding engineer all they could. The movement for the higher technical training of apprentices was rapidly spreading, and if one firm trained a good man for the benefit of someone else, a second firm might be training one for another's use and for his own preferment in that service. If the discussion had taken the direction of "What is the best training for an engineer?" rather than the title of Dr. Mellanby's paper, "The place of the Laboratory in the Training of Engineers," it had done so because, after all, the training of the engineer rather than his utilisation for laboratory research was the pressing problem; and if that were settled satisfactorily, Dr. Mellanby need not fear but that men capable of making the best use of the engineering laboratories of the country would be forthcoming. But there had been talk enough, and it was time to be up and doing. For some years many different schemes had been considered, the most recent and most prominent being those proposed by the Institution of Civil Engineers, and the North-East Coast Institution of Engineers and Shipbuilders. Dr. Mellanby had proposed yet another "sandwich" system, and one recognised that it had many merits; but the Engineering Committee of the Glasgow and West of Scotland Technical College, of which he was a member, were about to suggest a plan which seemed to it a big step in the right direction; while, at the same time, one which would involve no appreciable disorganisation of either the works on the one hand or the college on the other. This plan was clearly shown in the letter which Mr Alexander Cleghorn, who had acted as convener of the section of the Engineering Committee, had just read, and proved, he thought, that the whole question was receiving very careful consideration. The letter, as he had stated, was being addressed to the engineering and shipbuilding firms of the Clyde area, and the Committee was very hopeful that it would bear rich fruit. The replies

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from employers would be helpful, and the letter was for the purpose of getting the general opinion of those who had the making or marring of the scheme. Dr. Mellanby's paper had produced a very full discussion of the whole question, and many different theories had been advanced, but it was now time to move on to action. All schemes could not be tried at once, and in view of the standing and character of the well-known engineers who had produced the plan proposed by the Technical College, and of the fact that it was not out of harmony with the arrangements of the University as well as of the Technical College, action, so far as the Clyde was concerned, might be concentrated on this scheme and it should be given a trial. Dr. Mellanby had spoken of the necessity for research. Here was a research at their hand. Let them enter upon it, and, borrowing from the example set by Dr. Mellanby in his professorial work, if not exactly following the suggestion contained in his paper, let the engineers of the Clyde join with the colleges in an experiment which offered good prospects of success in the endeavour to settle the problem, how best to train the engineer. If it did not succeed, as they hoped it might, it would do nothing but good to those who were its subjects, and they would have gained valuable experience with which they could make a new departure. He asked them to join in according a hearty vote of thanks to Dr. Mellanby for his valuable paper, and for the renewed interest he had given them all in this important subject.

The vote of thanks was carried by acclamation.

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Mr W. Reid Bell (Member) observed that Dr. Mellanby expressed the opinion that the subject of technical education was not yet exhausted, and he (Mr Bell) ventured to express the hope that it never would be. It would be a bad day for the industrial nation when the best course of training was laid down to a hard and fast calendar, under the impression that the labours of the educationist and the employer in this direction were over. It might be worth while to recall the fact that, the term civil or civilian engineer was first applied to practitioners bearing the same relation to millwrights that architects bear to builders, to distinguish them from the designers of military works and engines. These civilian engineers were generally brought up as handicraftsmen (or linen drapers perhaps) in the first instance, and in process of time, as they came to be masters of a scientific profession, they felt, in many cases, the limitations and drawbacks due to the want of a training in pure science. Now, he ventured to say that had these pioneers been equipped, each with a complete scientific training in their day, such a training as, *mutatis mutandis*, people expected young engineers to possess to-day, they would necessarily have been indifferent workmen; they would, in fact, have achieved some additional facility in design, at the expense of perfection of construction. Now, the crying defect in the qualification of young engineers at the present day was not inability to analyse, nor incapacity for original research, but the want of thorough fundamental knowledge of construction and of materials, and this was a very serious matter indeed in the case of structures coming within the province of the so-called civil engineer. It would be found that for one error in design due to ignorance of theory, there were ten errors due to ignorance of construction, and this followed from the fact that nine-tenths of ordinary design were governed by considerations of construction into which theory did not enter at all—at any rate as far as the designer was concerned. No doubt some would be found to say that this was an attempt to reintroduce the old bugbear of theory *versus* practice, but there must be no misunderstanding; if such a catchword were allowed to enter into the discussion the case would be hopeless, for no advance would be made. Theory never built anything, but it pointed the way to perfection of production; it supplied to a considerable extent the

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confidence which otherwise length of experience alone could give, and it saved years of experiment, and disaster. Practice, on the other hand, could achieve most things, but only by trial and error, or, in other words, by experience, and in opening new fields it was powerless without theory, for the reason that the magnitude of its operations were nowadays too big to be the subject of trial and error. It must therefore be conceded that everyone was of one mind as to the necessity of combining theory and practice, and as to the fact that no knowledge or learning of any kind was without value in the training of an engineering mind. It, however, often happened that one forgot the actual conditions governing the student's case. The schemes that were usually set forth for technical education all seemed to take it for granted that every youth could afford the time and the money, and had the capacity to train as an original inventor or investigator. Now, he strongly urged that nothing of the sort was wanted. The paramount question was the education of engineers who were to construct and design the work of the future. After a man became an engineer, if he had the talent, by all means let him become an investigator or inventor, but it should be remembered that that was not engineering proper. An education for the rank and file was wanted, and this was constantly lost sight of. Above all, it was absolutely necessary to have a strong rank and file—solid, honest workers at whatever their hands found to do, fearing no drudgery—the drudgery which made ninety-nine hundredths of their lives, and in the honest and faithful performance whereof lay the true nobility of mankind. From actual experience of the youthful material calling themselves engineers with which, since the war, South Africa had been flooded from Britain, the Colonies and Europe, he concluded that the systems in vogue were inadequate to turn out men capable of fulfilling the ordinary functions of an engineer. That was to say, if a manufacturer produced an article fit to hold its place in the market, he must produce an *even quality*,

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and in the case of human products of a school, its diplomés should all come up to a certain standard of skill in the ordinary work-a-day routine of their profession. It seemed to be the aim in many cases to produce men capable of tackling, on the theoretical side, the most intricate problems of engineering, forgetting that the success of an engineer lay in the faithful daily performance of routine and drudgery; and, without a rigid training in routine, not to be learned in a college, not one engineer in a dozen would be of much value to himself or his employer. If the ordinary daily functions of the engineer were studied, and the acquirements necessary for their fulfilment considered, one would probably conclude that, before a working solution—he did not say a final one—of the education question could be found, it would be necessary to specialise, and even to abandon the name "engineer," as far as training was concerned, leaving that honourable and much-abused title to be won as a mark of standing and experience. He was glad to see that Dr. Mellanby laid great stress upon workshop apprenticeship, and from his own personal experience of what had been most useful to himself and what he had seen useful to others, he considered that the essentials of an engineer's training were (*a*) a moderate proficiency in some handicraft; (*b*) a thorough grounding in pure science; (*c*) and in design and applied science. These acquirements were really essential to everyone intending to follow the profession of engineer, whether in civil, electrical, steam, or any other branch of engineering in any way dealing with construction. The first (*a*) *must* be acquired in the workshop, and (*c*) partly in the drawing office and partly in the college, while (*b*) should be learned at school and at college. In specialising, it was proper to inquire what were the requirements of the market to which the students would carry their wares? Were they all required as scientific investigators or inventors, or were they wanted as draughtsmen, constructors, surveyors, or computors, or as business engineers? Each of these occupations required

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special talents and training, and in the present state of the arts it was impossible that one man could be trained equally perfect in all these divisions, and when it was considered that all these divisions were further specialised in each branch of engineering, it simply showed that the college was not an organisation for turning out engineers. Engineering would not take its proper place while people persisted in miscalling it a profession. True engineering and true architecture were in reality in the highest sense arts. They both made use of mathematical science and of the relatively inferior arts of construction. These were the engineers' and architects' tools, and it should not be permitted to any one, because he made use of these tools in everyday work, to call himself an engineer or architect. To his mind, the function of the college in education had been wholly lost sight of. The true function of the college was to teach science and science alone, and, further, he was strongly of opinion that of all science, pure science was of greater importance to the engineer than applied science. When a man was thoroughly trained therein he could always apply the science to his own needs, and he carried in his mind principles in place of formulæ. Next, the arts of construction could only be taught, in the first place, in the workshop. Afterwards when a man had passed as a tradesman, a technical school was to him of the greatest value. The present evil was that the technical school was supposed to teach the rudiments of trade, whereas such an institution could only be of use to those qualified to profit thereby. In such a school, after a man had learned his trade he was shown other people's methods, he was shown the science and theory underlying the practice he had already learned, and he was enabled to investigate and to work out new advances for himself. When these facts were grasped by educationists, and their houses set in order in accordance therewith, they would find employers to give them all the sympathy, the assistance, and the money required, and their real progress would be made in real labora-

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tories. These matters required also to be discussed publicly, so that the parents and the youths themselves might understand what they required and what they were aiming at. Dr. Mellanby's paper confirmed the experience of the employers when he said that, much difference of opinion existed as to whether the right class of men were turned out of the colleges, and this was emphatically corroborated when he acknowledged that employers after all these years did not support the technical schools. What did employers want? Did they want men qualified in original research for designing, or past masters in design for works' managers and foremen? Whether was it more difficult to obtain scientific design or sound work? And which was most frequently encountered—good work expended upon bad design (very often a good workman corrected a bad design), or good design spoilt by bad work? Surely there was only one answer to that. By a misconception of the functions and scope of public education, it seemed to the writer that, ever since the inauguration of the board schools the whole education of the nation, both general and technical, had been directed to a false end, while the fact that the very existence of the nation depended at bottom on hand labour, had been lost sight of. It was *not* good that all, or that the many, should be trained as field marshals or lord chancellors, neither was it good that such dignitaries should be trained in a different manner to common people, but it was good and very necessary that every man and woman in the land should learn to use their hands first and their brains afterwards. If the technical school were a fit place for a highly-trained engineer to learn handicraft, or even the rudiments of handicraft, it ought to be a fit place for, say, a fitter or a mason to learn his trade, and the question might be asked—What would he earn per week when he passed through such a training? If such a place were not fit for the workmen, it was not suited for the master. Again, the notion that, in the college, students could obtain any practical knowledge of engineering more than could

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be got out of books was most mistaken. They were likely to learn some very pernicious habits of slovenliness, and so on. He knew of a most modern school, inaugurated under the auspices of a professor well known in Britain, where the shop engine was rocking on a foundation too small for it, and the iron smoke stack was out of plumb. The students could be seen any day tapping a hammer on a cold chisel in the fashion of a wooden doll in a pantomime, under the delusion that they were learning to chip. What was the lesson learned by students brought up to behold such things unreproved and uninstructed? Surely that, to the highly scientific mind, soundness of work, accuracy of eye, and efficiency of hand were of no importance, and were beneath the notice of constructors. Dr. Mellanby hit the mark when he said the laboratory should be of the greatest value to engineers in practice.* Its true function, besides mere demonstrations to students and practice in testing materials, was in the direction of post graduate instruction and research. Now, supposing a youth left college at the age of nineteen, with a fair theoretical knowledge of engineering, and could make a reasonably neat drawing, test specimens of material, and take indicator cards, did that constitute him an engineer? Would an employer give him 30s. per week? Rather he had only qualified himself to begin his pupilage, in the course of which his first lesson would be to do as he was told, and he would have to unlearn many habits. If employers looked askance at the technical colleges it must be because they had not had a practicable scheme presented to them, and though they were, in general, willing to afford their apprentices opportunities of self improvement, they realised that the discipline of the workshop, and the importance of the work, must be worked into the apprentice's mind, if the product of his labour were to be of value either to his employer or in his own training. Everyone knew the value of the old premium apprentice who was allowed to drop into the shop about 6-45 a.m. with no fear before his eyes of losing "a quarter," and the students

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of technical schools, regarding manual proficiency, were exactly in the same category. He might probably be accused of being opposed to technical schools, but that was not the case. He knew too well what he owed to the technical schools of Edinburgh and Glasgow, but he was opposed to the modern idea of trying to teach in the schools what could only be learnt in the workshop and drawing office, and it was the good habits of the shop and office that were so important to be learned at the critical period of the youth's training. Nothing whatever could take the place of this, and at no other time of a man's life could they be learned. They were of supreme importance, and no teaching the college could give would make up for the want of them. He was strongly of opinion that education, like everything else, possessed a value to the owner strictly in proportion to its cost, and he would recommend to educationists the serious necessity for making technical training more difficult of attainment, and not less difficult. The basis of all construction was the handiwork itself, and the pupil or apprentice should be engaged in learning as a workman. Opportunity should be given to all apprentices to improve themselves in such subjects as pure mathematics, if they had not advanced sufficiently before leaving school, and science; and such apprentices as showed special proficiency should, if they desired to rise higher, be allowed to cut short their time in the workshop. After the minimum time required to obtain a grounding in mechanical art, the question arose, What was the youth's future to be? If he was to spend his life in the shops he did not need much higher technical training, and to take him away from the shop at this critical time would certainly lessen his value to his employer. But to those whose lives would not be spent in the shops, there was, at this stage, a natural break in the training in which the employer had no immediate concern. Here the office training would commence, and at this point it should not be detrimental to the youth, nor should he be of less value to his employer if he here divided the year into

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two portions, during one of which he would be employed continuously in the office or field, and in the other attending a session at college. It would remain thereafter how far the student could afford to pursue his studies, which would then, and then only, develop into research work. How many engineers were required or were fit for research? In fact, a man devoting himself to this passed out of the category of engineer, but a scientist whose training included the earlier experience sketched above would have attainments very valuable in his special career. It seemed too often to be taken for granted that every youth who merely wished to become an engineer was entitled to, and was capable of profiting by, the most exhaustive course of training. Now, no progress could be made in the subject of technical education, until it was recognised that it was neither possible nor desirable to equip every youth with a training such as only a James Watt or a Kelvin could make use of. When this was realised, and employers and educationists adopted the principle of close guilds of craftsmen, it would be possible to evolve some scheme whereby youths might all start level, and, maintaining the continuity of their theoretical training, might gradually be sifted out and drafted off according to their opportunities and capacities. He suggested that a strict system of apprenticeship should be inaugurated in all trades connected with engineering, including building trades. A certain standard of education in mathematics and physics, as well as general education, should be insisted upon, or two standards could be applied, one for those whose necessities or capabilities required them to qualify as handicraftsmen only, and a higher one for those destined to work up to the higher grades. This latter would delay the age of leaving school to sixteen or seventeen, when the youth would enter the workshop with a very fair and useful grounding in the lower mathematics, and a knowledge of the principles of chemistry and physics sufficient to view with intelligence practical questions that presented themselves in the course of his work. The entering examinations necessary

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would be the matriculation for the technical school, in which the students would be entered, and the apprenticeship would be worked under the supervision of the examining body. All apprentices should conform strictly to the rules and times of the works in which they were engaged without any regard to persons, and their progress therein would count as the sole pass to the further course. Such a plan would ensure that youths did not enter the works until they were strong enough to work full hours, and intelligent enough to pass rapidly to real work instead of being employed as shop labourers. During this time a very moderate amount of night work or classes would keep the apprentice from losing what he had learnt at school, and the college would test this from time to time by further examinations once or twice a year. One advantage of such a system was, that youths could pursue the course without requiring to leave their home district to attend college. After at least two years in the shops, say, at about the age of nineteen, on condition that a certain standard of skill had been acquired, the first sifting out would occur. Those whose future career required a further course in the shops would continue there, and others would enter the drawing office for the first six months and then proceed to college, passing the next two years, alternately six months at a time, at office or works and at college. Nothing but theory should be taught at college, but examinations should be held every time the student passed from office to college, and *vice versa*, upon the work of the period just closing. For such students the laboratory should be used for demonstration and for testing practice, and no research work should be undertaken by students until after graduation. Under this plan, a student would proceed as far as his abilities and his means allowed, and for every stage the college would grant certificates from the examining body and from the employers. In that manner there would be every inducement for the student to push on as far as he was able. And, further, the system should be very elastic as to time,

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the student being allowed to proceed in his studies at any time. As to the youth who neglected his education after leaving school, and after some years with an engineering firm determined to take a college training, he certainly would be in an unenviable position. He simply, whether from fault or misfortune, could not be an engineer. It was not the business of any educational body to provide for the rectification of such misfortunes. Such a proposition was as reasonable as requiring the State to provide the victims of accidents with cork legs in order to make soldiers of them, and the grievous part of education nowadays was that it attempted to perform such things. Finally, he would urge the importance of teaching pure science in schools, and that civil engineers, as well as all others, should be obliged to go through a workshop course. The ignorance of mechanics and mechanical art among young civil engineers was to-day very great.

Prof. ARCHIBALD BARR, D.Sc. (Member), observed that Dr. Mellanby in his paper, raised questions of a broader kind than the title indicated. The paper appeared to him to bring up for discussion the whole question of the course of training that should be recommended. This matter was very fully discussed by the "Committee on the Education and Training of Engineers," upon which Committee he had the honour of acting as the representative of this Institution. The Committee's Report* should be read by all interested in this subject, —and that, he hoped, included all engineers. It contained the opinion of a large number of engineers in practice, and teachers of engineering science, boiled down as far as possible into a general statement; but it also gave, in statistical form, the results of the wide enquiry instituted by the Committee. Dr. Mellanby began by stating that "there seems to be no unanimous opinion as to *the best* course of training," and proceeded in a later part of his paper to outline a scheme

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involving attendance at day classes for one session, then three years in works, followed again by six months in college, six months in works, and again six months in college. He would join issue with the Author at the outset by expressing, as strongly as he could, and as the result of thirty years' experience in teaching, and of a longer period of contact with engineering practice, that there was no *best course* for the training of engineers, and never would be. The most disastrous step that was ever taken in regard to elementary education was, he believed, the fixing of rigid codes that had to be worked to in place of the freedom enjoyed by teachers under the old parish school system, which allowed the teacher to train his pupils as he found best, and to recognise the fact that all boys were not made of the same stuff and could not be made the best of by the same means. Fortunately the rigidity of the code had been relaxed, though none too soon. A few minutes ago he was reading an interesting essay on the Development of Applied Art. Dealing with the movement represented by what was called "L'Art Nouveau" and the "serious results" that had come of it, especially in France, Germany, Austria, and Italy, the Author —J. H. Elder-Duncan—remarked, "There all respect for natural limitations in the materials has been cast to the winds. Wood is cut as though it were a grainless and fibreless substance like cheese; metal is twisted into the most weird and unnatural shapes . . ." May these words not be quoted as somewhat more than a simile in regard to the present subject? No engineer would dream of using a wood plane to shape iron or brass, nor would he attempt to fashion a piece of soft wood on an anvil. Indeed, much of the mechanic's skill lay just in his knowledge of how to vary his methods according to the most minute shades of difference in the nature of the materials he has to handle. In educational matters, on the other hand, people were only too apt—everyone was—to assume that what was good for Tom must necessarily be good also for Dick and

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Harry, however much they differed in their natures and in their capacities for being trained, and to imagine that the same tools could be used to lick them into shape, though they might be as unlike in nature as chalk and cheese, with, let it be hoped, a good deal of selfwill into the bargain. He did not desire to be taken as directing these remarks specially against the opinions expressed by Dr. Mellanby. He gathered that his paper was intended to open a discussion on the general question of "the best course of training for would-be engineers," and he desired to emphasise his own view that there was no one best training. In his own practice he advised some youths to come to the university direct from school. Others he advised to go into works, to do what they could to get a grounding in mathematics, mechanics, and other subjects, by attendance at evening classes, and to come up to the university later on in their course. Take two such cases as an average boy from an English public school and another, say, from Allan Glen's school; he could not see any special virtue, for these two cases in common, in Dr. Mellanby's proposal of one session at college, then three years in the works, and so on. One boy would probably know comparatively little of mathematics, the other might have at least a good preliminary knowledge of the calculus, and besides, the two boys might have entirely different temperaments, and casts of mind. They might be equally good fellows and equally good stuff of which to make engineers, but no one scheme could be said to fit the two cases ideally. Nor did all teachers teach in the same way, nor were any two colleges alike in teaching equipment. In this connection he would plead for as complete freedom as it was possible to attain. He might quote again the words of Carlyle, which he (Prof. Barr) used at the last meeting of the Institution—"Let each considerate man have his way and see what it will lead to . . ," and he would make these words apply to teachers and students alike. He was glad that the members of the Committee already referred to agreed to specify no particular course of training in their report. The ideal would be to have a separate curriculum for each of the hundred men or so that one had to arrange for each year. Of course this was impossible, but he thought most progress would be made where progress was required, by starting frankly with the conviction that no one course was best for all students or for all colleges. He was far from considering the present provision for the training of engineers perfect, but he did not look for improvement by the prescription of any special curriculum as the best. On page 73 of the paper, the Author said, "if college training is to produce men who are capable of inventing new processes and improving existing methods of manufacture, then the training must not confine itself altogether to principles, but must direct attention to current engineering work." Whether or not he could agree with this depended altogether on the sense in which these words were taken. He would remark in the first place that he did not think college training could produce such men. The inventive faculty must be born in a man, as much as the faculty for creation in music. All that college training—he would rather use the word education, than training, to go to the root meanings of terms—all that education could do in this direction was to give men some guidance by way of knowledge of true principles and possibilities, and a scientific habit of mind in applying such knowledge; and this was a sufficiently important function. It ought not to be claimed that the inventive faculty could in any way be created, or the inventor *produced*, however much might be done to stimulate and draw out what was in a man. There was a fact regarding the history of inventions that he had often referred to, but which was so closely related to the subject in hand that he ventured to state it, though he did so with some fear that its bearing upon the training of engineers might be liable to be misunderstood. The more he studied the history of inventions, the more was he impressed with the fact that, in very few cases had great inventions been made by men whose training would seem to have been directed in any way towards the branch of industry which they had revolutionised. For example, in regard to the great inventions in iron and steel manufacture, one might go so far as to say that not one of the greatest steps had been taken by a man who had any training in the current practice of the metallurgy of iron. Roebuck, the founder of the Scottish iron trade, was a physician; Cort the inventor (or improver), of the puddling process, was a London merchant; Mushet, the discoverer of the value of the black-band iron stones of Scotland, was a clerk; Neilson, the inventor of the hot blast, was the manager of the first gas-works of Glasgow; Huntsman, the inventor of the cast steel process (still used in the preparation of tool steel and other high qualities) was a clock-maker; Bessemer was an engraver, and was forty years of age before he turned his attention seriously to mechanical pursuits; Siemens was a student of engineering, and he developed the open hearth process from his attempts to improve the hot-air engine; Snellus was trained as a school teacher, and began his study of applied science at the age of twenty-seven, specialising in chemistry; Thomas received a purely classical training, and also became a teacher, taking up chemistry and metallurgy later on; Gilchrist was also a chemist; and so on with others in the same department of industry. The history of iron and steel processes did not point at all clearly to the need for a special knowledge of current practice in that branch of industry, in the case of men who were destined to lead the advance, and the same might be said of many other branches of applied science. The first and the second Eddystone lighthouses were built of wood, both by men who were drapers to trade, and when a third lighthouse was wanted the work was entrusted, not to a carpenter, nor a mason, but to Smeaton who was a scientific instrument maker, like James Watt. Whitworth was trained in a mill and then in a mechanic's shop, but he had no special training in regard to some at least of the subjects of his great inventions. He greatly improved the rifle, but Tyndall says—"When Sir Joseph Whitworth began his experiments he was as ignorant of the rifle as Pasteur was of the microscope when he began his immortal researches . . ." Nor had Whitworth any special training, so far as he had gathered, in regard to steel making in which he introduced great improvements. Some years ago, when a discussion was raging in a certain engineering newspaper regarding the value—or rather the uselessness—of scientific training for engineers, the editor quoted in support of his plea for early and exclusive training in the workshop, a statement of the late Lord Armstrong's, as coming from a practical man who could speak with authority on that subject. Armstrong was a lawyer when he was forty years of age. But examples need not be multiplied. What do facts like these teach? First, that inventors were not made by training in the special direction of their future work. If the lives of the great inventors taught anything in this respect, it was the value of bringing to bear on a branch of applied science a mind not trammelled by too intimate a knowledge of how things had been done in the past, and—as was exemplified in the case of each of the men he had named—the value of a close study of the scientific principles that must be applied in order to improve upon what had hitherto been the best practice. The cases he had referred to were those of *great* inventions, but he believed it would be found on investigation that the like was true to a large extent of minor inventions and improvements. From his own experience, when he wanted a man to work in some special line involving an advance on what had been done before, he found it best to select a man who had been trained in quite a different branch of engineering practice. He quite agreed that all teaching of engineering science should be illustrated by reference to engineering practice, but he did not think that the teaching in college of current practice in one line of work, was what would produce the men who were likely to devise important departures

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in that particular practice. A few years ago (perhaps the same applied in some cases to-day) it was customary to devote a good deal of time, in classes dealing with the steam engine, to the study of the various types of valve gears. This was an excellent training in the kinematics of machinery—if given as such—and might prove exceedingly useful to a man who had to design, say, cotton spinning machines, or power looms. But what direct bearing would it have on the work of a man who had come to be employed in steam engineering, in the turbine practice of to-day? All the training that one could be sure his students would be called upon to apply was that part that had to do with principles, which were never superseded by any changes in current practice. The teaching of sound general principles was the important thing, and references to practice were necessary and valuable, chiefly by way of illustrating those principles. This would be the more evident when, out of a hundred students, it was remembered that no two might have the same needs in respect to their future practice. Regarding the special place of laboratory work in a college course, like remarks applied. A man might, in the laboratory, learn how to perform some special operations that he would have occasion to apply directly in his practice, but incomparably more important was the knowledge he would gain of what accurate and scientific experiment meant, and of the limits of accuracy attainable; the habit he might acquire of reasoning soundly from what he saw; and he would add the healthy distrust he would come to have of all results, wherever or by whomsoever published, that did not bear evidence, explicit or implied, of accurate scientific method, and sound reasoning. Long ago Dr. Coleman Sellars, the celebrated American engineer, said, "Laboratory work would teach a man that he must not make two experiments at a time if he wished to arrive at a definite result." What, for example, was the value of the multitudinous results that had been published regarding steam jacketing? In nearly all cases these results were worse than valueless. One man stated that he had got increased economy by use of a jacket, another that he found reduced economy, but apart from the probable inaccuracies of observation in so difficult a line of research, very little had been done in a scientific manner. In most cases a great many conditions had been altered, but yet people would argue from such experiments as to the effect of the alteration of one of the conditions. That was the kind of thing Dr. Sellars referred to. If, in the laboratory, a student learned to make only one experiment at a time—and other elements in the art of scientific research—the laboratory would have amply fulfilled its function in his education. It made comparatively little difference whether the subject matter of the experiments upon which he had been engaged appeared closely related to, or altogether remote from what he anticipated his future practice might be; and after all he never knew, nor could know, what would or would not be his future sphere of work, if he was going to be anything of an engineer in the proper sense. A man who, a few years ago, made a careful study of water turbines, was in a much better position to-day to fully understand the principles of the steam turbine, than one who had devoted himself exclusively or mainly to the study of the then current practice in the mechanism and action of steam engines. Most of what the latter learned, even of indicator diagrams and their interpretation, would avail him little—save as an education—when he came to deal with the more modern type of motor. It should be impressed on every student that what he had to learn in college was not the details of current practice, but how to study and to apply principles to practical needs, in order that he might be ready to tackle any problem that might present itself to him. Engineering laboratories might, of course, be utilised as places for original research, and there could be no better places as far as the limitation of their equipment permitted. All laboratory work, so far as the student was concerned, should be original research,

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whether or not an investigation on similar lines had been previously made by a more experienced experimenter. Even men with good practical training had usually much to learn in the art of investigation. Regarding the attitude of employers, he felt bound to record his own experience, which was that students were usually very generously treated if they showed themselves worthy. He did not look for any special scheme of co-ordination between the workshops and the colleges. Though each year there were a hundred or so of university students who wished to enter works or offices during the summer months, and though he looked upon it as a great favour on the part of employers to take those men on, he could only remember, during the seventeen years he had held the engineering chair at the Glasgow University, two instances of students telling him that they were not able to find openings, and in each case there was no evidence that any very serious attempt had been made to find a place. He did not think that, in the majority of cases, students were admitted to works because employers saw it to be to their interest to take them in — as Dr. Mellanby seemed to suggest in his paper. It was done in almost all cases as a favour, though he believed in not a few instances, it turned out to be to mutual advantage. And students were usually well treated in the works, so far as his experience went. He had, indeed, known of one case where a student of high scientific attainments was kept for some eighteen months turning one kind of bolt, but this was a species of unrefined cruelty that was very rare, if not unique, and even that was survived, for the man now occupied a very important position in the engineering world. In some cases, no doubt, students might be given better facilities for learning the essential elements of engineering practice. All he would ask of employers was to remember that such men as sought a university or college education, aimed at being engineers and not mechanics, and he thought they might be granted facilities for learning what they could of practice that would be of value to them, with little fear on the part of employers that they would thereby be training up future competitors. If employers did not find it to their advantage to retain the services of such men, the latter, in all probability, would drift by the force of circumstances, or by choice, into some different line of business or professional work, and in many cases such men, in their future practice, would be able to divert a good deal of business towards the workshops in which they had been well and considerately treated. He would ask for no hard and fast agreement between employers and college authorities. A youth who had the proper grit in him would be sure to find his way in the world, and by making a student feel that he had any kind of claim to be taken into a workshop, would remove much of the salutary experience that came from the necessity to push his own way, and justify his existence. On page 74 the Author referred to the comparative failure of the "sandwich system," though the course which he proposed was a sandwich system and no other. The sandwich system began in Glasgow University when the engineering chair was founded there sixty-seven years ago, and it had been the system followed by the great majority of students ever since. Even the name by which it was known originated there. He could not agree at all with the Author as to its having been a comparative failure. He believed as strongly in it as he did when, as a student, he adopted it himself, and he trusted that it would continue to be the system followed by generations of students, as it was to-day, by the sons of many who got their own training in that form. It had never been considered an integral part of the sandwich system to have its elements placed in any particular order, nor to make them of any particular thicknesses, and he did not think any rigid specifications should be drawn up in respect thereto. The Author spoke of the "schoolboy student with which colleges were filled." This was descriptive of most, if not all, colleges

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in which the sandwich system was not followed, but he was glad to say that it was not so with the University. As a rule students at the Glasgow University did not take any engineering classes in the first year of their course. Of the 60 or so students taking the first year's course, he had no statistics, but of the 126 students in the second and third years' classes, he found that the youngest were one of 17 and three of 18 years of age on entry. The average age all over was about 22 years. He had records which showed that of these at least 106 had had some practical experience, and many a great deal. The Institution was to be congratulated upon having the subject brought up for discussion by so able an authority as the Author of the paper, and he hoped that Dr. Mellanby would pardon him if, in the expression of his convictions, he might appear to differ somewhat widely from him on some points. He might have misunderstood Dr. Mellanby's meaning in some of the passages he had ventured to discuss, but if his remarks were understood, it would be seen that he welcomed differences of opinion as to the course of training engineers should undergo, and he neither looked for, nor desired to see, unanimity on a matter that he did not think admitted of being reduced to any kind of formula.

Mr WILLIAM J. GOUDIE, B.Sc. (Member), observed that while reading Dr. Mellanby's paper, he had noticed the Author's encouraging statement regarding the Clyde engineering employers, that now, " Many are prepared to make considerable sacrifices to further the advancement of those under their charge." The practice of sending boys from school to college before they had any idea of the practical side of the mechanical engineer's work was a mistaken one; in fact it was an inversion of the natural order of things. If those employers who looked askance on the purely college trained youth would give the technical teaching profession the sympathetic support asked for by Dr. Mellanby, he was convinced that, in a few years, they would talk in a different strain from what they did

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at present. Apart from any sentimental considerations, and regarded from the purely business point of view, this co-operation would pay them. Shop experience should undoubtedly come first, and concurrently with this a sound grounding in elementary mathematics and physics, as pointed out by Dr. Mellanby. He did not think, however, that a preliminary year at college was at all necessary, if the secondary schools did their work in an efficient manner. He was also of opinion that the present evening class machinery could be modified to deal with these subjects in such a way that no undue mental strain would be put upon the students. Granting, however, the contention that while serving in the shops the apprentice should be freed from evening class work, but still be enabled to continue his studies, he would make the following suggestion, alternative to that of Dr. Mellanby's, regarding the necessary day classes, namely, to substitute morning for afternoon classes. If these were held, say, from 7-30 a.m. to 9 a.m., two mornings per week, the selected apprentices could easily go to their respective works after breakfast time, on class days, at 10 o'clock. This arrangement, he thought, would cause less derangement of the routine of the shops, than a break in the working day later on; and it certainly would be conducive to the benefit of the students. The selected apprentices would be those applicants for the privilege, who, after a month or two of probation, were found to be steady time-keepers and diligent workers. They would require to obtain satisfactory reports from the teachers of these special classes, of regular attendance and satisfactory progress in class work. A strict system of discipline could be instituted, any breach of this to be followed by forfeiture of the privilege and relegation of the offender back to the ranks of ordinary apprentices. The courses for these special classes in mathematics and physics might be made to extend from the beginning of September till the end of March. This work would of necessity require to be carried on in the near neighbourhood of groups of the works

Mr William J. Goodie, B.Sc.

from which the students were drawn; and regarding this point there need be no difficulty, in the Glasgow district, with so many first-class secondary schools available, as the School Boards already co-operated with the Technical College in evening class work. The graded curriculum could be drawn up by a representative committee of engineers from this Institution, to ensure that the teaching would be on the lines best suited to the needs of future engineers. As Dr. Mellanby pointed out, the substitution of prepared works-apprentices for the raw schoolboys in the subsequent day classes would lead to the greatly increased efficiency of technical colleges. The work that at present had to be rushed through in two sessions could be spread over three, and more time could be devoted to individual tuition and effective laboratory training. While it should be part of a professor's or lecturer's business to keep his classes posted in the latest developments of engineering practice, he considered that the "thrashing out" of information given in engineering societies' papers ought to be kept quite apart from the regular college work. Students sufficiently advanced to be able to appreciate and enter into the spirit of these things could join the graduates' or students' sections of these institutions, and there find plenty of scope for their debating talents. Regarding the now much quoted subject of "research" in mechanical engineering, he was afraid Dr. Mellanby was inclined to be over sanguine regarding the increased facility for this work, which the suggested modification of training would ensure. It should not be forgotten that the function of an engineering laboratory was primarily an educative one, as it existed in the first instance to enable future experimentalists to be trained in those habits of accurate observation and methods of experiment, without which no one could hope to carry out any investigation satisfactorily. If the regular laboratory work essential for this purpose were to be efficiently carried out by professors and instructors, the amount of original work which could be attempted was, therefore, of necessity limited in amount. It was to be hoped that this discussion would not be left, like previous ones, almost entirely in the hands of those connected with technical teaching; but that it would get full justice from the leading engineering employers on the Clyde. At this momentous period of its history, it would be a fitting thing if the representative Engineering Institution of Scotland took this educational difficulty seriously in hand, and settled it once and for all.

Mr W. H. ATHERTON, M.Sc. (Derby), remarked that Dr. Mellanby's paper was really a plea for closer co-operation between engineering employers and colleges, in promoting the higher technical education of engineers, and in utilising the laboratory equipment and staff for research work on a commercial scale, instead of for comparatively elementary education. Incidentally he briefly described the present system of training engineering apprentices in technical schools and colleges, which he courageously condemned as defective and even absurd. He then proceeded to point out a better way, and outlined a higher standard of college work that would produce men of a more valuable type to employers than hitherto. He did not discriminate, however, between different classes of engineering students. It seemed that there should not be one course for workmen, another course for foremen and draughtsmen, and another for managers and directors. Apparently all had equal talents, all might climb to the top, and all should be trained alike. Some authorities thought otherwise, and did not hold this democratic view. After all there was no getting away from the fact that a long and systematic course of college training, such as that leading to a degree, though valuable in itself, was really of secondary importance from the point of view of the employer. It was more valuable to the teaching and consulting engineer than to the executive and commercial engineer. He entirely agreed with Dr. Mellanby that a year

Mr W. H. Atherton, M.Sc.

at college or technical school should precede entry to the commercial workshop; though a portion of that year might be spent with advantage in a good college workshop, such as that of the Manchester Municipal School of Technology. A suitable short course would greatly increase the receptivity of a lad, and save much time in the end. As for the return to college after three or four years in the shops, he feared that would only be feasible in exceptional cases; as, for instance, when a clever young fellow, who had done well in evening classes, won a scholarship. Such students were always welcomed by college professors, and almost invariably did well, the seed falling on good ground. For Dr. Mellanby's encouragement, he might add that one pleasing instance was known to him, where a director of a Limited Company was now paying privately for the scientific training of a skilled moulder, in the metallurgical department of a famous university college, trusting that the man would ultimately justify the faith reposed in him, and prove of great service to his employers.

Mr EDWIN H. JUDD (Member) considered the subject of Dr. Mellanby's paper as important as it was open to diverse opinions and criticism, but it did not receive the careful consideration of many employers that it deserved, seeing that the boy of to-day was the man on whom they had to rely on the morrow. One very striking fact which emphasised the view that it was more a matter of the man himself, than of the facilities lavishly thrown in his way, was that, long before the days of the present advanced and expensive technical colleges, there were giants of engineering intellect and genius such as Watt, Stephenson, Scott Russell, Macquorn Rankine, Armstrong, Nasmyth, Whitworth and others. In the end, the determining factor which influenced an employer to decide on a certain employee as being suitable to fill a certain responsible post was not only what mathematical gymnastics he could perform, what research work he could do, or how many different kinds of steam, gas, oil, air, and other engines, etc., he could test; but also, had he

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a thorough knowledge of first principles of mathematics and mechanics, combined with a good practical training and knowledge of the work he had been engaged in on his employer's behalf; could he use common sense in applying these qualities to various modifications of new designs and methods; further, had he determination and grit to stick to his work; and last, but not least, had he character. He (Mr Judd) did not want him to specialise in work more advantageous or creditable to the technical college than to his own works. From what he had seen in his own experience, it was not the most privileged youths who had had special university or technical college training, and gained innumerable certificates—B.Sc. degrees, Whitworth Scholarships, etc.—who had turned out either the most successful or the most useful, but those who had gone through the full four or five years apprenticeship in actual manufacturing shops, and studied at the evening classes during the winter sessions. The very determination and grit which made them willing to work from 6 a.m. to 5-30 p.m., and then study three, or, say, four nights a week, was one of the very best factors in moulding their character. A little extra inducement to perseverance in evening class studies, such as the monetary rewards offered by Messrs. Barr & Stroud, Messrs. D. Rowan & Co., and others, seemed a step in the right direction. One of the main objects of the course of study outlined in Dr. Mellanby's paper appeared to be—as stated on page 75—to enable the student to discuss, go into, and thrash out, the subjects of papers read before such institutions as this, as they would then have "sufficient practical information to see their bearing on current engineering work and sufficient knowledge to go into it fully." He was afraid that fourth and fifth year apprentice-cum-students would scarcely be capable of fully appreciating, let alone thrashing out subjects which had been contributed by experienced practical men, who had devoted to them years of study and perhaps costly experiments. In most works not more than one or two classes of machinery

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were really specialised, and which necessitated real serious research work. In these cases it was almost always much more to the employer's advantage to carry out such in his own works. For example, a machine-tool builder preferred to carry out all his experiments in feeds and speeds, qualities of various steels, etc., on steels of his own manufacture, and in the privacy of his own works; and an engine builder would gain much more valuable knowledge by carrying out tests on engines of his own particular type and sizes, than on some specially constructed, handy, all-round model engine in a technical college laboratory. The same argument applied equally well to steel manufacturers, chemical engineers, and others. Then as to the suggestion that the apprentice be allowed to attend classes on, say, two afternoons per week. It caused sufficient disorganisation to works to allow as many apprentices as wished to attend during the winter session, returning more or less in the spring like birds of passage, but to break up, or to interfere with the routine of a fully occupied shop by interruptions every two or three days, would only make matters worse, and he did not wonder that the experience of those firms who were stated to have tried it was only fairly satisfactory. Another objection to an apprentice breaking into his regular time, which became much worse after his apprenticeship was completed, was that during his absence from works he often lost an opportunity of promotion. The writer knew of several cases where young men would have been appointed to vacancies which had suddenly occurred had they been present, but others had been appointed in their stead. If an employer was going to benefit by, and to help financially the course of study outlined in this paper, he should have some assurance, firstly, that the apprentice who left his work after the first three years, for an intermittent period of study at the college, would complete his apprenticeship in the employer's own works after each of the day class sessions—there being very few, if any, bound apprentices now—and, secondly, that if the apprentice intended to

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go in for extensive and useful laboratory research work, he would be chiefly or entirely engaged in work in the same line as his employer was interested in. By all means let there be good laboratories for apprentices and students attending them, but on no account should apprentices be allowed to imagine that a few months playing at engines in a college laboratory—which it practically was to most of them—could make them such competent engineers, in the thorough sense of the word, that they would jump into responsible posts immediately they had completed their college course. In submitting the above criticism, one should not forget to render due credit to such technical college research work as had been done by Professors Mellanby, Nicholson, Watkinson, Weighton, and others engaged on investigating practical subjects, the results of which all engineers should be grateful for.

Prof L. D. COUESLANT (Sunderland) observed that in his opinion the function of the laboratory in engineering schools could not be absolutely defined without a knowledge of the school, the nature of its work, its students, and its teachers. Dr. Mellanby said that the usual reason given for not undertaking original research was, that the students were altogether unfitted to carry it on. As he said, it was true of the majority of schools, and it would still be true if he had said teachers and students, instead of students only. There was an appalling waste of time going on in the laboratories of this country, on the assumption that every youth was a potential discoverer, and that every teacher that had managed to secure some kind of scientific qualification could show him how to discover. There was also an unfortunate tendency among teachers of engineering to support this superstition, because of the prestige that was rightly accorded to original work. The truth was, that careful and systematic teaching of such a comprehensive subject as engineering was incompatible with the intense concentration, for months or years, on a single group of phenomena necessary for any research worthy

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of the name. In ten years' experience of technical education he had not met, or even heard of, a single professor who excelled both as a teacher and a discoverer. It was a notorious fact that the more eminent a man was in original work, the more futile he was as a teacher of all except the most exceptionally endowed students. He should say that, generally, the function of the laboratory in the ordinary technical school (and in the term ordinary school he included every school in the country except one or two) was, not to do original work, but merely to illustrate and teach already well established facts. After all it was a sufficiently honourable career to be concerned in the making of even ordinary men. Research should not be allowed to interfere with the engineer's training at any time before he had completed his general training as an engineer, at least up to the standard of the ordinary university degree. Thereafter a small, rigorously selected number of scholarship men might go on to do original work, under eminent men in the one or two institutions devoted to work of this kind. Being students of exceptional ability, they would be able to triumph over defects in presentation, and might be expected to do something more than burlesque research. There was at present a good opportunity to establish such an institution at South Kensington, which promised to be missed for the sake of building another polytechnic, of the ordinary type, in a district where far too many such institutions were already wasting their energy in fruitless competition. It must not be concluded from all this that the laboratory was not needed in the ordinary technical school. It was an indispensable adjunct to the library and the blackboard, inasmuch as it gave a reality to the teacher's exposition that could not be obtained in any other way. Under a conscientious teacher, who was in continual attendance in the laboratory while work was going on, who gave as much attention to the preparation of his laboratory work as he did to his lectures, and who did not regard the laboratory classes as an opportunity to do some-

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thing else, it would be the most efficient department in the college. Otherwise it would be, as it too often was, a miserable and costly farce. Dr. Mellanby suggested that "The student after leaving school should immediately proceed to college, and there take up the first year general course." This amounted to a proposal to let the technical college replace the secondary school. He could not see any reason for this. It was, of course, desirable that there should not be an interval of casual employment between 14, the age of leaving the elementary school, and 16, the age at which apprenticeship usually began. This interval should be spent in improving the general and scientific education at a secondary school, but it was doubtful if the specialists of the technical school were the best men to give this general training. As he had very recently dealt with the combination of workshop with college training, in *Engineering*, October 11, 1907, he would not occupy more time in doing so on this occasion.

Prof. J. T. Nicolson, D.Sc. (Manchester), observed that he had much pleasure in giving his support to the views advocated by his friend and former colleague on the subject of the proper training of young engineers. He had given much earnest thought to the question, and begged to be allowed to contribute the following statement of his views. They were the result of many years' experience, both in the workshop and drawing office and as a university student and teacher. The object of industrial training and education was ultimately the improvement of processes of manufacture and the cheapening of production. Apart from politico-economic considerations, this object was to be attained by seeking a closer and clearer insight into the physical processes and scientific principles underlying all manufacturing operations, and by training the powers of reason and observation and cultivating the inventive faculties of all industrial workers. It was obvious that before a man could hope to invent a new appliance or to improve an art, he must possess a complete knowledge of his subject-matter. This knowledge must include an intimate acquaintance with those branches of applied science which underlied it. There must, in short, be both a practical and theoretical training, and it was most important to observe that the latter must be complete and thorough so as to enable the trained man to initiate improved methods and indicate new directions for advancement. In order that such knowledge might be possible, the relatively short time which could be spent upon acquiring it must be utilised to the utmost. It must not be wasted upon descriptions of elementary facts, appliances, and processes which should be learned by personal observation and actual handling in the workshop, and, therefore, care should be taken that the period of practical training preceded that of theoretical and experimental study. This might appear to be a mere platitude. Yet the systems of technical training followed in this country, with but few exceptions, agreed in denying its validity, since they were based upon its very converse. Under the present system, a boy intending to become an engineer generally went to college immediately upon leaving school, his workshop experience being relegated to a later period. This was so, not because it had been found to be the best way of training the boy, but because it was the only course open to him under present conditions. After three or four years of apprenticeship, he found it difficult, if not impossible, in the majority of cases, to stop work and take a college course. He had become of some value to his employer, was earning a wage, and was doubtful about giving up his immediate prospect for an uncertain future. On the other hand, he received no encouragement from his employer to take up the theoretical or experimental side of engineering, and had been afforded no facilities by him for preparatory study. He knew also that even after he had obtained his engineering degree or diploma, he would have to begin in the works exactly where he left off, as there would be no recognition, by preferment or increase of salary, that he was a more valuable man than he was before. Thus it was that when a parent was willing to afford his son the advantage of a college training, it was almost always allowed to precede the period of apprenticeship or pupilage in the works. The ordinary graduate of the engineering college who had not been in the works was found to be of but little more value to an employer than a boy who had just left school. This lamentable state of affairs was, however, largely the fault of the employers themselves. Owing to their shortsightedness and their attention rather to immediate profits than to ultimate advantage, they had allowed the great resources spent upon technical education to be largely wasted. Many of them took no interest whatever in the training and education of their apprentices. Others objected to assisting a process which they feared might some day produce a man capable of ousting them from their position, or of becoming a competitor in business. Others were content that the technical schools should act as "sieves for winnowing out the inferior material, so that the few who remain may be assigned a place in the structure of the mechanical engineer's business." The large majority, however, were not unwilling to assist; but they gave their services in bolstering up the present useless system, which spent the parent's money, the boy's time, and the teacher's energy almost in vain. For in many cases the pupils of engineering colleges and technical schools acquired, under existing methods, a very small proportion of even the theoretical knowledge which it might have been attempted to impart. Their interest in the subject had not been aroused by preliminary observation in the workshops of the objects to be studied, and one did not find in them that keen desire to understand the principle of an appliance or the theory of a process which was manifested by those who had had to work them. Their studies appeared to them a mere continuation of school work, and from long continuance too, often became a weariness. Hence the cry for the lectures to be "made more interesting," Prof. J. T. Nicolson, D.Sc.

and the cause of the absurd popgun element which so often made its appearance on the lecture table. As a matter of fact, the average youth from 16 to 19 years of age must be kept under discipline. He could not be trusted to maintain a steady application to work if left alone. When following a course of study at this age, he only learnt as much of applied science or practical manipulation as the vigilance of the teacher or the system of checks to idleness compelled him to do, so that any attempt to take up difficult, because really useful, work was a waste of time. If, on the other hand, he spent his time from the age of 16 to 19 years in the workshop he was much better employed. He was bound to work whether he wished to or not. He learnt the elements of his profession by direct observation of practical methods and the actual handling of the tools and machines, instead of having to picture them to himself from long descriptions and painful sketches. If naturally intelligent, his familiarity with these operations and processes aroused curiosity and initiated a spirit of inquiry regarding points of obscurity, so that students who had been in the workshop were much more interested in theoretical questions and in experimental research at the college than those who came straight from school. The writer's experience was that, almost without exception, engineering students who had previously passed through practice became, at the end of their college course, men of the very highest industrial value. Such, however, was the plethora of young engineers who, although graduates or diplomés, had never been inside a workshop for more than a few days, and with whom the really valuable man was usually confounded by the employer, that it was with difficulty that the latter got an opportunity to show his merits. To obtain such men, however, there must be a continuity of theoretical study from the school to the college, and it was here that the employer should be rightly called upon for the exercise of what appeared to be a certain amount of self-sacrifice. The employer must be asked to provide that, throughout the duration of the workshop period all the apprentices should be given facilities for improving their knowledge of mathematics, mechanics, and elementary science. The attempt, as in the past, to carry out this work by evening classes could only be described as a makeshift. It had met with an indifferent success relatively to the amount of public energy and money expended upon it. The small reserve of time and will-power possessed by the average apprentice after his day's work had been in great part wasted in travelling to and from the classes or in studying too many subjects, whereby he had obtained only a useless smattering of many things and no accurate knowledge of any. By the minority of really earnest students all that was required was a little direction as to what subjects they ought to study and what books to buy, the work being far better done by themselves at home than by lectures. For the majority, however, who were incapable of private study, another system was required. The employer must permit and facilitate the establishment of a system whereby boys in their first years of apprenticeship should receive lectures, for not less than three hours per week, in mathematics and elementary science *during the day*, and the evening must be left free for home study, instead of being wasted in travelling about and listening to elementary lectures on all sorts of unconnected subjects. At the end of each year examinations must be held, whereby the fitness of allowing any given boy to proceed further with theoretical study in the following year could be determined. Each year the number of continuations would naturally diminish, and by the third or fourth year of apprenticeship *a few youths* with a fair knowledge of mathematics and mechanics would be secured, from whom the employer must select, by personal inquiry as to character and general aptitude, and by written examination, *one or more* to be allowed the special privilege of a two years' course at a technical college. A selection of the best of those who did not develop an aptitude for theoretical work should be carefully trained in workshop methods, and from them ultimately would be obtained a supply of chargemen and shop foremen, a class which was now so difficult to obtain. By this method, in the case of the specially-selected apprentice, as much mathematics, mechanics, and science as were now ordinarily taught in the first year of an engineering college day course could be imparted during the first three or four years of his apprenticeship, so that upon entering the college course it would be possible to begin with strictly professional study and to carry it forward in two complete years, to an extent limited only by the knowledge and ability of the teacher and the resources of the school. In no other way could the American employer's method of "prospecting for talent as a miner prospects for gold" be so effectively carried out. A selection of young men, say one or two from each large works, picked for their superiority both in mechanical aptitude and in preliminary scientific knowledge, could thus be obtained, and the supply so furnished from a large industrial district would be not only numerically very considerable, but—what was of far greater public importance—of the best kind of material for the evolution of a peculiarly valuable type of young engineer. The field of useful work which could be entered upon by the experienced teachers in technical schools—if they were supplied with real students of engineering, instead of with ill-educated boys wishing only to get through a college course with as little trouble as possible—was simply endless. At present they were mostly marking time. Schemes for the provision of such a class of students were at present scarcely to be found in this country. There hardly existed on the part of employers even the wish to provide them, or on that of the education authorities the knowledge that they were desirable. It seemed obvious, however, to the writer that the stress of international competition would very quickly force those interested to "pan" over all their available raw material so that the precious metal it contained might be extracted and worked up to the best possible finish and lustre. By one or other means it must be made to pass through an all-embracing sieve so that nothing valuable might escape. The proposals herein suggested, and the sequence of preparation which they involved, seemed to the writer the most feasible and practicable way of securing the object in view. It could not surely be generally known that, except by strenuous personal exertion, it was at present impossible to obtain this sequence of training, a sequence which was the only proper and sensible one. The employer, the educational authorities, and frequently even the teachers themselves, all conspired to straighten the way leading to post-apprenticeship study. Employers naturally preferred men of 19 or 20 years of age working in their shops for apprentice's wage to raw boys from school. The educational authorities knew that if they did not get their pupil when he left school he would escape them altogether, and as, unfortunately, the teacher himself had often never been a practitioner, and felt upon surer ground in dealing with ignorant schoolboys than with young men well versed in practical work, he also gave his vote in favour of the present system. Thus, from a policy of expediency on the one hand and of self-interest or apathy on the other, the nonsensical system of "technical education" had grown up, and now flourished.

Prof. Francis G. Baily, M.A. (Edinburgh) remarked that a consideration of the education of an engineering student led to an advocacy of two differing courses. From one point of view the practical training should follow the scholastic; from the other, the order should be reversed. The advantages claimed for the first method were that, with some knowledge of practical work, a student was more competent to understand the utility of the scientific principles underlying practice, and was better able

Prof. Francis G. Baily, M A.

to follow the treatment of technical questions included in the college course. The second method offered the advantage that, with a sound knowledge of scientific and technological principles, the student was in a position to obtain more from his workshop experience. To gain the advantages of both arrangements the "sandwich" system had been organised, and with general acceptance of its merits. Discussion now centred about the proper apportionment of time and the inconvenience that such intermittent courses gave rise to. Dr. Mellanby advocated a sandwich system with a very large middle layer of workshop, a continuous attendance of three years in the shops after a single session at college, and in order that the effects of the college course might not wholly disappear during this interval, he proposed evening study during this time. This plan offered many advantages, and if he (Prof. Baily) offered any criticism, it was only a tempered and partial objection that he wished to make. That the first year course should follow immediately after school, he agreed with. The work continued and developed the school study, or made up its deficiencies, and a knowledge of practical work did not help the student to any extent, while any considerable lapse of time between school and college not only rendered the school knowledge hazy, but also tended to produce in the mind and methods of thought of the student a disinclination for general principles and fundamental conceptions. That at all events had been his experience in many cases. They were unable to see the wood for the trees, and having learnt through the hand for so long, they found a difficulty in applying their brains to anything beyond individual material examples. He only feared that for the average student a single winter session barely sufficed for the elevating of his mind. An additional advantage of a second session might be suggested. The technological courses of the second session did not deal with much detail of practice, and the equipment of the college laboratory usually offered sufficient illustration for the purpose, so that the absence of a workshop training did not much matter, while such a course gave a student just that insight into the principles of the subject, and that preliminary acquaintance with representative details, which would prepare his mind for mastering the work in the shops. But before the third year some experience of workshops was greatly to be desired, and while in his own college (the Heriot-Watt College) this experience usually extended over only half-a-year, he would not be sorry in some ways to see this time extended. But very much depended on the lad. For some lads, slow of mind and lacking in intellectual keenness, the first year's college course was almost wasted. Yet they showed no mean ability in the shops, and would afterwards find a much greater capability for theoretical work, when the practical facts were already known to them. On the other hand, unusually brilliant lads would pick up, by a short experience in the shops, visits to works, and intercourse with older men, a considerable acquaintance with the practical side, so as to appreciate thoroughly the technological side of the advanced courses, while their study of mathematics, physics, and mechanics was carried forward with unbroken continuity and conspicuous success. Nor had he found, in following the career of these students in their subsequent shop work, any of that swelled-headed contempt for manual labour and the details of practice that was put forward as a sneer—a rather cheap and irresponsible sneer—against the crack student. But the paper dealt, nominally at any rate, with laboratory work, and the Author advocated an advance beyond stock experiments and an introduction to research. That more interest attached to work, of which the answer was not known, he fully agreed; but he should like to say that if Dr. Mellanby's machinery was so well trained as never to give rise to unexpected problems and difficulties during the third year's working, he heartily congratulated him. His own machines, he must confess, were not so jog-trot, and even if they did show a lapse into monotony, it was easy to devise variations and interesting side issues

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sufficient for the most courageous student. One must distinguish clearly between the educational aspect of research and the intrinsic results. For students, research inculcated a high standard of accuracy, a keen attention to details and definiteness of conditions, an observant attitude towards unexpected developments, and a critical consideration of methods of experiment and the performances of the apparatus. But the devising and organising of the general attack, and the interpretation of the results, went beyond their powers, though attempts on their part were, of course, to be encouraged. But all this could be obtained with work that could hardly be dignified by the name of research; while real research, as one knew by bitter experience, nearly always involved either a long process of search for and elimination of errors and complicating side phenomena, or a laborious accumulation of continued experiments, or both. For this the amount of time that a student could spare was altogether inadequate, unless he definitely allocated to the work some space of entirely free time after his regular course was complete. He feared that no possible alteration of times and order of work would give scope for research, unless an extension of the college course was made. Where time could be spared for luxuries, he cordially agreed that a piece of original work was a liberal education in itself, but it should be rather a post-graduate study than an integral part of the normal curriculum. To the criticism occasionally made by works' managers, and mentioned by Dr Mellanby, that a college training did not add much to an assistant's value, he would like to point out that they were under a misconception as to the object of a college course. At college, men, as a rule, were not trained in the details of a particular line of work. For his own part he endeavoured to avoid treatment of details that varied in different factories, or the use of empiric formulæ valid only for a narrow class of work. The chief aim was the inculcating of an understanding of sound and intelligible principles, while the details of current practice entered only as illustrations. Now a junior assistant was rarely asked for an opinion on the general principles of the particular class of work in vogue in the shops he entered, but some managers expected him to come primed with the very information that he had come to the shop to learn. They expected him to be a specialist in their particular line, while the whole aim of the course had been to widen his mind beyond the restricted purview of a particular manufacture. It was a basis for specialisation in any branch, useless, perhaps, by itself, but invaluable for subsequent superstructures. To sum up, he thought that, beyond a few matters of detail, his only criticism of Dr. Mellanby's paper consisted of a fear that he was too sanguine as to possibilities, and that he anticipated from the average student what lay within the powers only of a very small minority. Though the minority were the true and almost the only joy of the teacher, one must organise the course for the average, and treat the others as special cases. Their numbers did not preclude exceptional facilities being found for them.

Professor MELLANBY, in reply, observed that many of the points raised in the correspondence had been answered in his previous reply, and for that reason he did not propose to consider them all in detail. The remarks of Mr. W. Reid Bell were of great interest, coming from one with so much experience in civil engineering. Although there were several details upon which he was not in entire agreement with Mr Bell, yet on the main points they were of the same opinion. Mr Bell's criticism of engineer students emphasised the weak points of the colleges in this country, and confirmed the statement made in the paper that the results of the present educational systems were most disappointing. It was particularly pleasing to find Mr Bell advocating the teaching of pure science. So many engineers were in the habit of calling out for colleges to make their teaching more practical that he was gratified to have such strong support in his plea for a thorough ground-

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ing in mathematics and physics. Mr Bell's notions upon the value of research to practical engineering would be modified, he hoped, on reading his reply to some of the speakers. Professor Barr objected to the Author advocating what he thought was the *best* system, and insisted that there could be no *best course* for the training of engineers. Professor Barr's idea was that each individual had different requirements, and in an ideal state there would be a separate curriculum for each student. This was a statement with which all teachers would agree. It was not correct to state that, because the Author put forward a scheme, he, therefore, advocated a rigid cast-iron type of training. In fact, if the scheme suggested were adopted, its effect would be exactly the opposite to that stated by Professor Barr. It was the present system that had the misfortune to be so rigid, and so incapable of taking advantage of the different developments of students. Much was made of the fact that it might suit some students to attend college immediately after leaving school, and that others would be better if they went to work first. But so far as the colleges were concerned, no difference was made in the training that these two types of students had to undergo. Both attended the same lectures and went through practically the same routine laboratory work. The proposed scheme, by bringing the student to such a condition that, in his final college year, he was to a great extent independent of lecture work, would allow teachers to take the utmost advantage of the different temperaments of students. The greater part of the time would be spent in the laboratory, where the work could be arranged to give every man the best possible opportunity of showing his special talents. The members were urged to take special note of this point, as the statement that, for each student it should be carefully considered whether works or college training should come first, was one that was continually being brought forward. As a matter of fact, the great majority of colleges were compelled to make their courses suit the schoolboys, and the so-called attention to individual wants became a mere pretence. The list of inventors brought forward by Professor Barr showed that, in the early stages of engineering, the men engaged in practice were very similar to those of the present day. It was remarkable how easily engineers were satisfied with the work they were doing, and how seldom any real effort was made by them to improve upon existing practice. It was often the outsider who saw the deplorable condition, and spent time and energy in attempting to make improvements. At the same time, the Author thought that no training could better make engineers adopt an inquiring spirit, and compel them to continually ask themselves whether some process could not be improved, than a good drilling in research work. He would also insist that no invention was ever brought to perfection without a good deal of laborious and painstaking investigation. He was glad that Mr Goudie had drawn attention to the fact that co-operation between employers and colleges would, from a business point of view, pay the employers. Mr Goudie's scheme had several attractive features and showed that he was quite alive to the necessity for obtaining youths in a better state of preparation for colleges. If every apprentice got the chance of technical education, and if only those who escaped the weeding-out process obtained the highest type of training, the best men for all grades could be selected. Mr Goudie was quite right in insisting that one function of a laboratory was educational. With better prepared students, the routine work could be finished in much less time than was now taken, and ample opportunities for research work given. Mr Atherton had summarised the objects of the paper, but was under a wrong impression when he stated that there was no discrimination between different classes of students. It had been previously pointed out that the adoption of the scheme would necessarily mean that only the most capable men could follow it out in its entirety. Mr Atherton held a responsible position in the

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engineering world, and his statement that a course of college training was not of much value from the point of view of the employer was another confirmation of the views expressed in the paper upon the deficiencies of our present educational system. Mr Judd commenced by stating that the training of apprentices was worthy of the consideration of employers, but followed it up by a series of statements which seemed to imply that, after all, he had only a poor opinion of technical education. His statement that many employers would prefer to carry out research in their own works was one with which the Author agreed. Mr Judd, like many others, appeared to imagine that men capable of carrying on these researches could be found without any trouble. It was probably this feeling which accounted for the ignorance displayed by machine-tool makers when the tool experiments carried out at the Manchester School of Technology were published. Professor Coueslant's statement that there was an appalling waste of time going on in our laboratories on account of what he insinuated to be a desire for research work, was somewhat startling. The Author thought he was acquainted with all the laboratories of importance in Great Britain, but had never yet entered one dominated by this frenzy for original investigation. The fact that Professor Coueslant had not yet come across a professor who excelled both as a teacher and a discoverer, might be explained by the fact that, among engineering teachers, for the reasons explained in the paper, there were so few discoverers. He was pleased to say that his own experience was quite the opposite. He had been a student under the two professors of engineering who had, he thought, done the maximum amount of original work in this country, and both were considered by their students to be exceptionally good teachers. In the other branches of science, such as physics and chemistry, it was the general rule that the brilliant research man was the most inspiring teacher. It was difficult to see how the suggestion that a student should

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proceed to college after leaving school amounted to a proposal to let the college replace the secondary school. At no college worthy of the name was the first year degree or diploma course of anything like so low a standard as the work done in a secondary school. The convincing contribution of Professor Nicolson was of great interest and added much to the value of the paper. Professor Nicolson and he were so much at one in the course proposed and the objects aimed at that, he would not do more than strongly recommend the members to give this addition to the discussion the careful study it deserved. They would find that it completely disposed of many of the arguments brought forward by various speakers. Differences in detail between Professor Nicolson's and his own scheme were accounted for by the fact that Professor Nicolson was thinking about the educational conditions in England, whilst he had in his mind the short college sessions common to Scotland. He was glad to have the criticism of Professor Baily, and he noticed that he was of the opinion that the work of the final year at college would be improved if the students had more workshop experience. As Professor Baily had mentioned, the scheme of the paper was mainly for the training of the best men, but the remarks of Professor Nicolson would show how other types of students would be provided for. The striking feature of the present system was that it did not aim at producing men fit for the highest positions and capable of putting the engineering industries of this country into the front rank. It had been previously mentioned that, so far as the rank and file were concerned, this country was probably in the foremost position. But, whilst other nations were devoting their energies to the training of men fit to become leaders in the industrial world, the colleges in this country seemed to aim at producing nothing higher than superior draughtsmen. This was the great deficiency of the present educational system and one that could only be remedied by the hearty co-operation of employers and colleges.

WIRELESS COMMUNICATIONS OVER SEA.

By Mr J. Erskine-Murray, D.Sc.

Held as read 17th December, 1907.

Although the principal subject of the present paper is electrical wireless telegraphy, it may be as well to commence with a short survey of marine communications in general, since, owing to a vessel's motion, *all* methods of communicating with it are necessarily "wireless."

In every case some type of wave motion is used as the means of transmitting the signal or message. Sound, which is one of the commonest, and perhaps the simplest form of wave motion, has served since the first dug-out canoe of prehistoric times was launched, and will continue to be of use as long as the human voice exists. That extremely simple instrument, the speaking trumpet or megaphone, renders communication easy up to several hundred yards in moderate weather, and only fails when the sound is drowned by other noises, or when a high wind carries it upwards and backwards, and so prevents it reaching its destination. The siren, though much more powerful than the megaphone, suffers, but in a less degree, from the same disadvantages, and since it is slow in action and occasionally fails and splutters at critical moments, is not of much use for anything but the simplest of signals. One great disadvantage of the whistle or foghorn as a means of indicating the presence of a vessel during thick weather is that, owing to the quality of its tone, the air seems to be filled with sound, and the ear cannot determine whence it comes. A deep note is essential in order that the sound may carry a long distance, but the quality of tone of an ordinary whistle or horn is about the worst that can be used in cases where it is important to distinguish the direction from whence the sound comes. What is wanted is a note rich in the upper harmonics, like the sound of a trumpet or motor horn, and not a pure tone like an organ pipe, to which the modern siren more nearly approximates. Lord Rayleigh has explained the reason for this difference in showing that perception of the direction of a sound is due to a difference in phase of the wave motions at the two ears—a difference which is more marked with the shorter waves of one or two feet in length which correspond to the higher notes, or harmonics, than with those of ten or twenty feet which correspond to the low note of a large siren. Acoustical means could no doubt be devised by which it would be possible to tell, at least on the open sea, the direction of the source of sound, but as far as I am aware this has not yet been done.

While on this subject I may point out a fact in regard to siren signals which does not appear to have been noticed hitherto, and as it is one which may well have contributed to disasters such as the loss of the battleship "Montagu" on Lundy Island, it is worth while going into somewhat carefully. I allude to the not uncommon case in which a large siren is set up immediately below and in front of a cliff. Under these circumstances the waves of sound reflected from the cliff may interfere with those coming direct from the siren, and may somewhat reduce the audibility of the siren over one or more sectors of a circle round it. It is obvious that there are two lines along which the distance travelled by the waves reflected from the cliff is an odd number of half wave lengths more than the direct distance from the siren. The result is that at the instant that a compression is arriving from the siren direct, a rarefaction is arriving from the cliff, and *vice versa*, these cancel one another and produce silence where one would have expected sound. In the case where the source of sound is an odd number of quarter wave lengths from the cliff, the two lines will coalesce and the sound will be fainter in a line at right angles to the cliff than on either side. Exactly similar phenomena have also been observed with other wave motions such as light, though in this case the scale is very different as the wave lengths are so much less. In the case of a vessel running ashore near a fog siren, which ought to have been audible, but which was not heard by anyone on board, it might be advisable to examine carefully by experiment whether the inaudibility may not be due to an interference effect, such as I have described, from the situation of the siren rather than to carelessness or to defects in the siren itself.

Submarine Signalling.

For very many years it has been known that sound travels far more easily in the sea than in the air. The sea, except just at the surface, is quiet and free from turbulence; there are no currents running at more than a very few miles per hour, and vortex motions, which are probably the greatest hindrance to the propagation of sound in air in stormy weather, are extremely rare. In addition, the actual speed of transmission of sound is much greater in water than in air, the values being about 1100 feet per second in air, and 4700 feet per second in water. It is only recently, however, that any considerable advantage has been taken of these most valuable properties of the sea itself. Perhaps the long delay has been on account of the difficulty of satisfactorily conveying the sound from the water to the ear of the listener. Recent experiments have, however, entirely overcome this difficulty, and it is now possible to hear in a telephone on the bridge of a ship the sound of a bell rung under the water from ten to twelve miles off. This system of submarine bell signalling has been much developed during the past few years, and it may be of interest to note that up to last July not less than 294 vessels, chiefly belonging to passenger lines on the North

Atlantic, and 74 light-ships, have been equipped with submarine bells and apparatus for the reception of submarine signals from a distance. Bells which are intended to act as fixed points, by which vessels find their course, are usually made to strike a distinctive number of strokes after the manner of a flashing light. The most of the light-ships fitted are on the eastern coast of the United States, and have thus proved useful to the Cunard and other lines trading to New York and Boston; but there are also four in England, two being in the Mersey, and two in the Thames; five in German waters; and six near the coast of the Netherlands, including the station of the Zeeland Steamship Company which serves their passenger steamers running between Queensborough and Flushing. I have to thank this latter Company for its kindness in supplying me with information on the whole subject.

This method of wireless sound signalling has already proved of great assistance to navigators during foggy weather, and the fact that it is possible by its means to locate the direction of the buoy or light-ship to which the bell is attached, with very considerable accuracy, from a distance of several miles, gives it an advantage over most other signalling systems which will certainly lead to its adoption in the near future in all narrow waters where fog is of frequent occurrence.

SOUNDING BY SOUND.

Some years ago the writer devised a method of sounding by means of the echo from the bottom of the sea, and more recently the matter has been taken up independently by an American inventor. The attainment of satisfactory results depends on the solution of a simple and well-known problem, namely, the measurement of the short interval of time between the moment at which the sound wave is started from the ship and the moment at which it returns as an echo from the bottom. On account of the high velocity of sound in water, the time taken for the echo to return from depths less than

20 or 30 fathoms is so short that it is difficult to register, but for greater depths there is no difficulty on this account. The apparatus would, therefore, not displace the lead line, or Lord Kelvin's sounding machine, except as a very rapid means of taking deep-water soundings such as would often be advantageous on approaching a coast at high speed or in foggy weather.

SIGNALLING BY LIGHT.

Passing by the well-known methods of flag and semaphore signalling, of Colomb's flash-light code, and of rockets and arrangements of lanterns, I may mention the recent developments of photophony, or light-telephony, a system of communication invented by Graham Bell in 1879, but only in recent years brought to the stage of practical utility. Telephone messages have been transmitted by means of a beam of light from a search light to a distance of eight or ten miles, the sender's voice being heard with perfect clearness. The system, however, suffers from the great disadvantage common to all visible signals, whether lighthouses or more complex arrangements, that they become useless during foggy weather and in snowstorms. It is somewhat strange that mariners should have had to depend for so long on a type of signal which is bound to fail just at the moment when its aid is most needed. The explanation is, of course, that up till recent years mechanical and electrical apparatus were too much of a mystery, and required expert handling. This is now no longer the case, and means of signalling more certain in themselves than the older methods, though demanding a small modicum of technical knowledge and manipulative skill, are rapidly being added to the time honoured methods, and will, to a certain extent, displace them in the future.

ELECTRIC WIRELESS TELEGRAPHY.

I shall not attempt a technical description of the apparatus used in any system of wireless telegraphy, but shall confine myself to its application to nautical purposes and to the general principles which define its scope, and the advantages and disadvantages of the various systems at present in use.

In order to indicate the magnitude of the wireless telegraph system of communications throughout the world, I have collected the following data from various Government and other reports on the subject.*

Total number of wireless telegraph stations 1550, which may be classified as follows:—

Commercial land stations, - -	195
Merchant vessels, - - - -	170
Lighthouses, &c. (Government stations)	150
Naval installations, - - - -	670
Military portable installations, - -	55
Experimental stations, - - -	310

These 1550 stations have been erected by the various companies in approximately the following proportions:—

Telefunken, - - -	41 per cent.
Marconi, - - - -	20 ,,
De Forest, - - -	6 ,,
Lodge-Muirhead, - -	3 ,,
Fessenden, - - -	3 ,,
Other systems, - - -	27 ,,

As regards commercial land stations:—

Marconi, - - - -	32 per cent.
Other systems, - -	68 ,,

On merchant vessels:—

Marconi, - - - -	56 per cent.
Other systems, - - -	44 ,,

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* See J. Erskine-Murray in "The Times" Engineering Supplement, 25th September, 1907, and 2nd October, 1907.

It is thus obvious that the adoption of the Radiotelegraphic Convention by this country, was a necessary consequence of the refusal of the Marconi Companies to allow their stations to intercommunicate with those of other companies, whether on sea or land. If the Convention had not been adopted, the only result would have been that any user of the Marconi apparatus would be excluded from communication with 80 per cent. of the stations of the world. The actual proportions in different regions are, of course, very various. On the North Atlantic the Marconi Company has a greater hold than elsewhere, though it is very far from having a monopoly, even in the British Islands. In South America, the West and East Indies, and on the Continent of Europe, excepting Italy, the Telefunken, Lodge-Muirhead, and De Forest Companies practically do all the business. It has, therefore, been necessary for shipowners, whose vessels trade in these regions, to adopt a system other than the Marconi.

General Principles of Wireless Telegraphy.

These may be summed up shortly, as follows:—

1. The energy which transmits the signal is propagated over the earth's surface as an electric wave motion.

2. This wave motion, or alternate current, may be either uniform like an ordinary lighting or power current, or it may be in the form of damped wave trains, *i.e.*, in short series of waves following one another at comparatively long intervals; each series or train commencing strongly and dying out after comparatively few waves. In the first case a high frequency alternate current generator, or a vibrating electric arc may be used; in the latter, the intermittent spark discharge of a condenser. Figs. 1 and 2.

3. In both cases it is necessary that the frequency of the current (number of alternations per second) should be high in order that the amount of electricity set in motion at each wave, and, therefore, the actual dimensions of the apparatus.

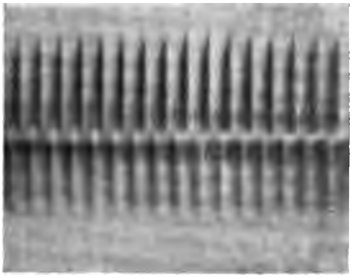

Fig. 1.

Fig. 1. Oscillogram of alternating current generated by Poulsen arc. Frequency 100,000 per second. The positive half oscillations are above ; the negative below.

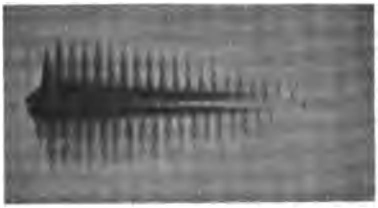

Fig. 2.

Fig. 2. Oscillogram of Spark Discharge of Frequency 180,000 per second, showing gradual decrease or "damping." The lengths of the dark portions correspond to the strength of the current in each half oscillation.

may not be impracticably large. This will be appreciated when it is recollected that a small quantity of electricity, or any material, when moving very rapidly, may transmit a large amount of energy. (A high speed de Laval steam turbine is a good mechanical instance of this). A high frequency is thus advantageous from an engineering point of view, though it is not absolutely necessary.

4. The receiving apparatus must, therefore, be capable of detecting and indicating currents whose frequencies are greater than 100,000 per second. There are now scores, possibly hundreds, of ways in which this may be done. These may be classed as follows:—

(*a*) Imperfect electrical contacts, or coherers, whose resistance is changed by the action of the received current;

(*b*) Electrolytic detectors, which indicate the received currents by an alteration in polarisation;

(*c*) Thermometric detectors which indicate the current through the effects of the change of temperature it causes;

(*d*) Magnetic detectors in which the magnetic state of a piece of magnetised iron is altered by the current;

(*e*) Electromagnetic detectors on the current balance, or electro-dynamometer principle;

(*f*) Valves or rectifiers which, owing to their property of permitting current to pass more easily in one direction than in the other, produce a more or less unidirectional and, therefore, measurable current directly from the alternating current received;

(*g*) A miscellaneous class whose methods of action have not yet been explained.

The best known forms of coherer are (1) the Marconi, Fig. 3, consisting of a glass tube of about 5 millimetres bore in which are two silver plugs about ·5 millimetre apart, between which a small quantity of very fine nickel filings is placed. The gap is usually V-shaped to admit of regulation by merely turning the tube as the filings only occupy about one-third of the space and are, therefore, more or less crowded together according as the wide or narrow end of the V is uppermost. (2) The Lodge-Muirhead, which consists of a razor-edged steel wheel about the diameter of a threepenny bit whose edge dips into mercury covered with oil, and which is kept revolving by clockwork. The Marconi coherer, which by the way is a modified form of Branly tube and is also used by the Telefunken Company, requires to be decohered by tapping or shaking it after it has recorded a signal, as it would otherwise remain cohered. This, though apparently a disadvantage, is in reality the essence of its success, for it is owing to this that it was first possible to maintain the effect of the passage of the high frequency current long enough to obtain from it a permanent record of the Morse tape, by means of ordinary telegraph instruments. The Lodge-Muirhead coherer is decohered after a small fraction of a second by the movement of the wheel.

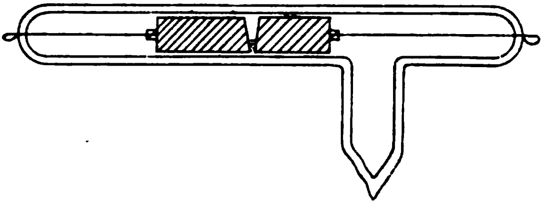

Fig. 3. Marconi's form of coherer.

The other detectors most in use are Marconi's magnetic detector, Fig. 4, and the electrolytic or barreter invented by Fessenden. Magnetic detectors are based on the fact that a high frequency current, even if of very short duration, may produce considerable changes in the magnetism of a fine magnetised iron wire. In Marconi's form an endless band of fine iron wires is kept travelling round two pulleys. Surrounding one of the straight pieces between the pulleys, is a small glass tube on which are wound two coils of fine insulated wire.

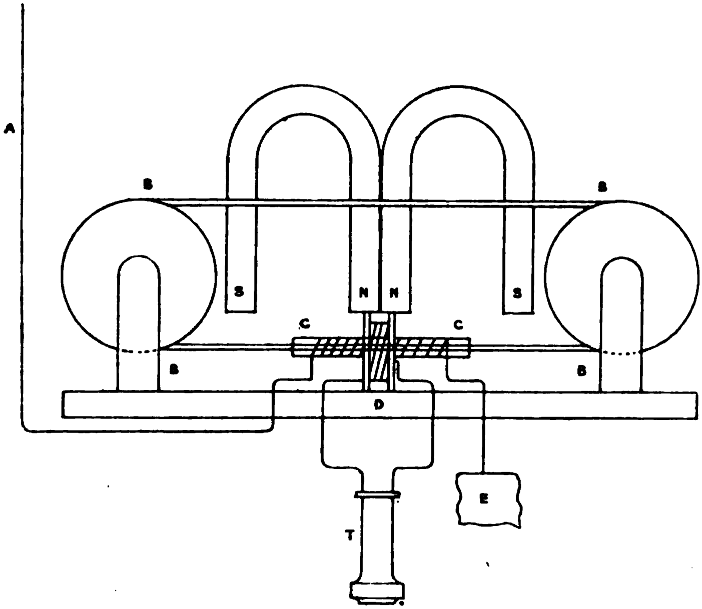

Fig. 4. Marconi's magnetic detector.

A, Aerial Wire ; E, Earth-Plate ; B B, Iron Band round Pulleys ; S N, Permanent Magnets ; C C, Primary Winding on Glass Tube through which the Iron Band travels ; D, Secondary Winding ; T, Telephone Receiver.

One of these is connected to the aerial and earth wires, and the other to a telephone receiver. Two permanent magnets are placed so that their lines of force include part of the travelling iron band in their circuit. The motion of the band draws the lines to one side through the retentiveness of the iron for magnetism. The high frequency current in the aerial wire, on passing through the small coil round the iron band, suddenly demagnetises it, or rather releases the lines of force. These spring back into a position at right angles to the band, and in so doing cut the coil connected to the telephone, induce a current in it, and thus produce an audible click in the instrument. The motion of the band soon draws the lines aside again and renders the apparatus ready to indicate a new signal. The Morse " dash " is, of course, represented, as in all systems of wireless telegraphy, by a close succession of dots.

The electrolytic receiver, or barreter, depends on the fact that if a constant voltage be applied between electrodes dipping into an electrolyte, one of which is of very small area, the current is, under certain conditions, unstable, and the sudden superposition of a high frequency current causes a sudden and considerable increase in the constant current. The action is not yet properly understood, though many theories have been stated. A telephone is generally used in connection with this detector which is one of the most sensitive of all.

It is noticeable that in the above list of detectors of high frequency currents there are very few, if any, which give directly an audible or visible indication of the signal. In practically every case it is thus necessary to have some auxiliary instrument to indicate to the operator that the detector has reacted. In some cases a telephone, syphon recorder, or Morse inker, may be used at will, in others the telephone is the only auxiliary suitable, and it is, therefore, not possible to obtain a permanent visible record of a message.

5. The waves are propagated outward from the transmitting station, either equally in all directions, or with a maximum in one direction according as the aerial wire is vertical or inclined. In the latter case the strongest transmission is in the direction of the lower end of the wire. This method is used at Clifden and Glace Bay, Marconi's transatlantic stations, and at Knockroe, the Poulsen transatlantic station now building.

The lines of electric force are in general attached to the ground and follow it, as they do a wire in ordinary linear conduction. The resistance and dielectric constant of the ground are important factors in determining the distance to which it is possible to signal with any given transmitter and receiver. In general the dielectric constant is the more important of the two, and the chief reason why it is more easy to transmit signals over water than land is that the dielectric constant of water is 80, while for dry sand or rock it is only about 5. Thus it is possible to transmit signals very much further over water with a given power than over land. The actual ratio of the distances is now calculable approximately in cases where the natures of the soil and subsoil are known.

6. It is now easy to determine with considerable accuracy, in fact within a few degrees, the direction from which a message is coming—a discovery which may in the near future become a great aid to navigation, since any two land stations within range of a ship will be able, by making simultaneous observations, to give their bearings, and thus to fix the actual position of the vessel. In these days of ever increasing speeds it is becoming more and more essential that the shipmaster should be warned, when still a considerable distance away, of his approach to land. This has been done for some years by wireless telegraphy, but it is only recently that it has become possible to add to the warning, a statement of the actual position of the ship at the time of sending.

7. The speed of transmission at moderate distances, and the reliability of a wireless connection, are now both as good as the same qualities in an ordinary land wire. A proof is given by the abolition of the Post Office wire from Hunstanton to Skegness, since wireless stations have been erected, and the fact that a speed of 90 words per minute has been attained between these stations.

8. The means of preventing interference between neighbouring stations have been developed to such good effect in

the last few years that it is now possible, as experience shows, to construct apparatus which will respond only to waves which do not differ by more than about 4 per cent. from the proper wave length for the station. An even greater sharpness in tuning has indeed been claimed by various workers, and may very probably have been obtained. A margin of 4 per cent. is, however, sufficient to render possible the efficient working of a very large number of stations in a comparatively small area without interference. The actual wave lengths to be used by ships and shore stations have been fixed in some countries; and in all which are parties to the International Convention, the wave lengths from 600 to 1600 metres are reserved for naval purposes; wave lengths below 600 metres being available for short distance stations, and those above 1600 metres for long range stations. The usual wave length for short distance stations (*i.e.*, under 100 miles range) is about 400 metres. The German long distance station at Nauen uses wave lengths of 2000 metres, Poldhu (Marconi) of about 2500 metres, and Clifden of about 4300 metres.

60 words per minute.

110 words per minute.

Fig. 5. High speed records taken by Poulsen system.

THE DISTRIBUTION OF WIRELESS TELEGRAPH STATIONS.

Having given a rough sketch of the present technical position of wireless telegraphy, it may be interesting to note the actual distribution of wireless stations on the surface of the globe. It is obvious that space does not permit an exact description, or even a mention of a tithe of the 1550 stations previously mentioned. I shall, therefore, content myself with merely touching on a few of the more important, and in particular with those in the British Islands. The appended Table thus makes no pretentions to completeness, but gives an idea of the ranges and types of stations which are now doing commercial, national, or experimental work throughout the world.

WIRELESS TELEPHONY.

As, in the bridging of the Atlantic, wireless telegraphy takes its place this year as a factor in the long distance communication of the world, one is suddenly made aware that a new agent has emerged from the darkness of the "experimental stage," and has arrived for good. The United States Navy has ordered twenty-eight sets of wireless telephones for use in communicating between warships. To those who have followed the experimental work which has been going on during the last eight years, this development is not a matter of surprise, but merely a logical consequence, and now that the apparatus has reached so reliable a state that it is deemed suitable for use in warfare, it is practically certain that wireless telephony will make such rapid strides that, within the next five years, the development will be as great as that of wireless telegraphy in the last decade. In fact, this country will, in 1912, be within measurable distance of opening up direct telephonic communication with every important city on the surface of the globe.

Fig. 6 shows the actual apparatus used in telephoning wirelessly, between Berlin and Copenhagen. On the right is the arc lamp with transverse magnetic field enclosed in hydrogen; next it come the helix and variable condenser forming the main oscillating circuit. In the centre are the microphones and mouthpiece, also the aerial and earth connections. On the left are variable condensers used to tune the aerial circuit.

Fig. 7 shows a receiving station. The aerial and earth wires are visible in the centre on the wall; they are connected to an oscillating circuit containing a condenser and helix. The secondary receiving circuit containing the detector and telephone receiver is on the table.

TABLE I.

Showing Maritime Wireless Telegraph Stations in the British Islands which are open for commercial communication.

Note.—There are in addition a considerable number of Admiralty coast stations, and a large number of inland stations. Also about 80 passenger vessels, and some hundreds of naval vessels.

The letters M, L-M, F, P, R-T, D. Me, denote Marconi, Lodge-Muirhead, Fessenden, Poulsen, Rochfort-Tissot, De Forest, and Maskelyne.

The ranges given are ordinary working distances, not *maxima*.

SCOTLAND. *Commercial.*	Range in miles.	System.	Owner.	Remarks.
Butt of Lewis	80	M	Lloyd's	Ship signalling & telegraphy.
Dunnet Head	80	M	Lloyd's	ditto.
Flannan Isles	80	M	Lloyd's	ditto.
Peterhead	80	M	Lloyd's	ditto.
Lochboisdale	80	M	G.P.O.	Postal Telegraph.
Tobermory	80	M	G.P.O.	ditto.
Machrihanish	3002	F	F.	Under repair, communicates with Brant Rock, Mass., U.S.A.

IRELAND. *Commercial.*	Range in miles.	System.	Owner.	Remarks.
Browhead	180	M	Lloyd's	
Clifden	2500	M	Marconi	Communicates with Glace Bay, Newfoundland.

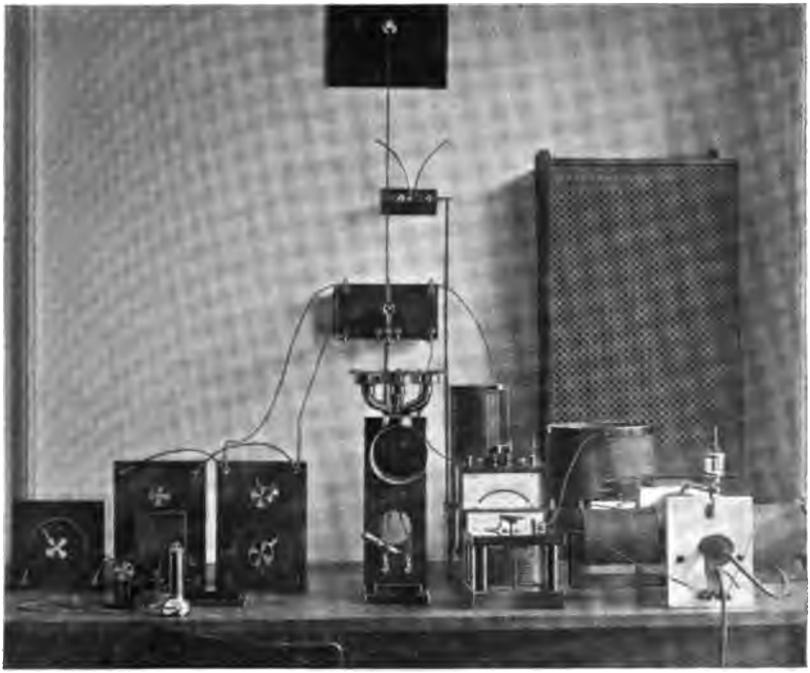

Fig. 6.

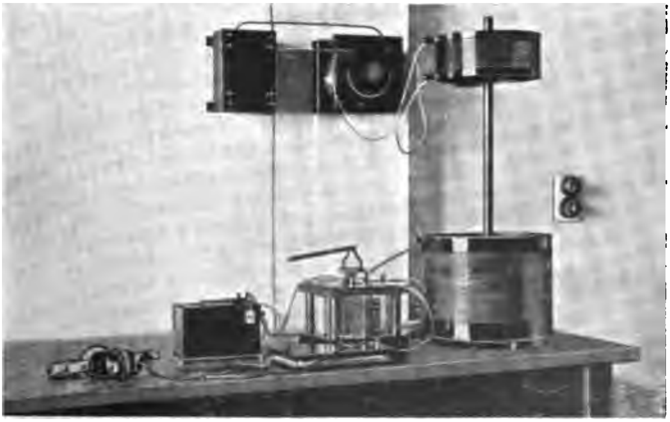

Fig. 7.

IRELAND *Commercial.*	**Range in miles.**	**System.**	**Owner.**	**Remarks.**
Fastnet	30	M	Lloyd's	
Inishtrahull	80	M	Lloyd's	
Malin Head	80	M	Lloyd's	
Rosslare	80	M	Lloyd's	
(Knockroe)	3000	P	Amal. Radiotel Co.	Building; for transatlantic work.

ENGLAND. *Commercial.*	**Range in miles.**	**System.**	**Owner.**	**Remarks.**
Heysham	100	L-M	Midland, Ry.	Communicates with Belfast steamers.
Newhaven	100	R-T	L.B.S.C. Ry.	With Cross Channel steamers.
Porthcurno	50	Me	Eastern Tel. Co.	To Cable Ships.
Hunstanton	50	D	G.P.O.	Postal Telegraph.
Skegness	50	D	G.P.O.	ditto.
Poldhu	2000	M	Marconi	Communicates with Atlantic liners.
Lizard	80	M	Lloyd's	
Niton	80	M	Lloyd's	
North Foreland	80	M	Lloyd's	
Cullercoats	650	P	Amal. Radiotelegraph Co.	Communicates with Lyngby and Esbjerg in Denmark and with ships.
LIGHT-SHIPS, &c.				
Caister	80	M		Communicates with Cross Sand Light-ship.
Cross Sand	40	M	Trinity House	These Light-ships are in communication with Admiralty and other stations not shown in the Table.

ENGLAND. (Commercial)	Range in miles.	System.	Owner.	Remarks.
Goodwin Sands	40	M	Trinity House	ditto.
Gull Light-ship	40	M	Trinity House	ditto.
Sunk Light-ship	40	M	Trinity House	ditto.
Tongue Light-ship	40	M	Trinity House	ditto.

It is thus obvious that a vessel fitted with wireless apparatus is practically never out of range of a commercial wireless telegraph station as long as it is within 60 or 70 miles of any part of the coast of the British Islands.

The same is true of Europe, of the eastern coast of North America from Labrador to Florida, and for the whole Gulf of Mexico and the West Indies. There are six or seven stations at various points along the east coast of South America, and ten or a dozen stations at points on the Pacific coast of South and North America.

On the route to India and the East, there are points of communications after leaving the Channel which simply bristle with stations, at Ushant, Corunna, all round the Mediterranean including even Tripoli, Tunis and Algeria; Port Said, Port Tewfik, Saugor Island (India), Diamond Island (Burma), the Andaman Islands, the Philippines, Tsingtau (China), the Japanese coast, the Sandwich Islands, and Samoa.

In addition to these stations which are open for commercial work, there are, of course, many more which are intended for naval and light-house communications only, but which would be available in case of emergency to any vessel in distress.

Discussion.

The AUTHOR exhibited a series of lantern slides, and conducted a few experiments to show how wireless transmission took place, and said there was practically no doubt whatever, now, that electric currents alternating very rapidly, as the electric currents used in wireless transmission usually did, were guided by a conductor. The earth was the conductor, and although in the first instance the currents might not be directly conducted by it, if they started without an earth connection, before the electric waves had gone a comparatively short distance, the ends of the lines of force had become attached to the earth and continued so as they moved along. That was also the system of transmission in the ordinary electric telegraph where the lines of force ran along a wire. There was no doubt whatever that the lines of force ran along the wire, and though near the station where they started they were somewhat curved, as they got further away they became practically straight lines. In the case of wireless telegraphy the lines of force also started as curves. With free radiation no one had ever telegraphed more than a mile-and-a-half, and it was with those radiations which were attached to the earth or the sea that long distance messages were obtained, and in this way that when the electric waves came to a wire standing up they ran up the wire and down again, and in doing so they had to pass through an instrument which was purposely put there. The difference between wireless and wire telegraphy was, that since radiation went out over the whole earth's surface from the centre from which the message was sent, a very large power must be used since, at the circumference of a big circle, say, 100 or 1000 miles in diameter, the receiver would take out only a very small fraction of the total energy transmitted from the centre. In an ordinary wireless station one might calculate that for a 50-mile station each spark would momentarily radiate at the rate of about 200 horse power, but, as the interval between successive sparks was very long in comparison with the duration of a spark, in reality only about 50 or 60 watts were being used, and that was a very small fraction—less than one-tenth—of a horse power. If, instead of the spark, which lasted only a very

Dr. Erskine-Murray.

short time, there was a uniform alternating current of very high frequency, it was necessary to use an integrating receiver, one which gradually stored the wave energy received until the current in it was sufficiently large to be detected. Mr Poulsen was the chief engineer of a company which was making a system which gave out alternating currents of about 100,000 cycles per second. In that system a comparatively small voltage was used in the transmitter, and there was a little automatic arrangement which allowed a swing to get up in the receiver, and switched it on to the actual receiver intermittently. That was, roughly, the general principle. There were several methods of producing high frequency currents of more than 50,000 cycles per second, the chief being the unstable arc and the high frequency alternator. A small quantity of electricity, if moving to and fro very rapidly, would transmit a large quantity of energy. About 95 per cent. of the stations in existence used the ordinary spark method, because it needed a less expensive outfit, which was more handy to carry about and easier to work than that for the production of continuous waves. The receiver had a wire collecting the waves which then passed through an apparatus affected by high frequency currents, the presence of which it might indicate by change of resistance. There was also a wire to the earth, or a large piece of metal in contact with the earth. There were several kinds of apparatus which would make a change in the detector apparent. Anything happening in the detector could not be seen, but if the resistance were changed it could easily be ascertained by electrical means. Instead of a telephone, a syphon recorder or an ordinary Morse printer could sometimes be used. That had been done with great success by Marconi. Recently there had been invented a recording instrument, suitable for wireless telegraphy, which would record over one hundred words per minute. Speed was increasing very much in wireless telegraphy, and working was now very

Mr R. T. Napier.

nearly as fast as the highest speeds possible on a land line. The United States Navy had recently been fitted up with twenty-eight sets of wireless telephones.

Mr R. T. Napier (Member) desired to know what the possibilities were of securing secrecy when wireless telegraphy was used. As explained by the Author, the one condition that ensured a message being received lay in the transmitting and receiving instruments being adjusted to suit the same number of vibrations per second. It would seem, to an outsider, to follow from this that any capable telegraphist could get together a series of receiving instruments covering a considerable range of variation in vibrations, and so be in a position to get all the messages that were in transit.

Mr Charles R. Gibson (Glasgow) said that on looking at the interesting statistics which Dr. Erskine-Murray had compiled, he was sure that it must be most gratifying to all to find such a large number of experimental stations at work, there being no less than 310 in operation. This involved a great outlay of capital with no hope of immediate return. It not only showed the confidence that was placed in wireless telegraphy, but it practically guaranteed the best possible progress. Things had fortunately changed since the early days of ocean cable telegraphy when Mr T. R. Crampton, in 1850, endeavoured to raise a sum of £15,000 to lay a cable across the English Channel, and only succeeded in doing so by subscribing one-half of the required amount out of his own private purse. One was often amused to find that, even at the present time, many intelligent people looked upon wireless telegraphy as a scientific toy. Thirty years ago, when the late Lord Kelvin introduced the electric telephone to a Glasgow audience, the invention was looked upon as nothing more than a scientific toy, and at that time it was little else. The position of wireless telegraphy was, however, very different to-day; a very great deal had been successfully accomplished. Possibly the reason why some people found it difficult to grasp the fact that

Mr Charles R. Gibson.

wireless telegraphy had come to stay was, that the medium of transmission seemed to them so mythical—a sort of mathematical fiction. But they should remember that it was the same medium upon which their existence depended—the carrier of energy from the sun to this planet. It should also be remembered that this ether was the medium by which ordinary telegraph messages were transmitted, the function of the wire merely being that of a guide to the ether disturbance. In connection with those systems which used the telephone as an auxiliary to the detector, Dr. Erskine-Murray had said that it was, unfortunately, impossible to permanently record such messages. At the moment he did not see why this should be impossible. If the telephone diaphragm were removed and a mild steel wire were drawn across, lightly touching, the electro-magnet of the receiver, it had been found possible to record sound. The wire took on, as it were, spots of magnetisation and retained these. When the wire was again drawn across the electro-magnet of a complete telephone receiver, the spots of magnetisation set the diaphragm vibrating as it would have done had it been directly acted upon by the original sound. The sound which had been received in silence by the telephone, had been magnetically recorded, was reproduced, and could be again repeated at will. The wire retained the message permanently unless it was purposely destroyed by magnetic or other influences. This principle had been embodied in an instrument known as the telegraphone and used on an ordinary telephone circuit, and as it was capable of recording and reproducing ordinary speech, it should be a much lighter task to record and reproduce the simple Morse clicks received by a wireless detector. He was interested to see from the detailed list at the end of the Author's paper that the Skegness station, which was able to transmit wireless messages at a rate of ninety words per minute, was worked on the De Forest system. From correspondence which he (Mr Gibson) had with De Forest in the early part of 1905, it was clear that he had then

Mr Charles R. Gibson.

no great hope of attaining high speed transmission—at least on a commercial basis. At that time he considered this attainment as " very problematical." It was, therefore, interesting to see that his system was well to the front in the accomplishment of high speed. This also indicated the rapid strides which wireless telegraphy had made. There were many questions one would like to ask in connection with wireless telephony; it was a subject upon which it was difficult to get much information in the English language, but he was interested to learn that Dr. Erskine-Murray had written a translation of Ruhmer's book on " Wireless Telephony," so that the first English book on this subject would come to hand very shortly. Referring to the wireless telephones taken up by the United States Navy, he would like to know if these instruments were selective, or was a preliminary signal sent to indicate which ship was to be called upon to receive a message? The Author's prophecy of the immediate future of wireless telephony seemed to him a very bold one, but Dr. Erskine-Murray was better able to judge of the practical side of the question than he was.

Mr A. CLEGHORN (Vice-President) said that the Members of the Institution were much indebted to Dr. Erskine-Murray for coming from London to be present that evening. He had dealt in a most interesting manner with a very abstruse subject, and he was sure all had gained new information by his expositions, based as they were upon practical experience. To all " who go down to the sea in ships," wireless telegraphy was of the greatest importance, as it afforded opportunity of communicating over sea with the land or with other vessels. Mr Napier had asked a question about the privacy of wireless messages. He supposed most of them were aware that from certain Marconi stations situated in Britain and on the Continent, wireless messages were sent out at a known hour, so that all ships fitted up with the Marconi apparatus and travelling within the radius of influence could pick them up. The operator at the receiving instrument had only to await the hour and pick up the messages by means of the telephone receiver, and in less than half-an-hour afterwards they were printed in the ship's newspaper of the day, and distributed amongst the passengers. By this means, and by the aid of vessels nearer land, in turn transmitting the messages still further outwards, news from land could always be had on board ships traversing many of the ocean highways. In the case of two large turbine vessels which his company had recently constructed to carry passengers between Marseilles and Alexandria, passengers would never be beyond communication from land by means of wireless telegraphy, and would be kept continually informed, by means of the ship's daily newspapers printed on board, of what was going on in the principal bourses and capitals of Europe. When tuning up and testing these instruments in the Fairfield Dock, they frequently trapped what the "Lusitania" and other boats were saying when nearing Queenstown harbour. There were great possibilities in this modern invention of wireless communication over sea.

Dr. ERSKINE-MURRAY, in reply, said that on the subject of privacy it must be remembered that, in one way, it was much more easy to tap land wires than to tap wireless telegraphy, because they knew where the wire was. Between Glasgow and Edinburgh there was a wire along the high road, and one might go on a dark night and throw a wire over this wire, and, by connecting it to a telephone receiver, hear everything that was transmitted. There was no privacy to be had in mere geometric considerations. With the wire telegraph the message was limited to a line, but with the wireless telegraph it was limited to a plain surface. No doubt the plain surface was larger than a wire, but if one saw a wire one knew that there must be messages, while the mere appearance of the earth would give no clue to the presence of wireless messages. In time of war it would be a simple matter for a ship to get the enemy's messages if no special provision were made to prevent it. With operators who were not extremely expert electricians, it was an advantage that the apparatus should not be so exactly adjusted that there would be a chance of the receiver missing a message by the merest hair's breadth, say, through the alteration of capacity caused by a sea wave breaking against the wire. It was not advantageous to tune very exactly for sea work at all. In the case of a fleet getting signs of messages from the enemy, probably an effort would be made to read them, but if the code was not available then the messages could not be read. If the commander of a ship in a fleet discovered that somebody else was in his neighbourhood, if he had any sense at all, he would alter the wave length of his transmitter and his receiving instrument according to a pre-arranged scale; he might alter it 5 per cent. every minute, and he might go jumping up and down the scale. The enemy might guess that the wave-length was being altered, and might change his wave-length and try to get messages, but suddenly he would be cut off at the end of the minute. All these things were perfectly simple, being merely matters of arrangement. Another point was that ordinary telegraphy required only a telephone to hear the message, but wireless telegraphy required a very much more complicated apparatus. As to the telegraphone, mentioned by Mr Gibson, if one had sufficient energy one could get a record on the wire, but he might point out that the record was still a magnetic record, and he was not certain if one could translate it into a visible record. Possibly one might do so by hanging filings on the wire, but he did not think that that was sufficiently exact. Some kind of record might be obtained, but it was still a magnetic record and not a visible record. A visible record was useful at high speeds, because, though it might be read, and written down up to 35 words a minute, that was impossible at 90 words per minute, which had been done wirelessly between Hunstanton and Skegness by the Post Office, with a syphon recorder which made a readable trace on the tape. As to the naval telephones, he thought that, as used by the United States Navy at present, they were not selective, because, in naval telephony, the Admiral very frequently wanted to speak to all the ships at one time for combined evolutions, so that each vessel might know what the other was doing, otherwise he could call any desired ship by name before transmitting the order.

Mr ALEXANDER CLEGHORN (Chairman) said he had great pleasure in asking members of the Institution to award Dr. Erskine-Murray a hearty vote of thanks for his interesting paper, and for coming from London to be present that evening in order to show his diagrams and give a personal explanation of them.

The vote of thanks was carried by acclamation.

Correspondence.

Mr JAMES CALDWELL (Member) remarked that Dr. Murray had presented a most interesting and instructive paper, being chiefly a description of the different methods adopted for signalling at sea with special reference to wireless telegraphy. His former important position with Marconi entitled his views on matters pertaining to wireless telegraphy to be highly respected, and he would recommend the perusal of the Author's recently published book to all those interested in the various sensitive sending and receiving devices in use, as they were there discussed both as regarded their practical performance and their scientific basis. Referring to the section of the paper dealing with submarine signalling by sound, this expeditious and simple method, although already used on about 400 vessels and light-ships, might with advantage be utilised in the future to a much greater extent. Experiments in submarine signalling were performed in 1826, when it was ascertained that the speed of sound in water was about four times as great as in air, besides being retarded less by currents. A bell was then suspended 1 metre below the surface of Lake

Mr James Caldwell.

Geneva and struck with a hammer, the sound being distinctly heard 9 miles distant. Dr. Murray mentioned the difficulty experienced in conveying the sound at the receiving point to the ear of the listener, and he (Mr. Caldwell) wished to describe a recent method, due to Mr Gardner, by which this object was attained. The apparatus at the sound-receiving station consisted essentially of a vibrator V, of steel tape shown on Fig. 8, mounted on a ship's side either by one or both ends, and exposed to the arriving sound. This vibrator responded to impulses of the note or its harmonics to which it was tuned, amplified by the vibration of the free part of the strip, the travel being insufficient to break an electrical contact, but sufficient to materially increase the electrical resistance between two carbon contacts on the arrival of a sound of the same pitch as the vibrator. Carbon contacts C¹ and

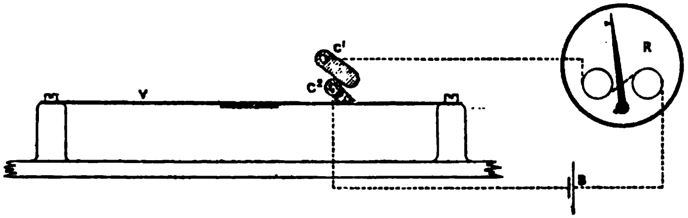

Fig. 8

C², Fig. 8, the former being fixed to the strip and making constant contact with the latter, were connected to a polarised relay of high resistance through which a low voltage current normally passed. When the resistance between C¹ and C² was increased, due to the sympathetic vibration of V, the current through the relay was diminished, so that it was no longer able to retain the armature or pointer, which then swung back and made contact with the opposite contact, thereby closing another circuit that gave warning where required. In place of the relay an ammeter might be substituted, and arranged so that when the current decreased, the index pointer broke the microphone circuit and completed the local circuit by touching a fixed contact on the dial. Differently tuned vibrators, G, E, C, Fig. 9, might be employed to correspond to respective senders, or several might be grouped together in parallel with the same relay or ammeter, so that the local circuit would not be connected, until the resistance of the microphone circuit was sufficiently decreased by the imperfect contact at the vibrators of the combined instruments. By installing apparatus similar to that described, automatic warning could be given on board ship when approaching lighthouses, light-ships, or other vessels, by causing a bell to ring on the bridge or even to blow the whistle and thus warn those in charge. Again, the apparatus might be utilised to set in motion several distinct mechanical operations, controlled at the receiving points, such as an automobile mine or torpedo, where the propeller was started and stopped, the rudder controlled, and the explosive charge fired by appropriate sounds.

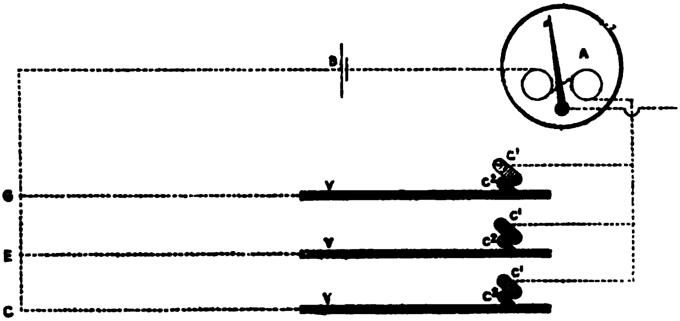

Fig. 9.

Mr. Charles A. Stevenson (Edinburgh) observed that the subject of the Author's communication was a very important one. The modern fog horn for communicating its note of warning to vessels afloat was a siren and megaphone combined, and was perfectly reliable and could be depended on. The megaphone should be made to revolve round a vertical axis so that it could be turned into the "eye of the wind," thus

Mr Charles A. Stevenson.

getting the maximum range possible against wind, the hearing area thus altered its shape from being fan-shaped to being more or less circular, with maximum range possible to windward. The dipping of megaphones had also been found efficient for getting a better range against wind, as the sound did not pass in straight lines as light did, but in lines curving up. The reason for not being able to locate one note as readily as another was primarily that the one was not so powerful as the other. A very delicate sound was very difficult to locate, and in this fact lay the art of ventriloquism where delicate sounds were made. If a high note were equalised in strength with a low. so that they both ceased to be heard, say, at three miles distance, then they were of equal power and the one was just as easy as the other to locate. At least for practical purposes of fog signalling this was so. A short sound, say a 1-second blast, was much more difficult to locate than a long-maintained sound, say a 4-second blast. For the same reason a gun, unless loud and easily heard, was difficult to locate. In the case of the battleship "Montagu," the difficulty was not that the siren at the north end of Lundy Island could not be heard, but that the report of the tonite signal at the south end was not heard. Experience at sea had shown that these tonite signals could not be relied on even for half-a-mile against a very light breeze, whereas a siren could be depended on much further, its range to windward being never curtailed to the same extent as the short report of a gun or tonite signal. It was no fault of the Commander of the "Montagu" that she was lost; the accident was due to having such a signal as a tonite signal with 10-minute intervals. There were no such long intervals of silence in the Scotch signals. The well-known silent areas referred to by the Author occurred sometimes where there were no cliffs. These areas had been nearly entirely removed by the use of the Scotch motor-driven siren. With respect to submarine signalling to vessels which the

Mr Charles A. Stevenson.

Author referred to, trials made by Messrs. Stevenson at Cape Wrath, some years before there was any station or buoy fitted with the system, showed that the sound could be readily conveyed underneath the sea surface and that its range was unaffected by strong tides or waves, but that the vibrations were, unfortuntely for some purposes, cut off by land or shoals. The most important recent advance in signalling, which had just been made by Messrs. Stevenson, was the carrying out of a submarine cable to outlying dangers, and working the sirens or reeds electrically. This novel use of electricity had been accepted by the Harbour authorities of Guernsey to guard most dangerous rocks lying a mile distant off the north end of the Island, known as the Grand Braye and the Platte Fougere. The electric plant on shore would consist of dynamos, etc., and a 3-phase system working induction motors on the rock, which would work the air compressors and siren apparatus. The motors on the rock would start up simultaneously with the starting of the dynamos on shore. This system had also been proposed by Messrs. Stevenson for a position at the approach to Dundee, as well as for another situation on the Forth. With respect to wireless telegraphy itself, the Commissioners of Northern Lighthouses, in conjunction with Lloyd's, have erected signal stations at Butt of Lewis and Flannans. Mr Charles Stevenson, in 1892, telegraphed without wires a distance of ¼ mile by means of induction coils with a number of turns of wire. This adoption of a number of turns of wires was subsequently used by Preece in his experiments to illustrate the induction method, but Marconi came on the scene and developed Lodge's coherer system.

Dr. ERSKINE-MURRAY, in reply, observed that Mr Gardner's invention, described by Mr Caldwell, was a most interesting application of the principle of resonance, or tuning, and showed how by this means it was possible to send independent signals by sound waves which did not interfere with one

Dr. Erskine-Murray.

another. Non-interference with wireless transmission depended on exactly the same principle, the only difference being that electrical vibrators (circuits) were used instead of mechanical ones. Quite recently, Mr Poulsen stated, at a lecture on wireless telephony, in London, that it was possible on his system to work non-interfering stations in the same neighbourhood, although the difference in wave lengths was only one per cent. In regard to Mr Stevenson's most interesting remarks, he might say that his (Dr. Erskine-Murray's) opinion as to the ease with which the direction of sounds of different characters might be located, rested mainly on his own observations, and might possibly be due to the fact that his hearing was unusually acute, and particularly so for very high tones. He found that the deep bass of a large steamship's siren, which was often almost a pure tone without the higher overtones, seemed to fill the air, coming from no direction in particular, while the "pang-pang" of a motor horn, or the stroke of a hammer on steel, gave an instant and unmistakable sense of direction. He did not include any ordinary type of whistle among really high-pitched sounds, as though the fundamental tone might be fairly high, say, 1000 per second, there were hardly any overtones. In the case, however, of a hammer striking steel, or a beating reed pipe, such as a motor horn, the overtones of even 20,000 or 30,000 per second were still quite strong. He would be much interested to hear whether Mr Stevenson had experimented with horns giving different qualities of sound, that was different overtones, as well as with those giving merely different fundamental notes of the same quality. His remarks as to the uncertainty of foghorn signals were based on such observations as the following:—The master of the N.D.L. steamship "Chemnitz," in a report dated 19th March, 1908, stated that, when as far away as ten miles off the East Goodwin light-ship he heard the submarine bell distinctly, as also that of the Sandettie light-ship. The East Goodwin was subsequently passed within

Dr. Erskine-Murray.

about two miles distance, but "on account of the fresh southerly breeze we did not hear the sound of the foghorn." The master of the Cunard liner "Ivernia" also reported that, on one occasion he got the submarine bell signals 45 minutes before hearing the ordinary foghorn on the light-ship outside Boston Harbour. It was clear, therefore, that submarine bells were capable of giving much earlier warning of approach to a danger region than was possible with a horn. The only disadvantage of the bell was that the ship must be fitted with receiving apparatus, but as this was now done for a very small annual charge, proportional to tonnage, commencing with £18 per annum for vessels below 750 tons gross, it could not be said to be a serious obstacle. He was pleased to see Mr Stevenson's condemnation of explosive signals, as they had always appeared to him to be most misleading and unreliable. The reason for this was pointed out in a most interesting article by Lord Rayleigh in the November (1907) number of the *New Quarterly*, on "How we perceive the Direction of Sound."

COST OF POWER PRODUCTION.

By Mr I. V. Robinson, Wh.Sc.

Read 21st January, 1908.

A notable feature of the last few years has been the extensive development of water-power stations in various parts of the world—stations capable of generating up to 100,000 horse power.*

Since the electrical transmission of power through great distances became an accomplished fact, water power has been developed very considerably, and new centres of industry have been formed in the neighbourhood of these new sources of power, and new processes have been placed upon a commercial basis. There are now many manufacturing processes which require as an essential factor for their commercial success a large amount of cheap power. Among these may be mentioned the manufacture of aluminium and calcium carbide, both of which are now being carried out upon a very extensive scale. Another process that requires a large amount of power is the electrical production of steel. The development of water power has rendered possible the manufacture of steel in many districts where ore is available but no coal at hand for smelting purposes.

A process that is likely to see considerable developments within the next few years is the manufacture of nitrogenous manures by the fixation of atmospheric nitrogen. This problem has been attacked by many chemists, and one of the most successful methods in use at the present time is that

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*** M'Call Ferry Power Station of the M'Call Ferry Power Company, of Pennsylvania, U.S.A.**

patented by Messrs Birkeland & Eyde. They started with an experimental laboratory at Vermoen, near Arendal, in Norway. At a later date they established a factory on a commercial basis at Notodden, Norway, and this plant has now been considerably extended. I believe that they propose utilising at Svælgfos some 30,000 horse power for the development of this process. All these manufacturing processes require cheap power as the first essential for their success.

Until the development of water power on a large scale, coal was used almost exclusively for power generation, and all industries naturally located themselves in the neighbourhood of a supply of cheap coal. This neighbourhood was well provided with transport facilities and was naturally the best centre for manufacturing purposes. It will be noticed that coal-mining districts in Great Britain are in every case the most densely-populated portions of the kingdom, with the exception of London. With the development of water power other new centres of industry are being formed. Niagara has rapidly become the centre of many industries, and the same can be said of many of the Italian rivers, such as Pescara, Bormida, etc.

There is one important difference to bear in mind when comparing power obtained from water and from coal. The coal is the result of the action of the sun in remote ages and there is only a certain quantity of this fuel available. The flow of water down rivers and over falls is a direct result of the action of the sun at the present time and will, therefore, go on as long as the action of the sun continues. It might thus be said that in using water for generating power only income is being spent, but in the utilisation of coal there is an encroachment upon capital.

The recent Royal Commission on Coal Supplies stated that there was sufficient coal in sight to last a very considerable period, but it is still of interest to consider what the result would be of the complete working out of the coal fields in

Great Britain. As I have previously pointed out the centre of power becomes the centre of industry, and in that case the industries would naturally be transferred to a district where water power is available. As regards water power, Great Britain is very badly situated and has no falls or rivers from which the power now in use could be generated. There are a few large water-power plants in Great Britain, such as those at the Falls of Foyers, Loch Leven, Snowden, etc., but these are only small when compared with those that have been developed upon the Continent and in the United States. If there were no coal available all engineering industries would cease, as there would be no means of manufacturing iron and steel. Should, therefore, the British coal supply run out, Britain would then be dependent upon other countries for practically all her necessities, and eventually would fall out of the manufacturing world and perhaps become a solely agricultural nation. It is, therefore, a very important matter to economise fuel in every way possible, but any economy will only postpone and cannot avert the time when Britain's coal supply will become exhausted.

Owing to the recent development of the large gas engine, a considerable amount of power can be generated from the waste gases of blast furnaces and coke ovens which are at present being blown into the atmosphere. Of the total output of gas from blast furnaces, a certain proportion is required for heating the stoves and providing the necessary power for use about the furnaces. The amount of gas to spare depends entirely upon the plant that is installed at the furnaces. If there are steam blowing engines and steam is generated in gas-fired boilers there is not much gas to spare, but by the use of gas-driven blowing engines a large amount of surplus power is rendered available. It has been estimated that the blast furnaces of Great Britain could provide power to a total of at least 1,136,000 horse power. From the waste gases of the coke ovens which provide coke for the blast furnaces, a total of 350,000 horse power could be obtained.*

The adoption of the gas engine under these circumstances would, therefore, render available about 1,500,000 horse power in Great Britain.†

As I will endeavour to show later, this power could be generated at a cost that would compare very favourably with water power.

In comparing these two sources of power, account should be taken of the fact that water power is very often in a district remote from transport facilities, and extra expense is incurred in transferring the finished article to the markets. On the other hand blast furnaces are always situated in the middle of a busy district and the manufactured article may actually be made in the market.

I, therefore, propose comparing the cost of power generated by gas and by water, as it appears that for generation of power in large quantities from coal, gas engines will be almost exclusively used. The mechanical difficulties that were experienced with large gas engines have now been overcome, and a large gas engine can be obtained that will run with every satisfaction and reliability.

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* L. Greiner gives the following approximate rule for the amount of power available for external use:—

(a) With blast furnaces, the continuous available horse power is equal to the number of tons of iron made per month.

(b) With bye-product recovery ovens, the continuously available horse power is equal to the number of tons of coke made per week.

Paper read before the Liege Association of Engineers, March, 1907.

† It may be interesting to calculate the cost of the coal that would be saved by the complete utilisation of these waste gases. A consumption of 3 lbs. of coal per B.H.P. per hour is a fair average for all classes of engines. Central power station plant uses about 3 lbs. per kilowatt hour, and engines in old mills, etc., may use as much as 6 lbs. per B.H.P. per hour. With coal at 6s. per ton, the cost of coal per H.P. per year is about £3 10s. 0d., or for the full amount of power £5,250,000. Allowing for a load factor of 25 per cent., the annual cost of coal which might be saved is about £1,312,500.

One point in which the steam turbine has a decided advantage over the gas engine is in the space occupied and the total power of units. Steam turbines may be obtained to give anything up to, say, 12,000 kilowatts in one unit, whereas gas engines cannot be built for a greater output than about 3000-4000 kilowatts. The capital cost of a steam turbine plant is less than the cost of a gas engine plant using producer gas. Where the fuel to be used is either blast furnace or coke oven gas, the gas engine plant costs practically the same as the turbine plant owing to the latter requiring gas-fired boilers, condensing plant, and a much larger cooling tower where a natural supply of water is not available.

Owing to this higher initial cost, producer-gas engines are not more economical than steam-turbine plant in cases where there is a low load factor. I propose dealing chiefly with the question of supplying power for electro-chemical and electro-metallurgical purposes and will confine myself to gas engines, as they are more economical than steam turbines when they are working on a high load factor, such as is obtained in work of this nature.

I will take for purposes of comparison, a power station designed for a continuous output of 20,000 B.H.P. and will estimate its capital cost assuming (1) that waste gas from blast furnaces are available, and (2) that gas producers, and with them ammonia recovery plant, have to be provided. With these capital costs I propose comparing the costs of water-power stations of about the same output. In an estimate of this nature it is impossible to allow, except by including power transmission lines, for the fact that the water-power station may be in a comparatively remote district and that transport of raw material and finished products will be more expensive.

As an up-to-date example of a water-power station, I will give some information of the cost of equipping two stations on the River Aveto in Italy, by the Societa Idroelettrica

Ligure, Milan. This river has its source on the north side of the Ligurian Apennines and is a tributary to the River Po. The Apennines are situated comparatively close to the coast of Genoa Bay and there is, therefore, a rapid fall from them on the south side. On the north side the fall is more gradual, and the water from storage reservoirs in the hills would have to be conveyed a great distance to obtain a reasonable head. To reduce the capital cost, Professor Zunini, of Milan, suggested tunnelling through the hills and placing the power stations on the south of the hills. By this means a rapid fall has been obtained and the expense on pipe lines reduced to a minimum. Owing to the total head available being so great it has been decided to divide the fall between three power stations. The first station will generate 28,000 H.P, with a fall of 1150 feet; the second 17,500 H.P., with a fall of 625 feet; and the third 12,000 H.P., with a fall of 550 feet.

The total cost of the first and second stations is estimated to amount to £640,000, or slightly over £14 per horse power developed. The cost is divided amongst the various items as follows:—

Purchase of land	£80,000
Rebuilding of roads, schools, churches and houses	40,000
Compensating reservoirs, etc.	60,000
Power reservoir and water course, including tunnels, sluices, gates, penstocks, etc.	160,000
Pipe lines	60,000
Masonry for power houses	32,000
Hydraulic machinery	20,000
Electric machinery including switchboards, generators and step-up transformers ...	60,000
Transmission lines	68,000
Step-down transformers and secondary distribution	60,000
	£640,000

It will be noticed that this estimate includes the cost of the transmission line, transformers and distribution system. For a comparison with a gas-power station I consider that the cost of the transmission line and transformers should be included. As the power station has to be built where the water is available, in the comparative cost must be included all expense entailed in bringing the power to the place where it is required. It is not necessary to include the distribution system, as for electro-chemical or electro-metallurgical work this would not be a very large item, such work usually being placed close to the power station or sub-station. I will assume that £40,000 has been allowed for this item, reducing the capital cost to £600,000, or £13 4s. 0d. per H.P. developed.

Owing to the electrical loss in the transmission line the whole of the power generated is not delivered at the consuming point. This loss varies with the length and section of the transmission lines and may be anything from 5 to 20 per cent. for long lines. If it be assumed in this case that the loss is 10 per cent., then the capital cost per H.P. delivered is about £14 13s. 0d.

In a report recently issued by The Mexican Light & Power Co., it is stated that the Company proposes the erection of a second water-power station to contain six units of 8000 H.P. each. The first unit will cost £156,500, this apparently including the building of the complete station, etc., as each additional unit will only cost £52,100. The total cost of the station containing in all 48,000 H.P. will be £417,000, or about £8 14s. 0d. per H.P. developed.

Water power is very abundant in Canada and a Commission was appointed some time ago to report to the Canadian Government regarding the power obtainable in the Province of Ontario, the cost of developing it, the probable market for it, and the price at which it would be supplied. In the reports issued by this Hydro-electric Power Commission full details are given of the cost of developing many large water-power schemes, and, as an example, the Cameron Rapids Development is here cited. The following details are abstracted from the fifth report of the Commission. All prices have been converted from dollars to pounds ($4·85 = £1).

It is estimated that the Cameron Rapids are capable of developing 16,350 H.P., and that the bulk of this power would be transmitted to Port Arthur and Port William, 75 miles away. The Commission's chief engineer reports as follows regarding the scheme:—

> "The power is situated on the Nepigon River about 14 miles north of Nepigon Station. The very considerable importance of this power is due to the fact that it is within transmission distance of Port Arthur and Port William, and that it is available for the development of the extensive pulpwood areas of the Nepigon watershed. In addition to this, the remarkably favourable topographical condition in the neighbourhood of the power site and the magnificent storage facilities offered by Lake Nepigon, with its 1500 square miles of area, which would obviate all necessity for artificial regulation for some time to come, combine to make this a most attractive proposition from an engineering standpoint."

The estimates are based on information collected by the Commission's engineers and on such other information as was available and known to be authentic.

In estimating the total working costs the Commission has allowed for the renewal of the so-called permanent works, such as dam, headworks, power house, etc., in 40 years, and of the transmission and transformation plant in 15 to 30 years. Interest on capital has been allowed for at 4 per cent.

The capital cost of the complete generating station, including all the headworks, etc., is estimated to be £168,300, or £10 6s. 0d. per H.P. developed.

The transmission line is estimated to cost £1145 per mile, made up as follows:—

Equipment	£933
Right of way protection	21
Engineering and contingencies	191
	£1145

Total capital cost of 75 miles, £85,800

Owing to the transmission-line resistance, there will be a loss of 1900 H.P. or 11·6 per cent. The cost of the transformation station is also given, but this will not be taken into account.

The estimated annual generating and transmission expenses for the Cameron Rapids scheme are given as follows:—

Wages, labour, etc.	£3380
Maintenance and repairs	3575
Replacement fund	3450
Administration	1000
Interest at 4 per cent.	6715
Total generating expenses	£18,120

Power generated = 16,350 H.P.

Generating expenses per H.P. per year = £1 2s. 3d.

TRANSMISSION EXPENSES PER MILE.

	£	s.	d.
Interest, maintenance, repairs, and replacement fund	£63	0	0
Right of way protection	1	2	6
Engineering and contingencies	12	17	6
	£77	0	0
Total capital charges for 75 miles ...	5765	0	0
Patrol of line	465	0	0
Total transmission expenses ...	£6230	0	0

Power transmitted = 14,450 H.P.

Total generating and transmission expenses = £24,350.

Generating and transmission expenses per H.P. per year = £1 13s. 8d.

In the above estimate interest is allowed at 4 per cent. In the gas-engine estimate the interest allowed is 5 per cent. With the higher rate the above estimates become as follows:—

Generating expenses per H.P. per year =	£1	4	3
Do. and transmission expenses per H.P. per year =	1	17	3

Some remarkable figures have been recently published by Professor S. P. Thomson regarding the cost of water power used at Notodden for the Birkeland & Eyde nitrogen-fixation process. He states that the total costs per unit are ·025d. and that they will be ·0151d. at the new power station at Svælgfos. The figures are equivalent to 13s. 7d. and 8s. 3d. per H.P. per year respectively. No information is given as to whether this includes replacement-fund charges, interest on capital, etc.

Various estimates of the cost of water power have been made, and the capital cost, and cost per horse power per year for a number of schemes are given in the following tables:—

(See Appendix for Table of Capital Cost of Hydro-Electric Schemes.)

TOTAL COST PER HORSE POWER PER YEAR.

Situation.	Price.			Remarks.
Svælgfos, Norway	£0	8	3	No transmission costs included. No information regarding capital charges, etc.
Notodden, Norway	0	13	7	No transmission costs included. No information regarding capital charges, etc.

Situation.	Price.			Remarks.
Cameron Rapids, Ontario ...	£1	2	3	Total generating costs. Interest 4 per cent.
Do. do.	1	4	3	Total generating costs. Interest 5 per cent.
Do. do.	1	13	8	Total generating and transmission costs. Interest 4 per cent.
Do. do.	1	17	3	Total generating and transmission costs. Interest 5 per cent.
Toronto, Canada	2	17	9	Hydro-electric Power Commission's offer delivered to Corporation's boundary from Niagara.
Horahora Rapids, New Zealand ...	3	0	0	Proposal of Waihi Gold Mining Co.
Montreal, Canada	3	3	0	Average price obtained by Shawinigan Water & Power Co. for 19,000 H.P. delivered in Island of Montreal.
Montreal, Canada	3	18	6	Montreal firm's contract with Shawinigan Water & Power Co. for 3250 H.P.
El Oro Gold Mines, Mexico ...	10	0	0	Purchase price of power transmitted 76 miles from Nexaca Station of Mexico Light & Power Company.

EQUIPMENT OF GAS-ENGINE POWER STATION.

Size of Unit.—Engines capable of developing 4000 B.H.P. as a normal load and 5000 B.H.P. as a maximum load have recently been set to work in America. It is stated that the Californian Gas & Electric Corporation, San Francisco and Oakgate, have two units of this size at work and another in course of erection. The United States Steel Trust have recently placed an order for 36 engines of 4000 B.H.P. capacity each, for their various works (25 for the new Gary Steel Works at Gary, Indiana, 7 for the Carnegie Homestead Works, Pittsburg, and 4 for the South Chicago Works, Illinois Steel Co.). These engines are of the four-cylinder twin-tandem double-acting type, and some are direct-coupled to 25 cycle alternators, the remainder driving blowing cylinders. The cylinders are 42 inches in diameter by 54 inches stroke, and the speed is 83·3 revolutions per minute.

The largest gas-engine cylinder working in Great Britain has a diameter of 1200 millimetres, or about 51¼ inches. The stroke of this engine is 1400 millimetres, or about 55 inches. There are several engines at work now with this size of cylinder, but they are all of the single-cylinder, single-acting type. The larger the cylinder the more difficult is it to make it sufficiently strong. It becomes heavier, more awkward to design, manufacture, and handle, and the cost per H.P. developed would probably increase with larger sizes of cylinders. The double-acting gas engine is now a success and the size of the cylinder is thereby considerably reduced. The latest practice is to have tandem double-acting cylinders even for driving blowing cylinders, as this reduces the maximum force exerted by each explosion.

The tandem double-acting engine runs with sufficient regularity to drive 25-cycle alternators in parallel with a moderate fly-wheel capacity. For driving 50-cycle alternators in parallel it would be advisable to instal twin-tandem engines with the two cranks at right angles. It is quite possible to drive them in parallel (many plants of this nature are at work) with single-crank engines, but a greater fly-wheel capacity is required.

A number of engines have been installed in Great Britain having double-acting cylinders 39½ inches in diameter by 43½ inches stroke (1000 millimetres by 1100 millimetres), and I propose taking engines with this size of cylinder as the unit in the power station. A twin-tandem engine fitted with this size of cylinder would be capable of giving a continuous output of about 2850 B.H.P. when running at 94 revolutions per minute. To ensure being on the safe side, the normal full load will be taken at 2500 B.H.P., and eight engines will be installed for the full load of 20,000 B.H.P. A ninth would be installed as a spare unit, although it should be noticed that seven units running at 2850 B.H.P. would practically give an output of 20,000 B.H.P. With nine engines installed the station really has two spare units.

Figs. 1, 2, 3 and 4 show some modern installations of large gas engines of various make.

Messrs Cockerills' blast-furnace gas-power station is shown in Fig. 1. This station contains two old engines of 700 H.P. each, at the far end, and four more modern engines of 1400 H.P. each. A larger engine is at the present time being built for this station. The estimates of running a gas-engine power station, given later in this paper, are based upon experience obtained with this power station.

In Fig. 2 another installation of Cockerills' engines is shown. These engines have been supplied to the Société de la Providence à Marchienne-au-Pont. At the far end of the engine house are three 600 H.P. blowing engines, and there are also three 1400 H.P. engines direct coupled to electrical generators.

An installation of Nuremberg engines is shown in Fig. 3. This consists of five 1200 B.H.P. tandem double-acting engines each direct coupled to a continuous-current dynamo. These engines use blast-furnace gas and are situated at The Georgsmarien Bergwerks, Huttenverien, Osnabruck.

Another gas engine that has been developed on a large scale is that made by Messrs Erhardt & Sehmer, and an example of this is shown in Fig. 4. The installation consists of a number of 1200 B.H.P. engines of the twin-tandem type, each cylinder being double acting. The engines are situated at the German Government collieries at Heinitz and they are direct coupled to alternating current generators. The fuel available in this case is the waste gas from the bye-product recovery coke-ovens.

Generators.—For many electro-chemical and electro-metallurgical processes continuous current is required, but for the fixation of the atmospheric nitrogen by Birkeland & Eyde's method a large proportion of the power is required as alternating current. Generators of either type would be mounted on the shaft between the two lines of cylinders. If generators of both types were required it would be advisable to install two motor generators, each capable of supplying all the current required for exciting the alternators and working the various small motors about the station. Where all the generators are of the alternating-current type, a small gas engine driving a dynamo should be installed in place of the second motor-generator. When this station is to be started up with all units standing, the small engine would be put to work and would provide the excitation required for the large alternators. After these were running on load, the motor-generator taking high-tension alternating current on one side, could provide the excitation, etc., and the small engine could then be shut down.

Foundations.—The foundations for a gas engine are generally more expensive than those required for a steam turbine. A water-power station requires much more expensive foundations owing to the channels that have to be provided for the passage of the high-pressure inlet water, and also for the escape of the water from the turbo. For a gas engine, it is advisable that the total weight of concrete foundations should be equal to about six times the maximum force exerted on the piston during one explosion. With a two-line engine they should be heavier than this, as the concrete is spread over a larger area than with a single-line engine, and the maximum explosive force is equal to that obtained in a single-line engine with similar cylinders.

Engine House.—Each of the 2500 B.H.P. engines would require a clear ground space of approximately 40 feet wide by 60 feet long. The width is measured over all gear attached to the engine, and the length from the end of the piston-rod rear support to the frame of the generator. Allowing for 10 feet clearance between adjacent engines, and 15 feet at either end of the house, the total length of the house will be about 470 feet. The width should be at least 80 feet. There should be sufficient space between the two lines of cylinders in each engine for the motor-generator, air compressing plant (for starting the engines), jacket-water circulating pumps, etc. The switchboard should be placed upon a gallery from which the whole station might be seen.

The engine house should be a steel structure filled in with brickwork between the columns. As far as possible it should be built so as to exclude dust.

Gas-Cleaning Plant.—Gas-cleaning plant for blast-furnace gas varies according to the fuel used in the furnace. In Scotland where bituminous coal is the chief fuel, there is a lot of tar remaining in the gas after it has passed through the bye-product plant. This tar has been successfully removed by a cleaner introduced by The Summerlee Iron Company. The gas is made to pass through a number of narrow orifices and to impinge upon an inclined surface when moving at a high velocity. The heavier tar adheres to the surface and runs down to an inclined tray, from which it is removed at intervals.

In the Summerlee cleaner, the gas is drawn through the orifices by the suction of the gas cylinder when the engine drives a blowing cylinder. The gas reaches the cylinder under a vacuum of from 6 inches to 12 inches water gauge according to the atmospheric conditions. For electric power gas engines, it is advisable to force the gas through the cleaner by a centrifugal fan, to avoid any variation in the suction pressure and to ensure a more regular speed.

Where coke is used as the fuel in the blast furnace, there is no tar and the chief trouble is dust. The Theisen gas cleaner has proved successful in removing dust, and consists of a motor-driven cylindrical drum fitted with projecting vanes. Water and gas enter the annular space round the drum at opposite ends, and the water removes the dust. The gas then passes into a vapour-separating chamber and is thoroughly dried. During a three months' test with a Theisen cleaner, the quantity of dust contained by the emerging gas varied from ·0019 to ·0043 grammes per cubic metre, *i.e.*, ·0019 to ·0043 ozs. per 1000 cubic feet—about half a litre of water was used per cubic metre of gas, or about 6¼ gallons per 1000 cubic feet.

A Theisen cleaner is shown in Fig. 5, the gas inlet being on the left, and the driving motor, gas outlet, and vapour separating chamber on the right. Fig. 6 shows sectional views of this cleaner from which its action may be understood.

Other forms of gas-cleaning apparatus have been developed by Mr B. H. Thwaites—the pioneer in Great Britain of the use of blast-furnace gas in internal combustion engines—the Power Gas Corporation, Mason's Gas Power Co., Zchocke, Sahlin and others.

CAPITAL COST OF 20,000 B.H.P. GAS-ENGINE POWER STATION USING BLAST-FURNACE GAS.

The approximate total cost of the complete power station is given in the following table. The cost of the various items per B.H.P. is compared with an estimate given by M. Leon Greiner in his paper previously mentioned. M. Greiner's total cost per B.H.P. is not divided into similar sub-divisions to those adopted here, but the total per B.H.P. is practically equal in both cases.

Fig. 1.

Fig. 2.

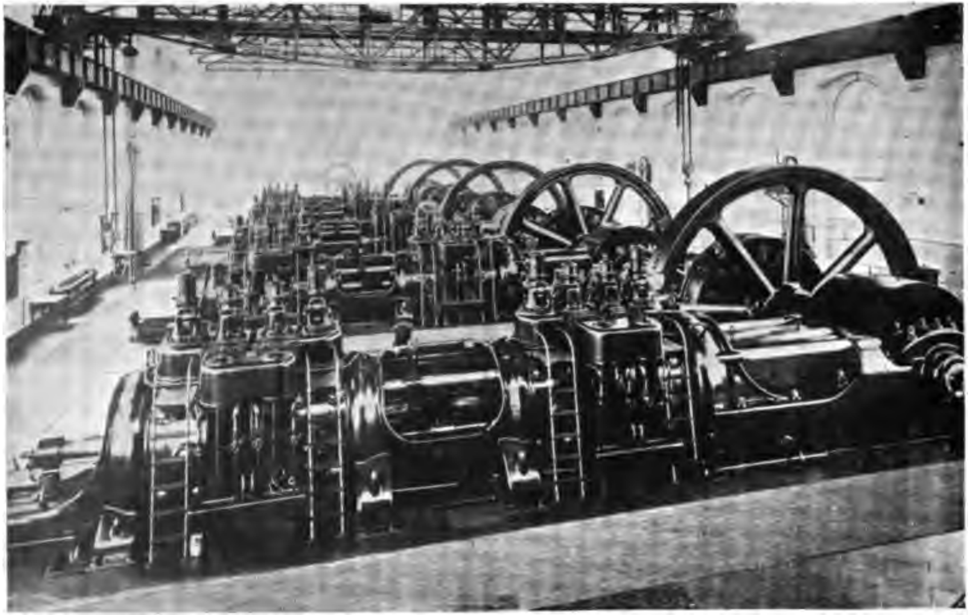


Fig. 3.

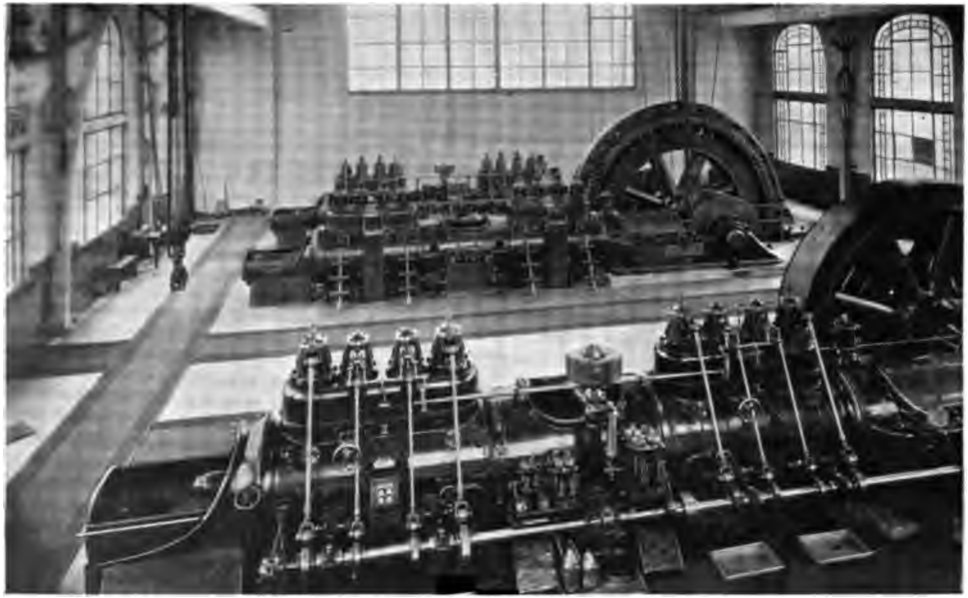
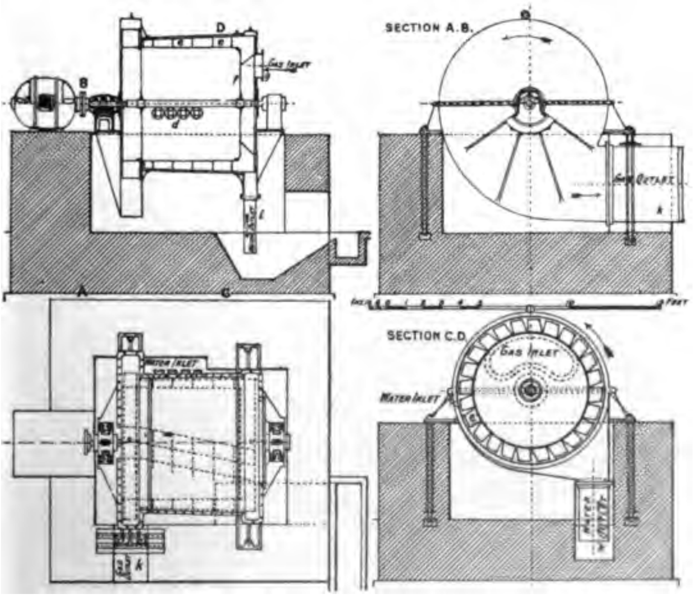


Fig. 4.

Fig. 5.


D
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SECTION A.B.
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GAS OUTLET
k
FEET
SECTION C.D.
GAS INLET
WATER INLET
WATER INLET
k

Fig. 6.

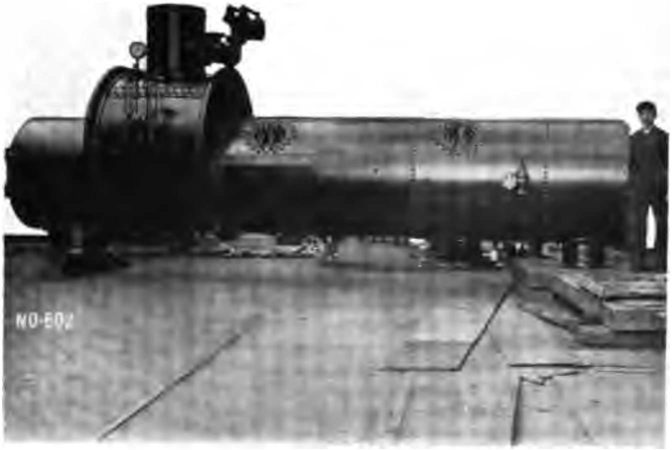

Fig. 7.

Fig. 8.

		Cost per B.H.P. according to	
		This estimate.	M. Leon Greiner's.
Nine twin-tandem double-acting gas engines to develop 2,500 B.H.P. at 94 revolutions, ...	£112,500	£5 12 6	£4 14 0
Nine 50-cycle 5,000-volt three-phase alternators for direct coupling to gas engines, ...	26,000	1 6 0	1 11 4
Centrifugal-type gas-cleaning plant, ...	12,000	0 12 0	1 11 4
Switchboard, motor-generators and connections to alternators.	10,000	0 10 0	—
Engine-house, 470 feet by 80 feet, steel structure, brick-filled, with 20-ton crane,...	24,000	1 4 0	1 11 4
Foundations for gas engines and engine house about 14,000 cubic yards, ...	14,000	0 14 0	0 10 5
Cooling towers for jacket-water, 300,000 gallons per hour, ...	2,000	0 2 0	—
Water pumps, air compressor, and reservoir for starting gas engine, ...	1,500	0 1 6	0 10 5
Incidentals and supervision,	11.000	0 11 0	—
	£213,000	£10 13 0	£10 8 10

CAPITAL COST OF 20,000 B.H.P. GAS-ENGINE POWER STATION USING PRODUCER GAS.

The equipment of the station would not be altered except that a gas-producing and ammonia-recovery plant would be substituted for the gas-cleaning plant. The capital cost of this plant complete with all producers, gas cleaners, ammonia-recovery towers, exhaust-gas-heated boilers for supplying steam required by producers, would be about £75,000 or £3 15s. 0d. per B.H.P. The total cost of the station would be £276,000 or £13 16s. 0d. per B.H.P., as compared with £10 13s. 0d. for the blast-furnace-gas station. There would be two coal-fired Lancashire boilers for providing steam when the plant is starting up from all standing, and if all boilers were of this type instead of the exhaust-gas-heated boiler, the total price would be reduced by about £4000.

A Wilson exhaust-gas boiler designed to take the exhaust from a 1000 B.H.P. engine is shown in Fig. 7. In this boiler steam is only raised in the portion having the greater diameter, the remaining portion acting as a feed heater. The exhaust gases are led through internal tubes and leave the boiler at about the same temperature as the steam. Any reasonable steam pressure may be maintained, and about 2½ lbs. of steam per hour is obtained per B.H.P..

COST OF GENERATING POWER BY GAS ENGINES.

The total cost of generating power by any means consists of two portions (1) the working expenses, such as fuel, oil, labour, repairs, maintenance and superintendence, and (2) the capital charges comprising interest on the total cost of the generating plant, and sinking-fund charges for redemption of capital.

With a gas engine the first portion is low owing to its high thermal efficiency, and the second item is higher than for steam-turbine plant owing to the heavier initial expense. With water power the second item constitutes the bulk of the total cost, owing to the generally very heavy initial cost and the fact that no fuel is required.

Some interesting figures were given in M. Greiner's paper regarding the working costs of Messrs. Cockerills' own central gas-power stations. The larger station contains in all six engines, aggregating 7000 B.H.P. and using blast furnace gas. In the other station are two engines using coke-oven gas and having a combined output of 1000 B.H.P.

In 1900, all electric power required in Messrs. Cockerills' works was generated by steam engines with a total capacity of 1000 kilowatts. Commencing in 1901, they gradually replaced their steam engines by gas engines, and owing to the success of the initial engines they largely increased the number of motors in use. By 1906, all the steam engines were removed and they had gas engines in use developing 5700 kilowatts.

In the following table the total working costs per B.H.P. per hour are given for each year. The steam plant was not of the most modern type, but the most up-to-date steam turbine plant would not be able to approach the figures given for 1906-7.

Year.	Plant.	Units per annum.	Working Costs per B.H.P. per hour.
1900-1	Steam only	1,789,781	·629d.
1901-2	Gas and steam	1,930,740	·554d.
1902-3	do.	2,007,290	·428d.
1903-4	do.	5,387,612	·212d.
1904-5	do.	9,999,216	·147d.
1905-6	do.	14,915,919	·116d.
1906-7	Gas only	24,000,000	·047d.

The output for 1906-7, of 24,000,000 units, corresponded to a load factor of 50 per cent. calculated upon a full year of 8760 hours. All working costs for a large blast-furnace gas-engine plant are practically independent of the average load of the engine. Lubrication and attendance are almost the same at all loads, but the cleaning and repairs may be increased with the load. With a higher load factor, the working costs per unit are thus decreased. M. Greiner gives the following figures based upon his experience:—

Load Factor.	Working costs per B.H.P. per hour.
25 per cent.	·0864d.
50 ,, ...	·0465d.
75 ,, ...	·0311d.
100 ,, ...	·0233d.

For a load factor of 95 per cent. which may be attained in electro-chemical or electro-metallurgical works, the total working cost per B.H.P. per hour would be about ·024d. On analysis of the working costs it was seen that they could be divided approximately as follows:—

Labour, including engine attendants, generator and switchboard hands, superintendence, etc.	45 per cent.
Lubrication	20 ,,
Cleaning, upkeep and repairs	35 ,,

With a total cost per B.H.P. per hour of ·024d., the above three items amount to ·0108d., ·0048d., and ·0084d. respectively.

The fixed charges depend upon the useful life, the capital cost of the plant, and the interest to be paid upon this capital. Large gas engines have not been in use yet for a sufficient length of time to say from experience what useful life they will have. As this has a very great effect upon the fixed annual charges, three cases are taken, assuming that the life is (1) 10 years, (2) 15 years, and (3) 20 years. It is necessary to allow only the same useful life to the alternators and foundations as they might not be utilised for new gas engines.

For the gas-cleaning plant, switchboard, motor-generators, etc., a useful life of 15 years may be taken. A 20 years' life is assumed for the water pumps and air compressors, but only 12 years for the cooling towers, depending upon the quality of the timber used in their construction. The engine house should last at least 40 years. For depreciation I have assumed that a sinking fund would be formed, and that 3 per cent. compound interest could be obtained upon annual payments. For the engine house a separate sinking fund should be formed owing to its life being so much longer than the other items. To obtain the period in which the sinking fund should mature, the cost of each item is multiplied by its allowable life, and the sum of these products is divided by the total capital cost. The annual payment to the sinking fund for the engine house amounts to £310 per annum. For the remaining items in the blast-furnace station, £189,000 has to be redeemed in 20 years, for the longer life of the engine, etc. For the 15 years' life the equated period is 15·35 or, say, 15 years, and for the 10 years 11·3 or, say, 11 years. The annual payments are £6820, £9810, and £14,280. In addition to the sinking fund there is the interest on capital to be allowed at the rate of 5 per cent. per annum.

The station is assumed to work at an average load of 19,000 B.H.P. for 8760 hours per year, or at a load factor of 95 per cent. The output is then 166,000,000 B.H.P. hours per annum.

With this output the total annual working costs of the blast-furnace gas-engine station will be as follows:—

ITEM.	LIFE OF PLANT.		
	20 Years.	15 Years.	10 Years.
Labour 166,000,000 @ ·0108d.	£7470	£7470	£7470
Lubrication 166,000,000 @ ·0048d.	£3320	£3320	£3320
Cleaning and repairs 166,000,000 @ ·0084d.	£5810	£5810	£5810
Works cost	£16,600	£16,600	£16,600
Sinking fund, engines, etc. ...	£6820	£9810	£14,280
Do. house	£310	£310	£310
Interest, ...	£10,650	£10,650	£10,650
Total costs	£34,380	£37,370	£41,840
Cost per B.H.P. per year	£1 14 4	£1 17 4	£2 1 10

To estimate the cost of power generated by a gas-engine power station using producer gas, the extra net cost of the gas has to be added to the expenses previously indicated. There are several gas plants at work producing gas equivalent to upwards of 20,000 B.H.P., but the major portion of the gas in all the plants is used for heating purposes. Producer gas used in heating furnaces is similar to that used in gas engines, except that it is not cleaned to the same extent.

Fig. 8 shows one of the largest producer-gas plants at present at work. This belongs to the Staffordshire Mond Gas Co. and is capable of producing gas equivalent to 16,000 H.P. On the right are the producers, and then the various towers connected with the ammonia recovery plant. The buildings shown on the left contain the various pumps and boilers required for the ammonia recovery plant. One of the buildings is used as a store for the ammonium sulphate.

From experience gained with these large producers, it appears that the total cost of producer gas for engines with a capacity of 20,000 B.H.P., working with a 95 per cent. load factor, will be as given in the following table. Coal has been taken at 7s. 6d. per ton, although an ordinary price for fuel of a suitable grade in the Glasgow district is 6s. per ton. The coal consumption per B.H.P. per hour has been assumed at 1·2 lbs., or 1·6 lbs. per kilowatt hour. This includes the raising of all steam required for the ammonia-recovery plant, etc. The yield of sulphate of ammonia per ton of fuel has been taken at 92 lbs.. This figure depends upon the composition of the coal and is a fair average value. The market price of sulphate of ammonia has ranged from £12 to £13 5s. 0d. per ton during the last six years, and is now £12 5s. 0d. The sale price of the sulphate of ammonia obtained from the gas has been assumed to be £11 per ton instead of the market price. The higher price would be more favourable to the cost of producing the power.

For the 10 years' life of the engine the sinking fund has to mature in 12 years, owing to the fact that a 15 years' life is allowed for the gas-producing and ammonia-recovery plant.

Labour at the gas plant	£5300
Acid, stores, repairs, etc.	9300
Water	770
Fuel—89,000 tons at 7s. 6d. per ton	33,375
	£48,745
Less 3660 tons of ammonium sulphate @ £11 per ton	40,260
Net cost of gas ...	£8485

ITEM.	LIFE OF PLANT. 20 years.	15 years.	10 years.
Works costs (excluding fuel)	£16,600	£16,600	£16,600
Net cost of gas	8485	8485	8485
	£25,085	£25,085	£25,085
Sinking fund, engines, etc.	£9200	£13,480	£17,700
Do. house ...	310	310	310
Interest	13,800	13,800	13,800
	£48,395	£52,675	£56,895
Cost per B.H.P. per year	£2 8 5	£2 12 8	£2 16 11

The various estimates given for the cost of gas-engine power are collected in the following Table:—

Gas Used.	Cost Price per H.P. per Year.			Life of Plant.
Blast Furnace.	£1 14s 4d			20 years.
Do.	£1 17s 4d			15 ,,
Do.	£2 1s 10d			10 ,,
	Price of Coal per Ton.			
	6s	7s 6d	9s	
Producer Gas.	£2 1s 9d	£2 8s 5d	£2 1s 1d	20 years.
Do.	£2 6s 0d	£2 12s 8d	£2 19s 4d	15 ,,
Do.	£2 10s 3d	£2 16s 11d	£3 3s 7d	10 ,,

In comparing gas and water power, the reliability of the supply should be taken into account. The gas-engine station can fail either by the breakdown of the plant or shortage of fuel. The former is guarded against by careful design and the installation of spare plant. Labour trouble might cause a temporary shortage of fuel.

The water-power station might cease to supply power from either of the above reasons, the fuel in this case being the water. Careful design and spare plant are relied upon to overcome breakdowns. The water supply to the station may be interfered with by the formation of ice. Some interesting information on this point was given in a paper read by Professor H T. Barnes, of Montreal, before the British Association recently. From this it appears that the most troublesome form of ice is the frazil ice, which forms in thin plates and crystals in turbulent waters. This changes into large spongy masses which adhere to the metallic portions of the turbines and eventually chokes them. This may sometimes be prevented by local heating of the turbo casing, so that the masses of frazil ice are unable to adhere to the metal.

Where the water, on its way to the power station, passes from a turbulent portion of the stream through a quiet pool which freezes over during frost, the frazil ice acts in a different way. It rises under the surface sheet of ice in the quiet pool and becomes attached to it. This action may eventually choke the passage under the ice, and the water in that case rises behind the ice and may force the whole mass down to the power station intake.

Anchor ice forms on the ground due to heat radiation during cold nights. Frazil ice becomes attached to this and forms large masses. With a slight rise in temperature the anchor ice rises to the surface, often carrying large stones, boulders, etc., with it. These may cause considerable trouble in the water turbine. In many situations ice may thus cause considerable trouble to water-power stations.

From this comparison it appears that power generated from blast-furnace gases costs about the same as water power, when the capital cost of the generating station, with or without transmission lines as may be required, is about £18 per horse power delivered at the consumers' boundary. In the Table giving estimated cost of hydro-electric power stations, it will be seen that the majority of plants are estimated to cost more than this figure.

Power from gas engines using blast-furnace gas is, therefore, worthy of more attention than it has received up to the present time in Great Britain. During 1905 the various Scotch blast furnaces turned out 850,000 tons of pig iron. According to Greiner's rule, with this output the spare power would be about 71,000 H.P., on the assumption that the works are equipped with modern gas-blowing engines, etc. If this power were used for the manufacture of calcium carbide, aluminium, or nitrogenous manures from atmospheric nitrogen, it would be possible to get a return of at least £2 per H.P. per annum. There is thus an annual loss in the Scotch blast furnaces only of upwards of £140,000. To harness this power the capital cost would be about £750,000, according to the estimate given for the 20,000 H.P. station. A return of £2 per horse power per year would give upwards of 18 per cent. on this capital expenditure, in addition to the 5 per cent. interest allowed in estimating the cost of the power. There is, therefore, a large future before the blast-furnace gas engine, particularly for the manufacture of artificial nitrogenous manures, of which large quantities will be required in the near future to enable the wheat-growing ground to produce sufficient wheat to satisfy the rapidly increasing number of wheat consumers.

The gas engine, using either blast-furnace or producer gas, could be adopted with great advantage by public power supply companies and by municipalities where there is a good day load. Gas engines should be installed of sufficient capacity to deal with the average day load, and steam plant kept to deal with the peak. With this arrangement the gas engine plant would always be working with a high load factor, and would be able to generate power cheaper than an equivalent steam plant. This combination of steam and gas plant has several advantages, and is now receiving the careful consideration of many power supply companies.

Discussion.

Mr Richard A. McLaren (Member) observed that Mr Robinson made some very interesting comparisons between the cost of gas and water powers under certain defined conditions, but the question that occurred to him on reading the paper was, whether these conditions were such as were likely to be found in practice. Mr Robinson claimed, and he had no doubt he was right in claiming, that gas was more economical than water, but as in this country there were no large water powers available, and as, where there were water powers available, there were not usually blast furnaces, it seemed to him more or less of academic rather than of practical interest. One question, however, remained—Could blast-furnace gas be used advantageously for general industrial purposes? In the first place, the industries which employed large powers with a 95 per cent. load factor were very few. He thought, in the meantime, that the fixation of atmospheric nitrogen referred to by Mr Robinson might be neglected. Assuming that such an industry were about to be started and the promoters proposed to put their works in the vicinity of blast furnaces, one of the first questions that would arise would be, "Where shall we go?" To solve that question they must ascertain what power was available. Mr Deacon, in his evidence before the Royal Commission on coal supplies, said, "The general conclusion I have arrived at is that in a small plant (a plant, say, of three or four furnaces) there would be very little, if any, gas to spare for surplus purposes with any great degree of certainty; that is to say, that whilst a blast furnace owner might put down a gas plant and utilise the gas when he could

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	Remarks.
Lake Titicaca, Pe	eme outlined by Prof. Guarini of Lima.
Mexican Light & I	details see page 199.
Cameron Rapids,	details see page 200. No transmission costs included.
Augst-Wyhlen, ne	cted jointly by the Basle & Baden authorities.
Societa Idroelettri	details see page 198.
Aveto River,	owing for transmission loss. Page 198.
Societa Generale	n given is capital of Co. formed to erect stations in Camonica Valley, Brecia Province. Power transmitted 60 miles to Milan.
Santiago, Chili,	posal of the German Transmarine Electricity Co.
Horahora Rapids,	ect of Waihi G.N. Co. in return for certain concessions. Part power transmission to Waihi.
Cameron Rapids,	uding transmission 75 miles. Power delivered 14,450 H.P. Page 202.
Hauroko, ...	n report presented to House of Representatives, New Zealand.
Albula River, n Zurich, Switz	uding transmission line 87 miles.
Trollhattan, near	
Gullspang-Munkfo	uding transmission lines, etc.
Teviot, ...	
Clarence River,	
Opihi, ...	n report presented to House of Representatives, New Zealand.
Huka River,	
Hutt River,	
Turin, ...	uding transmission line.
Huka River,	n report presented to House of Representatives, New Zealand.

Mr Richard A. McLaren.

get it (being prepared to go without it when he could not get it), some considerable advantage might be gained from the surplus gas. But for public supply purposes, unless the plant were a very large one—ten or twelve furnaces—there would be no reliable supply of gas which could be utilised." Now, in the whole of the United Kingdom there was only one place where such a number of furnaces as that could be found. From a return made of the furnaces in blast on 31st December last, he saw that it was only at Gartsherrie, belonging to Messrs. William Baird & Co., where there were ten or twelve furnaces in blast. Even if it were assumed that Mr Deacon was far too conservative in his estimate, and that eight furnaces in blast at one time would provide a useful margin, What did they find? At the end of last year, when the iron industry was in a prosperous condition, there were only three such places in the whole of the United Kingdom—Coltness, eight furnaces; Gartsherrie, twelve; and the Clarence Works, eight. They could reach these same conclusions in another way. For every ton of iron produced in a coke-fed furnace there was, roughly speaking, 160,000 cubic feet of gas. Of that, 35 per cent. was required for heating the blast and for power purposes in connection with the furnace itself; 10 per cent. was lost in leakage in the furnace and in pipes; and 20 per cent. was lost in cooling and cleaning the gas so as to make it suitable for use in the gas engine. That left 35 per cent. available, or, say, 56,000 cubic feet, and assuming 100 cubic feet per horse power, that gave 560 H.P. per ton of iron. Taking four tons of iron per furnace per hour, that gave 2240 H.P. per furnace per hour. The Author based his calculations on a plant of 20,000 H.P., so for that, nine furnaces in blast would be required. As he had just shown, there was only one place in the whole of the United Kingdom where there were nine or more furnaces, and only three places where there were even eight. These figures were a very liberal estimate. He had mentioned 2240 H.P. per furnace, but at the Cardiff meeting of the Institution of

Mr Richard A McLaren.

Mechanical Engineers, Mr Roberts estimated only 1000 H.P. per furnace per hour. Mr Robinson allowed nothing whatever for the use of that gas, and it seemed to him that one could hardly expect the proprietors of those three blast furnaces to be so philanthropic as to give this gas for nothing to the chemical company. There was another important consideration; in the paper to which the Author had referred, Mr Greiner, of the Cockerill Company, in dealing with this question, said, "But this economy is only a real one if the gas is employed immediately to produce the power and if this power is employed immediately." That meant that the output of the chemical company was absolutely dependent upon the output of the furnaces. If some of the furnaces were blown out, the chemical company must simply stop until they were blown in again. It was a matter over which the chemical company had no control, so that it was absolutely at the mercy of the blast furnaces. Then these calculations were based on the assumption that there was a regular supply of gas. It was a matter of common knowledge that blast furnaces did not produce gas in that obliging manner. Sometimes there was a very rapid production of gas and at other times very little gas indeed given off, so that there were a great many difficulties in that way, and if to these were added the notorious uncertainty as to the regular working of the gas engines themselves, he thought that the lot of the chemical company would be like the policeman's, not a happy one. The Author admitted that the steam turbine compared very favourably indeed with the gas engine in capital cost. Messrs Merz & M'Lellan had shown very clearly the paramount influence of capital charges on the cost of power production, and he thought that it could be clearly shown that, taking everything into account, under ordinary working conditions—not taking a load factor of 95 per cent., which was an extraordinary one—it would be found that the steam turbine would still be better than gas engine for the production of large powers.

Mr W. W. Lackie.

Mr W. W. LACKIE (Member) said that he was interested in the cost of power production, although the two methods described in the paper did not apply to a city supply except so far as it was referred to on the last page of the paper; and he would deal with the subject from a Public Supply Company's point of view only. Unfortunately the subject was one for figures, and was, therefore, difficult to discuss. He wished, however, to ask Mr Robinson a question. On page 212, he said the case stated by him was based on a 95 per cent. load factor. Was such a load factor possible in any ordinary industrial concern? He (Mr Lackie) took it that no manufacturing was carried on on Sundays and that, as a rule, there was a half holiday on Saturday afternoon, and generally about 14 holidays in the year. Assuming that this was the case and that a works ran for 24 hours a day throughout the year at maximum load, a load factor of 75 per cent. would be obtained. He was afraid, however, that a dead steady load of maximum output even for this time would not be obtained. There would be times of maximum and minimum demand which would further reduce this 75 per cent., and in practice it would be found that a night and day factory would not in itself have a greater power factor than 50 per cent. In the illustrations given of Messrs Cockerill's works, it would be found that the load factor last year was 50 per cent. He felt that it would have been better had Mr Robinson worked out his theoretical cost at a lower power factor than 50 per cent. From the figures given on page 211, it would seem that in Messrs Cockerill's works the total cost, *i.e.*, the total annual bill for working cost, was the same in 1900 when sending out 1,700,000 units, as it was in 1907 when sending out 24,000,000. Also, it would be seen from the Table of works cost, varying with the load factors, that the works costs were inversely proportional to the load factor. That was to say, a load factor of 100 per cent. had half the works costs of a load factor of 50 per cent., and a load factor of 25 per cent. had a quarter

Mr W. W. Lackie.

the works costs of 100 per cent. load factor, and half that of a 50 per cent. one. The other standing charges varied absolutely in the same way. This being so all the figures given on page 215 as the cost per B.H.P. per year, on a 50 per cent. load factor, would be practically doubled and would give "the fifteen years' life of the plant" at £5 5s. per B.H.P. per year. Taking now the supply of electrical energy in a city like Glasgow, where the load factor was only 15 or 16 per cent., these figures would require to be multiplied by 6·3 and it would be found that the cost would be £16 6s. per B.H.P. per annum. It was no use telling a consumer that if he only used the supply twice as long as he did, his rate per unit would be reduced. His annual bill would be greater although his rate per unit were less. What one did not want, said the adage, was dear at any price. What was the average charge per H.P. per annum in Glasgow to-day? Last year there was a demand equal to 27,000 H.P. and a revenue of £224,000, or an average cost per H.P. per annum of £8, which compared favourably with the apparent cost of £16 for the gas producer plant with the same load factor. At the same time there was quite a number of consumers whose rate per H.P. per annum was in the neighbourhood of £2. One other point he desired information upon. In Glasgow units of 5000 to 10,000 H.P. were now wanted, and no gas engine of this size could be had; and if it could, the capital cost would be very much greater than the cost of a turbine of the same size. The capital charges amounted to 70 per cent. of the total cost of electrical energy, and, therefore, it behoved the supply authority to keep down the capital cost per kilowatt to the lowest possible figure. What was the record of gas engine stations even of much smaller powers? In a town not far from Glasgow, some 12 or 15 years ago, gas engines were installed, and they were replaced by steam plant within two years. A few years later a city in Ireland erected a gas engine station, and this had to be abandoned at great expense to the ratepayers. Only last year

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a well-known Colonial city started up a very large gas-engine station which had since been dispensed with in favour of steam plant. These have been abandoned partly on account of unreliability, and partly on account of high works costs. The gas engine might come all right (some people hoped to get a gas turbine), but the supply authority could put aside the present demand and ask the consumers to wait. The Corporation and the Company alike must meet the obligations to which they were committed. He had thoroughly enjoyed Mr Robinson's paper, and conidered it a valuable addition to the papers recently written on this subject.

Mr Leonard Andrews (London) remarked that he quite expected that Mr Robinson would be very much attacked, and the previous speakers had certainly not failed in the onset, but it appeared to him from the remarks just made that the paper had been criticised from a different point of view to that to which the Author intended to draw attention. The paper referred particularly to the enormous amount of waste of power that was going on in connection with blast furnaces. It did not deal with what was an equally important subject, namely, that of supplying power to a town like Glasgow to which Mr Lackie had just referred. The Author had shown that surplus blast furnace gas, capable of generating over 70,000 h.p. continuously, was at present being wasted from Scottish blast furnaces alone, and it was the undoubted duty of all engineers able to appreciate this waste, to show that such surplus energy could be profitably utilised for chemical or other manufacturing processes. Such processes were at present being conducted in other countries, owing to the foresight shown by foreign engineers in utilising the available power from waterfalls and other sources of cheap power. British engineers ought to observe what had been accomplished in Germany in connection with large iron and steel works there. Mr Robinson had referred in his paper to the results obtained at the Cockerill Works, and his figures were most convincing, but he thought

Mr Leonard Andrews.

an even better example was that referred to in a paper read before the German Iron and Steel Institute, some time ago, by Mr Fritz Sellege, the gas engine manager of the Differdinger Iron and Steel Works. He had taken the figures given in that paper and had had them plotted out on a diagram from which Fig. 9 had been made. It seemed to him that

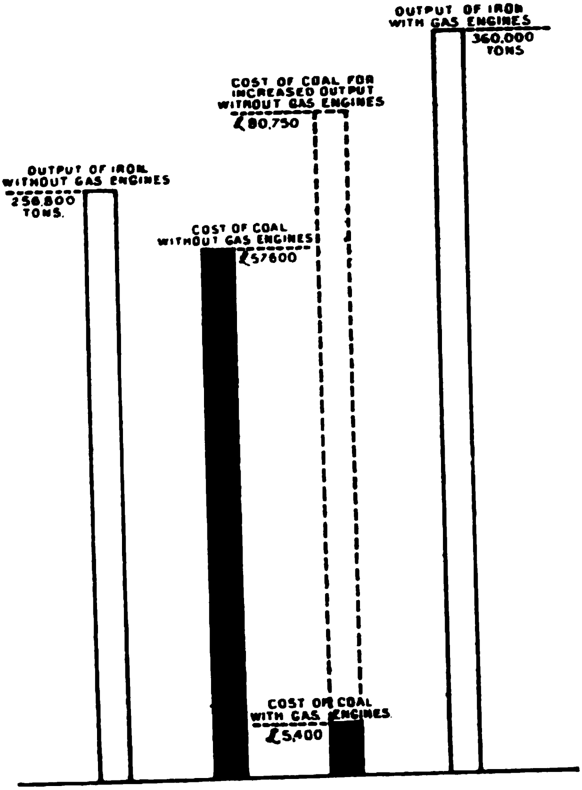

Fig. 9.

these figures were a record of actual results obtained which it was very difficult to get away from; they were facts clearly showing the terrific waste of energy that was going on in big iron and steel works, which engineers ought by some means

Mr Leonard Andrews.

to avail themselves of. Previous speakers had questioned whether a 95 per cent. load factor was ever met with in actual practice, but he had been in works in England where the load factor was, he believed, 98 per cent. These works were running day and night and all Sundays. For such special purposes as the Author had indicated, a very high load factor could undoubtedly be obtained. It would, perhaps, be thought that Mr Robinson had taken too sanguine a view of the running cost of a gas-driven installation. It might interest members of the Institution to know that he had occasion, a few months ago, to estimate the cost of running a somewhat similar installation to that quoted by Mr Robinson, viz., a 20,000 H.P. plant working on a 95 per cent. load factor, and he found that, taking the life of the gas engine at 15 years, the running cost per B.H.P. worked out at approximately £1 19s. per annum, as compared with Mr Robinson's £1 17s. 4d. Where they differed was that he had taken rather a higher capital cost than Mr Robinson had done. Mr Robinson estimated the capital cost at £10 13s. 0d. per B.H.P., whereas he had based his running costs on a capital cost of £11 per B.H.P., but allowing for that difference the cost would have been approximately the same. His figures, and, of course, Mr Robinson's figures, were based on actual results obtained from a number of existing works. A previous speaker had referred to the questionable reliability of gas engines. He thought that anyone who had doubts upon that point ought to take a trip to Germany, and see there some of the many large installations of gas engines running day in and day out on practically full load, for 24 hours a day. In all of these works even a momentary interruption of the supply would be most disastrous, but full reliance was placed in the gas engine supply alone. He would not say the gas engines never broke down, but they did not do so any more than a steam turbine or any other running machinery might be expected to do. There was no doubt that the modern large gas engine was as

Mr Leonard Andrews.

reliable as any type of plant it was possible to obtain. Mr Lackie referred to gas installations that were started some years ago, and had since been scrapped. He himself could refer to more than one steam turbine installation which had been started later than the gas engines referred to, and had proved an absolute failure, but it would be absurd to argue from this that steam turbines were unreliable. So far he had entirely agreed with the Author of the paper, but he thought Mr Robinson had laid himself open to criticism in one or two cases. In dealing with the cost of generating power in conjunction with ammonia-recovery plant, he thought that the Author had underestimated the cost of the gas. This was taken at £8485 only, whereas the cost of labour for the gas plant, acid, stores, water, repairs, etc., was £15,370. It was, therefore, assumed that not only did the coal cost nothing, but the sale of the by-products contributed close on £7000 to the labour, acid, and water charges. He really thought that that was much too sanguine a view to take. He possessed figures that had been given him by makers of ammonia-recovery plant, and they were nothing like so sanguine as that. He felt that Mr Robinson had gone astray in the figure that he had taken when he said, "The coal consumption per B.H.P. per hour has been assumed at 1·2 lbs. or 1·6 lbs. per kilowatt hour. This includes the raising of all steam required for the ammonia-recovery plant, etc." In the first place to obtain a ratio of 1·2 lbs. per B.H.P. per hour to 1·6 lbs. per kilowatt hour, it would be necessary to employ generators with an efficiency of 99·65 per cent. This obvious error would not, however, effect the cost of coal per B.H.P. The 1·2 lbs. given was too low. Assuming the coal to have a calorific value of 13,000 B.Th.U.'s per lb., and the efficiency of the ammonia-recovery plant to be 60 per cent., which was really too high to expect to realise with plant giving 92 lbs. of sulphate of ammonia per ton of coal, the engine consumption must not exceed

$$\frac{1\cdot 2 \times 13{,}000 \times 60}{100} = 9360 \text{ B.Th.U.'s per B.H.P. per hour,}$$

and although much better results than this had been obtained on tests, he did not think it would be possible to obtain them continuously in practice. It must also be remembered that the efficiency of the ammonia-recovery plant, from the point of view of gas production, decreased as the output of sulphate of ammonia increased, and a net efficiency of 60 per cent. was, he thought, too much to expect in conjunction with such a high output of sulphate of ammonia.

Mr R. B. Slacke (Manchester) said that while agreeing generally with the results of Mr Robinson's paper, there was one criticism he would like to make. Mr Robinson took his cost per B.H.P. at £5 12s. 6d., and, as far as one could gather, that included the cost of delivery and erection, and the pipe work. Figures which he had beside him of German installations came out somewhat more than that, and the explanation, as far as he could find, had been that the product of bore, stroke, and speed in the particulars that Mr Robinson gave, was about 17 per cent. less than the product of bore, stroke, and speed in the German engines of which he had particulars. That would reduce the cost of Mr Robinson's engine as against the German engine by about 17 per cent., but surely if these items of bore, stroke, and speed were so much less in Mr Robinson's engine, it must mean working with a correspondingly higher mean effective pressure to obtain the same power. A higher mean effective pressure indeed than the German engineers, whose engines had proved reliable, considered it safe to work with.

Mr Henry A. Mavor (Member) said that the diagram shown by Mr Andrews was an example of the kind of thing which was very misleading in dealing with such a problem. It was very usual for electrical engineers to find some of their confreres in the business, using such diagrams to show the saving that could be made by the use of electrical plant. He thought such arguments were very unwise from the point of view of anyone who wished to put the interests of his industry forward

Mr Henry A. Mavor.

on proper lines. One did not know exactly what the meaning of the diagram was. In the first place, it had no title, and no authority was quoted for the statements made. but the dotted line showing £80,750 did not seem to have any physical meaning whatever. It showed the cost of one item for doing the work in one way, and, on the other hand, the hypothetical cost of one item which was not used, for doing the work in another way. In other words, the cost of coal was placed against no cost of coal, and it was not said what the substitute had cost. In the second place, in such an installation, which he gathered was a rolling mill, the cost of coal used for driving the racks, shears, and saws by means of steam engines was a notoriously high figure. Without electric engineering in the setting out of an arrangement for a steel work, it was possible to reduce the coal cost probably down to one-third of that shown, so that a comparison between the cost of using blast-furnace gas with the cost of using coal was not being made, but a comparison between one modern economical method of doing the work and another old and very wasteful method of doing the work. With regard to the reliability of gas engines, it was perfectly true that they were not expected to break down. It was not breakdowns that caused the trouble. He did not suppose that breakdowns in gas engines were more frequent than breakdowns of steam engines when they were at the same stage of development, but an element of uncertainty was that one did not know where they might have to be stopped to prevent damage, or be stopped by too much air getting into the cylinder when the engine was heavily loaded. It was that kind of stoppage which was the irritating thing in gas engines. In that connection, he thought he was right in saying that, while the largest users of energy for chemical purposes in this country had been using gas engines with producer gas for some years, and with very great success, nevertheless, by far the greatest output from any one place was entirely by steam turbines; not only that, the supply of

Mr Henry A. Mavor.

energy was from an outside source, namely, the Carville Station at Newcastle-on-Tyne.

Mr Robinson remarked, in reply to Mr McLaren's criticism, that the object of the paper was to show that various electrochemical and electro-metallurgical processes could be economically carried out in Great Britain in the neighbourhood of blast furnaces, whereas, at the present time, they were generally established in foreign countries, where there was a plentiful supply of water power. Should the British ironmasters avail themselves of this large amount of surplus power, which they undoubtedly had, this country would not be dependent upon foreign countries for many chemicals, etc., which required in their manufacture a large amount of cheap power. The question of fixation of atmospheric nitrogen was one that was daily receiving more attention, and a considerable number of works were being established on the Continent to work various processes that had been proved successful in fixing atmospheric nitrogen. A load factor of 95 per cent. was certainly obtained in electrochemical and electro-metallurgical works. He had seen cement works in Great Britain that ran night and day, Sundays included, and had a load factor of from 94 to 98 per cent. The amount of surplus power available from blast-furnace gases depended upon the aggregate output from the furnaces, and not on the number of furnaces. The Coltness furnaces referred to were comparatively old and small furnaces, whereas the modern furnaces at Cargo Fleet and Frodingham were very much larger and would have more waste gas. The output of 20,000 B.H.P. was fixed upon simply as an example, and smaller plants could, with advantage, be established. In the case of two or three ironworks in the same district, each could establish a power station, and sell their power to an electro-chemical or electro-metallurgical company which might establish works in the neighbourhood. Taking the Coatbridge district as an example, the Gartsherrie, Summerlee, and Langloan Ironworks, being situated within a reasonable distance of each other, could each

Mr I. V. Robinson, Wh.Sc.

supply power to one company, or for the above nature. This would considerably reduce the variation in volume of gas available at any time, and would practically eliminate the chance of a complete shut-down. This was a system that had been very extensively advocated by Mr B. H. Thwaites, the pioneer in Great Britain of the blast-furnace gas engine industry. With reference to the output of the chemical works depending entirely on the gas available, this could not be a very serious objection, as a company manufacturing calcium carbide had established works on ground adjacent to a large power station in Yorkshire, and had arranged to take whatever power the company could spare during the 24 hours. As the ordinary load on the power station increased, when the lighting came on and overlapped the power load, the carbide company would then have to be content with a much smaller amount of power than it would get, say, from midnight to six a.m. No item had been allowed in these estimates for the cost of the gas, as it was assumed that the ironmasters themselves would put down works to utilise this gas to the fullest possible advantage. With reference to Mr Lackie's remarks regarding the figures given on page 215, it should be noticed that these figures were the total cost per horse power per year, and not per horse power per hour, or per unit. With a reduced load factor there was, of course, a smaller amount of fuel required, and therefore the total costs would be reduced. The cost per unit, however, with a lower load factor, would be greater, as the capital charges remained the same for all load factors. In the following Table the cost per unit was given for various load factors. For purposes of estimating these costs, it had been assumed that the coal consumption would be increased by 15 per cent. for the 20 per cent load factor, and proportionately for other load factors. This increase depended entirely upon the number of engines in use, and the average load on each engine. As the consumption of a gas engine at half load was usually about only 10 per cent. greater than at full load, this allowance of 15 per cent.

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on the lowest load factor should be ample. The yield of ammonium sulphate had been taken as proportionate to the fuel used. Labour, stores, oil, water, etc., were assumed constant, although with the lower load factors there might be some slight reduction. In one case coal was taken at 6s. and the plant with a twenty years' life, and in the other at 9s. per ton with a ten years' life.

PRICE PER KILOWATT HOUR IN PENCE.

Load Factor, per cent.	Coal 6s. Life of Plant, 20 years.	Coal 9s. Life of Plant, 10 years.
90	·087	·131
80	·100	·147
70	·118	·168
60	·142	·196
50	·176	·235
40	·226	·294
30	·311	·392
20	·480	·589

The figures given in the Table on page 215 were directly comparable with the revenue of £8 per horse power demanded, which Mr Lackie obtained in Glasgow. It should, however, be remembered that the items given in the paper did not include any item for rates, rent, etc., nor was there included any transmission or distribution system such as Mr. Lackie had in Glasgow. This transmission system was an expensive item, and when this was taken into account, the capital cost of a gas-engine scheme was only slightly greater than a steam-turbine scheme. It had been stated that a complete turbine power station could be installed at a cost of, say, £10 per kilowatt. This figure had been put as low as £8, and in a paper read recently before the Institution of Electrical Engineers it was stated to be between £12 and £13. The transmission and distribution system of a large company or municipality would cost at least £25, and probably £40 per kilowatt installed. In addi-

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tion to this there were usually preliminary expenses which might amount to £5 per kilowatt. For a steam plant the total cost per kilowatt would be as follows:—

Machinery, etc. - - - - - -	£10
Transmission and distribution system -	40
Preliminary - - - - - - -	5
Total, -	£55

Many municipalities and power companies had a capital cost of upwards of £70 per kilowatt installed, so that the above figure was by no means on the high side. Gas plant, according to the estimate given in the paper and closely confirmed by Mr Andrews' experience, could be installed for £13 16s. per B.H.P., or £17 10s. per kilowatt. The preliminary expenses and cost of transmission and distribution system would be the same for either type of plant, so that with the gas engine scheme the total capital cost per kilowatt would be as follows:—

Machinery - - - - -	£17	10	0
Transmission and distribution system	40	0	0
Preliminary - - - - - -	5	0	0
Total, -	£62	10	0

This was only 14 per cent. higher than the cost of a steam turbine station, and was comparatively small when one took into account the large saving in fuel which it had been demonstrated that gas engines gave. The gas engines were installed in a town near Glasgow about 1890, since then a considerable improvement had been made in gas engines. It was only in 1895 that engineers turned their attention to the large gas engine, and since then the development had been very rapid. The Colonial experience referred to by Mr Lackie had been unfortunate, but before one was able to judge of this fully, it would be necessary to know the inner history of the business. With reference to the yield of ammonium sulphate referred to by Mr Andrews, this figure was obtained from a leading firm interested in the manufacture of gas producers. The firm assured him that this return had been obtained with high efficiency, but a more usual figure was from 82½ to 85 lbs. of sulphate of ammonia per lb. of fuel, with which an efficiency of about 70 per cent. was usually obtained. The steam required for the producer in connection with the ammonia recovery plant was raised in exhaust-heated boilers. This reduced the coal consumption of the plant, and 1·2 lbs. per B.H.P. per hour would, under these circumstances, be sufficient. The item mentioned for engines in the estimate given on page 209 included delivery of engines and pipe work, and supervision of erection. The labour required would come out of the item allowed for incidentals. The engines referred to would not be running with a high mean pressure, and it would be more correct to compare the volumetric capacity of the engines referred to by Mr Slack, rather than the product of diameter, stroke and speed. Mr Mavor referred to the chemical company who had a large number of gas engines at work. It might be of interest to know that since this company took a large supply of power from the Carville power station it had extended its gas plant.

The PRESIDENT (Mr John Ward) stated that in the name of the members of the Institution he desired to thank Mr Robinson for coming north and delivering his paper, as well as giving them the opportunity of hearing such an interesting and spirited discussion. To the great majority of the members the subject appealed pretty much from its academic side, because their own work lay more in the region of vessels large and small, whose lengths, breadths, depths and guaranteed speeds, fitted with either turbines or steam engines, occupied their working hours and waking thoughts. He had no doubt that in the days ahead there would be great changes, and with such cost-saving results as Mr Robinson had put before them the gospel of gas was likely to claim many converts. He

The President.

asked them to join him in giving Mr Robinson a hearty vote of thanks for his paper.

The vote of thanks was carried by acclamation.

Correspondence.

Mr R. LEARMONTH (Associate Member) stated that the gas engines being supplied for the Gary Works of the Indiana Steel Co. were quoted by the Author as being of 4000 B.H.P. This was not strictly correct. These engines were of the four cylinder twin-tandem type, direct coupled to the cycle alternators as stated, but these alternators were only of 2000 kilowatts with an overload capacity of 50 per cent. It would, therefore, be only when carrying approximately this overload that the engines would develop 4000 B.H.P. The present station included 19 generating units of 2000 kilowatts, designed to carry 50 per cent. overload for long periods, and were as follows:—two Curtis steam turbines and fifteen gas engines driving twenty-five cycle alternators of 6600 volts, and two gas engines driving direct current generators. These latter ran at 85 revolutions per minute instead of 83·3 as stated. The diameter of the cylinders was 44 inches instead of 42 as stated, but this, he presumed, was a clerical error. There were also two rotary transformers of special design connected through static transformers to the extra high tension wires on the cycle alternator side, and on the direct current side to a large storage battery, which would act as a buffer for the peaks due to the sudden dropping and taking up of the load caused by the bloom or rail entering or leaving the rolls. One of these engines had lately been completed at the Illinois Steel Co.'s Works at South Chicago, and had proved very satisfactory, and was carrying the full load for which it was designed, namely, 2000 kilowatts and upwards, very successfully. Mr Robinson proposed to instal eight engines of about 2500 B.H.P. for a full load of 20,000 B.H.P., and also to add a ninth as a spare one. He was of opinion that Mr

Mr R. Learmonth.

Robinson would find before the station had been long in operation that he had not sufficient plant.

Mr **Robinson**, in reply to Mr Learmonth, observed that, strictly speaking, gas engines had no overload capacity, and if the engines to which Mr Learmonth referred were capable of giving 4000 B.H.P., with the alternator overloaded, they were capable of giving this for a continuous period. The fact that the alternator was not capable of continually absorbing the normal output of the engine did not affect the capacity of the engine. The speed of these engines, for a frequency of 25 cycles, must be either 83·3 revolutions per minute with a 36-pole alternator, or 88·4 with a 34-pole alternator. A speed of 85 revolutions per minute was impossible with this frequency. The engines quoted in the paper were rated below their maximum continuous capacity, so that seven of them would supply the specified 20,000 B.H.P., in which case two engines might be held in reserve as spare.

THE INTERRELATION OF THEORY AND PRACTICE OF SHIPBUILDING.

By Mr. J. J. O'NEILL (Member).

SEE PLATES III., IV., V., VI., VII. AND VIII.

Read 21st January, 1908.

IN preparing this paper it has been found necessary to restrict its scope to the examination of the speed-power aspect of the question. Some years ago, while engaged in plotting curves of power, the character of the residuary resistance curve impelled the conclusion that, in developing dimensions of vessels, the wave-making resistance decreased so rapidly that it was felt a period was reached when it became constant for a time, only to increase at a later stage when the vessels were still further enlarged. The relation of the wave-making resistance to skin friction was also interesting. In extending the length, a time came when the skin and wave-making resistance became equal, further extension revealing the fact that skin friction increased at a more rapid rate than decrease of wave-making resistance, inviting the belief that increased length did not secure the advantages commonly held as appertaining to it; that, in fact, it became disadvantageous to increase length beyond a certain limit, or, rather, that equal speed-power results would be obtained by attention to the other dimensions. Colonel Rota, in the Italian experimental tank, further illumined the matter in a series of researches, which were generously given to the profession. He took a particular model and modified successively, in constant ratio, one of the dimensions, length, breadth, and immersion, leaving in each derived form the two other dimensions invariable. Twelve models were tried in three series:—First, the breadth and depth constant and length varying; second, the length and depth constant and breadth varying; third, length and breadth constant and depth varying—the only drawback to the procedure being that surface and displacement in the various models changed. Figs. 1, 2 and 3 graphically show the results. His deductions were that:—

1st. The increase or decrease of breadth or depth produces an increase or decrease of E.H.P. at the same speed.

2nd. With the same variation of displacement the E.H.P. is greatest when the breadth rather than the depth varies.

3rd. Skin friction remains the same when the displacement is constant whether the breadth or depth varies.

4th. Increase of length produces a marked decrease of resistance due to the formation of waves, but, on the other hand, comparatively to the increases of the other two dimensions, a rapid increase of skin resistance.

5th. Each derived vessel, in changing the longitudinal dimension, possesses a particular speed for which increase or decrease of displacement, within ordinary limits, does not produce at the same speed practically any notable variation of power.

The corollaries from the fourth deduction, taken in conjunction with the curves, appear to be that a period comes when increase of length after a time does not secure an appreciable reduction of wave-making resistance, and that the principal resistance is due to skin friction; hence, the only advantage accruing to the longer and heavier vessel is explained by the latter resistance increasing at a lesser rate than dimension. The fifth deduction also implies that varying displacements can secure equal speeds with equal powers.

It will be seen from Fig. 1 that the wave-making reductions are great as the displacement is augmented, the resistance at small displacement being very much greater than the skin resistance, and the latter at the higher displacement becomes of major importance. The character of the E.H.P. curves also indicate that dissimilar displacements are driven at equal rates with the same power. Observe that, in Fig. 3, at 20 knots the wave resistance-curve rises to a period of comparative uniformity before ascending rapidly at the higher displacements to its maximum. What aspect these curves assume at still higher limits remains to be determined; at any rate, their progress reveals possibilities to the inquirer. A period, however, apparently arrives when wave augmentation ceases, permitting increased displacements to secure constant speed without increase of power. This period is specially valuable to the shipowner, enabling greater carrying capacity to be obtained without increased first cost and upkeep of machinery and coal consumption. Following out the previous idea respecting the behaviour of the curves when extended, these forms have been enlarged to the displacement of 37,000 tons, and Figs. 4, 5 and 6 give the E.H.P. for skin and wave-making resistance at various high speeds, showing their relation to each other. Here, in Fig. 4, vessel 2, the skin and wave-making resistance curves if produced would be equal at about 18 knots, and again at about 30½ knots, so that between these limits the skin friction is the principal resistance to be overcome, and is at about 24 knots, twice that of the wave-making resistance.

With regard to vessel 3, on examining the wave-making resistance curve, it will be noticed that at from 24 to 30 knots it bears a very minor proportion of the total resistance, and at, say, 20 knots, is at a minimum. The power introduced into the vessel, therefore, in this case, is used principally to overcome skin friction, which, as is well known, depends on surface and not on form; reduction of length appears, therefore, to be desirable.

Curve for vessel 4 presents similar features to that of vessel 3, but more pronounced, wave-making resistance being a minimum at about 24 knots. The difference of E.H.P. required for vessels 3 and 4 from about 26 to 28 knots is about 300, the E.H.P. at 26 knots being for vessel 4 just 30,000. In these three cases the ratio of depth to breadth has been constant, with length and breadth ratio varying. Elongation has been effected without change of form, or redistribution of displacement longitudinally, which, as is known, affects resistance. The practical realisation of this data here presented is manifested by the appearance on the Atlantic of such vessels as—" Baltic " and " Adriatic," " Cedric " and " Celtic," " Saxonia " and " Ivernia," and " Carpathia," " Sylvania " and " Slavonia," of large displacement and length at relatively very slow speeds, disclosing, at the same time, the fact that absence of the necessary power prevents the attainment of the speed their lengths demand. Incidentally it may be remarked that in these slower ships it seemingly was thought better to have earning capacity, in the shape of constantly changing cargo, than power represented by constant and permanent machinery weight, with decreased cost of upkeep and coal consumption. At the same time the dimensions permit of extensive passenger accommodation. In these cases it is quite evident that speed was not the primary factor of the design; but weight, cargo and passenger facilities, while stability considerations determined dimensions, which involved speed as being purely incidental. Its primary character, therefore, was temporarily lost, only to be regained in the same vessel when desired by the necessary introduction of the weight to secure the power demanded for its attainment, possibly, but not necessarily, at the expense of cargo capacity.

These vessels also appear to confirm the experimental results given by Mr Johns in his last paper read before the Institution of Naval Architects. It was shown that in vessels whose lengths were twice the square of the speed, residuary resistance is constant for a variation of form, represented by a range of prismatic coefficient of 20 per cent. In other words, surface being constant, between the limits of 50 per cent. and 70 per cent. prismatic coefficient, variation of form permits of equal speeds being secured with equal powers. Form, in these cases apparently, has no influence on the results.

Curves 5, 6, 7 and 8, Fig. 5, are for vessels of the characteristics indicated. They show the effect of disposing displacement breadthwise. Vessel 6 was the basis vessel, the ratio of depth to length in vessels 5, 7 and 8 being the same as vessel 6, the breadth-depth ratio varying, and length constantly decreasing, thereby reducing skin friction but increasing wave-making resistance.

This illustrates the handicap war vessels labour under on speed grounds, owing to their inability to carry armament and protection high up, without increasing beam to secure stability, the length being fixed. The importance of this factor of stability increases so as to become almost the most vital. To attain certain results, it becomes imperative to divide the power into twin and triple engines with relatively smaller screws running at high rates, reducing thereby the weight of machinery, to realise conditions of speed. No such limitations of dimensions restrict the designer of merchant vessels, excepting in the case of the present type of liner, having seven or eight decks, with superstructures, where stability becomes increasingly difficult to secure, making this factor the controlling element of the combination.

Stability thus becomes the measure of the power available, in so far as it determines the weight of machinery, the hull weight being constant, that can be applied, and in this way affects speed. This is equivalent to saying that speed is always possible of attainment when all the other determining conditions are fulfilled.

Curves 9, 10 and 11, Fig. 6, show the effect of redistribution of displacement depthwise. The ratio of breadth to length is constant. Vessels 5 and 7, Fig. 5, are identical in length to vessels 9 and 11—the breadth-depth ratio varying. Clearly,

	3b.	5b.	12.	13.	14.	15.
	31,300	11,000 to 14,000	...	...	...	32,000
,000	14,250 to 25,200	...	...	...	...	27,500
	37,600	30,550	...	...	...	...
,600	...	...	...	35,250	36,000	24,000
	34,700	27,200	...	...	...	...
	...	35,400	...	...	...	...
,300	...	...	...	...	...	...
	31,500	11,000 to 22,600	...	...	...	...
	38,800	32,000	...	...	...	40,000
	..	...	33,400	29,200	29,600	21,200
	...	...	26,600	24,200	24,800	18,800
,400	12,000 to 27,400	...	...	...	...	...
	36,200	28,100	...	...	...	33,000
	...	...	21,600	20,000	20,800	16,600
,800	...	...	...	...	...	...
	33,000	23,400	...	...	39,000	28,000
	...	...	17,600	16,800	17,600	14,600
,000	...	...	...	...	...	...
	28,600	17,300	35,800	34,000	31,600	23,500
	...	39,500	...	...	...	...
	...	...	14,400	14,000	15,000	12,800
	20,000	6,600	30,600	26,000	25,600	19,800
	42,000	35,700	...	...	...	39,400
	...	...	11,600	1 ,400	12,600	11,200
	...	...	25,400	30,200	30,800	16,600
	37,000	30,900	38,600	40,000	39,200	31,000
	...	...	9,000	9,200	10,400	9,800
	...	...	20,200	15,800	16,800	14,000
	30,800	24,500	33,600	31,000	31,500	24,600
	27,500	20,500	...	...	...	...
	...	...	6,400	7,000	8,500	8,400
	...	...	15,400	12,200	13,600	11,400
	23,900	16,600	28,400	23,200	24,200	19,000
	...	...	...	...	6,600	7,000
	...	...	10,600	9,000	10,600	9,000
	15,600	10,000	...	...	...	...
	...	...	6,000	6,000	8,000	6,800
	...	...	17,400	12,200	13,400	10,600
	...	...	11,000	8,000	9,200	7,000

on comparison, this is the most desirable manner of disposing displacement. It is along these lines that the merchant navy has broadly developed.

Figs. 7 and 8 give curves for similar displacement to the preceding, interpolated from Mr Froude's latest contribution to the literature of the subject, and require no special explanation.

Figs. 9 and 10 introduce curves of E.H.P. for wave-making and skin friction separately and combined for these vessels, plotted to a basis of displacement. They reveal the same general characteristics and confirm the previous researches. The E.H.P. curves for 1*a*, 3*a* and 5*a* can be compared with those of 1*b*, 3*b* and 5*b*, as they are for constant lengths, but varying breadths and depths. The block coefficients are the same in each pair, the displacement being merely rearranged.

These are all relatively short, wide vessels, typical of war practice. A study of these curves invites the conclusion, with regard to wave-making resistance, that there is a period in the growth of displacement when it is the least possible. In addition, had curves at speeds below 24 knots been plotted, from their very nature it could be safely predicted that the pronounced wave-making resistance at high speeds, on small displacement, would rapidly decrease in intensity on expansion of dimension, to again increase by a further augmentation of displacement of ship. At the minimum stage, and while it lasts, power is apparently required principally to overcome skin friction. Further, the curves show a diminution of power between displacements wide apart, and that dissimilar displacements can be driven with equal speeds by equal powers. It is this region that invites attention, the gleanings of which will be found worthy of the reaping, and an abundant harvest gathered.

Figs. 11 and 12 show curves of E.H.P. at the speeds corresponding to the various displacements. Those on Fig. 12 represent actual vessels, on the assumption of 50 per cent. propulsive efficiency, as stated by Mr Froude to be war practice generally. Table I. gives the various powers required for the speeds at the various displacements enumerated. They cover a very wide range and are extremely instructive. The following data for some high speed Atlantic liners have been gleaned from various sources:—

TABLE II.

	L/B.	L/D.	B/D.	Displacement in Tons.	Speed in Knots.	I.H.P.
"Campania."	9·23	24·00	2·6	18,000	22·0	30,000
"Kaiser Wilhelm Der Grosse,"	9·47	22·32	2·35	20,880	22·8	32,000
"Deutchland."	9·9	22·86	2·31	23,620	23·5	36,000
"Kaiser Wilhelm Der Zweite."	9·42	23·00	2·44	26,500	23·5	39,000
"Lusitania" and "Mauretania,"	8·69	32·38	2·7	36,840	25·0	68,000

In comparing these steamers with the corresponding experimental ones, it must be remembered that great latitude is permissible in determining dimension to secure equal results, since, providing sectional areas and water line form be maintained, great variation of character of midship section is possible, as Mr Froude's researches clearly establish. Care must be taken that the longitudinal distribution of displacement be unchanged, as experiment shows that dimensions and block coefficient remaining constant, redistribution longitudinally considerably affects wave-making resistance. With this restriction the data given are very flexible and capable of wide application.

Referring to Table I., compare vessel 15, of practically similar characteristics, with the "Lusitania" and "Mauretania" at 25 knots. The results are identical. The vessel from which No.

15 is derived was fitted with slow-running reciprocating engines, and the latter with up-to-date turbine machinery; the propelling efficiency here appears to be no greater and may be less than the 50 per cent of tradition. This is also borne out in other instances where reciprocating machinery and turbines, in similar vessels, secured the varying speeds with equal powers up to 25 knots. Afterwards the turbine seemed to gain.

It may be remarked that the character of the lines of No. 15 and the recent Cunarders bear no resemblance to each other. The former are straight and the latter hollow. Other Atlantic liners, known to the writer, also have wide divergence of form, yet, with equal surfaces, secure equal speeds with equal powers. Wide variations of form also can be found on similar dimensions in channel steamers, with similar results. More research work on various types is certainly necessary before definite statements can be made on the value of form.

Now, compare the "Campania," whose displacement is practically similarly disposed to her German competitors. Her 28,000 I.H.P. drives 18,000 tons displacement at 22 knots. This displacement could be increased to 20,800 tons requiring 32,000 I.H.P., the power of the "Kaiser Wilhelm der Grosse" to secure 23 knots; to 26,000 tons displacement and 23·5 knots for the "Deutchland," with 36,000 I.H.P.; or to 26,500 tons displacement and 23·5 knots with 39,000 I.H.P. for the "Kaiser Wilhelm der Zweite." The results show that no great advance has been made propulsively for over a decade, but has followed traditional lines, the increased speed being attributable to increased dimensions merely.

Since the preparation of this paper further light has been thrown on the question of wave-making resistance by a contribution to the proceedings of the American Society of Naval Architects and Marine Engineers, New York. In dealing with the problem of "Submarines of Battleship Speeds," Mr Chase prepared a model which was run at varying speeds in the experimental tank at Washington, both on the surface, and at different depths of submergence.

Curves of E.H.P. were obtained, after correction for skin friction, for vessels increasing from 100 to 200 feet in length, and from 5 to 18 knots speed. At certain high speeds the usual humps and hollows appeared, confirming the belief that on indefinite enlargement these distortions would be similarly periodic. The most curious phase appears in comparing the power curves of the submerged and surface conditions. At a certain speed, just succeeding the pronounced distortion, the ordinate value of the curves coincide.

Wave disturbance develops at the surface, where it is a maximum, decreasing in intensity to extinction at a given depth, until it may be inferred that at a submergence of 14 feet in this case no waves were formed. Hence the power curve represents only skin resistance. The agreement of this curve with the surface one, at this speed, necessarily implies absence of wave formation, or very little, in the surface condition. The power curves for the submerged condition exhibit no corresponding humps and hollows, due to the absence of wave disturbances, and at high speeds indicate less power than those obtained under analogous circumstances at the surface. There appears to be no escape from the conclusion that a time arrives, it may be on commencement of the movement of a ship, when a wave comes into existence, and after developing intensity to a maximum, absorbing power for its maintenance, it gradually diminishes on relative decrease of power, due to the equivalent enlargement of ship.

This can be further illustrated by assuming a given ship capable of indefinite enlargement and increased power. On movement wave formation begins, which develops on acceleration to visible surface disturbance, waves being formed, gradually increasing in intensity from a minimum to a maximum, power and wave-making being interrelated. The presence of the one involves, for maintenance, the introduction of the other. At the maximum stage, indefinite enlargement of vessel, without change of form, brings with it the accompanying phenomenon of relative decadence of wave formation. Enlargement of hull thus becomes related to power, or degradation of wave-making, controlling wave resistance. A period appears when one of two conclusions follows—either after the minimum of wave-making resistance due to the enlargement is reached, further enlargement will increase resistance; or, that wave-making ceases to augment, becoming constant, requiring no increased power for a time for its maintenance.

Summing up the preceding, it is submitted that the lengths of the present Atlantic liners warrant the belief that greater speeds can be obtained, providing the power their dimensions invite is present. Very little economies can be made in the weight and distribution of scantling in the type of vessel now becoming general, except by the introduction of high tensile steel, the centre of gravity fluctuating but little. Stability finally determines displacement, so that, on given length, reduction of displacement makes for both its realisation and the attainment of speed, the two being closely interrelated.

The curves of power also show that the present speeds can be attained on shorter lengths, and that the variations of form involve relatively small gains. Is this, then, to be the end? Cannot practice bridge over the gulf separating it from theory? On closer inquiry the limiting cause appears to be the machinery end of the combination, demanding for the realisation of power to attain the desired speed results, such weights as to adversely influence the reduction of the dimensions of ships the speed invites. Generally speaking, it has hitherto been thought the easiest and cheapest way to secure speed economically by increased dimension of hull, rather than the character of the machinery. Running machinery at 80 revolutions as the maximum appeared the limit experience warranted. The quick-rotating reciprocating machinery of the Royal Navy at twice the speed, with its weight inversely as the revolutions, with all its possibilities, or even a compromise, was deemed unworthy of adoption in the merchant marine, owing to its cost and want of endurance. This latter may be true; but the former cannot be demonstrated. Total cost may be divided between hull and machinery, and had curves been plotted it would have been found that a time came when, instead of enlargement of hull increase of character of machinery secured greater economy as to speed results; and the high speed reciprocating engine, although intrinsically more costly, when its weight was considered and compared with the slow, heavy reciprocating engine, was cheaper power for power, the total of small hull and high speed machinery being very much less than contemplated.

With regard to endurance, it is submitted that the exigency of the situation will, in time, force another condition into the problem, viz.—the length of life of hull and machinery. The demand for increasing high speed will continue inevitably, so that it will be a matter for consideration whether the policy of building ships for posterity rather than the immediate future continues to be advisable. Long ago the slow, reciprocating engine, with its single cylinder succumbed to the double, which was followed by the triple, quadruple, and even quintuple cylinder engines—all tending to economy—until the limit of the close cycle process appears to be reached, bringing into existence by natural and gradual stages the open process, the machine par excellence—the marine turbine. This should, in a large measure, lessen the gap between navy and merchant practice, and finally dispose of the arguments of endurance against the high rotating machinery; as it is universally admitted that the efficiency of the turbine, *per se*, depends principally on its high speed of rotation. In examining the curves of power, some of which represent vessels fitted with turbine machinery, it is found that up to 25 knots the turbine secures no advantage propulsively over the relatively slow reciprocating engine of the merchant marine, although running at twice its rate; nor yet over the high speed reciprocating engine of war practice under like conditions. Even in torpedo boat destroyers, with usual powers, and running at a still greater ratio of rotation, no perceptible increase of efficiency is observed. In this connection it may be well to state that the principal advantage claimed for the new machine is " its capability of securing greater power on a given weight of machinery than any other marine contrivance known," and further, " in applying turbines to marine propulsion, it is not a question of securing a greater propulsive efficiency, but to determine the most suitable design and arrangement of propellers and turbine, in order that their combined efficiency may be at least as good as it is with ordinary reciprocating machinery." This is borne out by experience. It has not hitherto obtained increased efficiency of propulsion, although the Hon. C. A. Parsons, in his paper of 1907, states:—" That not only does weight diminish, but efficiency also increases, by approaching the higher limit of revolution; and increased revolutions are also desirable, permitting smaller dimensions, adding both to the mechanical perfection and efficiency of the turbine. There is also for given speed, H.P., and efficiency, very little variation in the weight of mercantile or naval turbines. Smaller steam consumption is also claimed, and a further decreased weight of installation in consequence; reduction of space occupied, also of propeller diameter, permitting for same draught increased immersion and preventing racing." Its chief function, however, at present apparently is its capability to obtain greater powers on a given weight than its competitors. Two special instances may be quoted bearing on this aspect of the case. The torpedo boat destroyer "Viper," fitted with turbines, of similar dimensions to destroyers equipped with high-speed reciprocating engines, realised 37·9 knots with 18,000 I.H.P., and 1180 revolutions, on 73 tons weight; against its reciprocating competitors of 30 knots with 6000 I.H.P., and 450 revolutions, on 80 tons. There is, however, another side to this achievement involving ship design. The vessel's form evidently permitted this excess of speed to be obtained on practically the same displacement, owing entirely to the presence of increased power, and this with the high rotation of screw, without encountering serious cavitation. Conversely, it may be argued that had speed as well as displacement been constant, increased fulness of vessel would have secured augmented sea qualities and enlarged space, so very desirable in this class of boat. Again, in the "Amethyst" and "Topaze," whose performances are now becoming historic, the machinery weights apparently were equal, for some unexplained reason, but the turbine-driven vessel secured 14.000 I.H.P. against the 10,000 I.H.P. of the reciprocating one. These figures show the possibilities, still remembering that no increased propulsive efficiency is claimed. These vessels cannot be taken as types for, say, the Atlantic passenger trade, but it is still urged "that at higher powers better economy will be reached, and that at least 10 per cent. reduction of weight can be secured in large vessels. With reduced steam consumption, greater power will be obtained from the same weight, or the same power with less weight and coal supply." These are claims made by responsible persons. The possibilities of the future, therefore, considerably widen the vista of engineering practice; for it is at least established that the weight of turbine machinery is equal in the two services, and that the efficiency of the high-speed reciprocating engine has been reached, with the endurance it apparently lacked.

Attention is now drawn to Figs. 13 and 14, which graphically show the happenings to performance when the screw propeller receives the attention it deserves.

The characteristics of these propellers are as follows:—

TABLE III.

	Diameter.	Pitch.	Pitch Ratio.	Developed Area.	Dev. Area. Disc. Area.
A.	12·5	15·75	1·26	52	·333
E.	13·0	16·50	1·27	49	·290

A comparison of these results with those of Constructor Taylor's experiments given in the American Transactions shows that at the slips observed, viz.:—A, 7 per cent., 8¾ per cent. and 11 per cent., at 15, 17½ and 18 knots respectively, the efficiencies were—77 per cent., 78 per cent., and 78 per cent., or the maximum possible; E=9 per cent., 11½ per cent. and 13 per cent. slips at the same speeds as A—74¾ per cent., 77¾ per cent. and 78¼ per cent. respectively. There is therefore very little to choose between these propellers on efficiency grounds, and one must assume that with 20 per cent. increased speed of rotation, permitted by the reduction of area, enabled ½ a knot extra speed to be obtained; or taking the speed at 18 knots, a saving of 8 per cent. of power. In these trials of actual screws, the displacement and trim and general conditions were the same.

Compare B with E of same pitch, but different diameter—

TABLE IV.

	Diameter.	Pitch.	Pitch Ratio.	Developed Area.	Dev. Area. / Disc Area.
B.	12·5	16·5	1·32	47	·301
E.	13·0	16·5	1·27	49	·290

Here, where equal powers secured equal speeds, the slip of B was 16¼ per cent., the efficiency falling off. E at 10½ per cent. was more efficient, and continued to be, to 18 knots, due to the slip only increasing to 13 per cent., the loss of efficiency being scarcely perceptible; whereas B started handicapped, and remained so, notwithstanding its slip was increased to about 22 per cent., where efficiency was reduced by 8 per cent. The increase of speed secured was ¾ of a knot, and had power been fixed, the speed of 18 knots could not have been attained.

The diameter of the B propeller was evidently the cause of failure. On its alteration with practically equal area, the desired result was obtained by propeller E, with about 10 per cent. increase of revolution.

The classic researches of the Froudes are well known, and have been handed down and cherished with great care. The experiments of Mr Yarrow, some 25 years ago, as to the best position of the propeller, laterally, longitudinally and vertically, were, and still are, of great value. The information furnished by the exhaustive trials of model screws in the experimental tank at Washington, by Constructor Taylor, cannot be over-estimated. The determination of the values of the functions which constitute a propeller have been made for almost every range of pitch and diameter ratio, area, and efficiency, and generally show that efficiency of screw, *per se*, rises to a maximum at about 20 per cent. slip, and falls off at higher slips by increase of thrust. The measure of efficiency of a screw appears to be related to its capacity for absorbing power, and delivery of thrust. The inference to be drawn from these results is, that high speed of rotation, coupled with the necessary area, is the most economic way of securing propulsive efficiency at high speeds. In most cases, small propellers operated by reciprocating machinery running relatively rapidly, secure better speed results at high speeds than large propellers running relatively slowly. The reason appears not far to seek. A change of pitch alone sometimes secures better results, as in the case of a recent destroyer, fitted with turbine machinery, 1½ knots over 33 was reached by merely altering this factor. In the case of the cruiser "Berwick," an alteration of screw proportions gave better results. One is almost inclined to think that had the same attention been directed to the screw propeller problem as has been bestowed on the form of vessels, greater advantages than any slight variations which form effected would have been secured, and the advent of the turbine delayed for a decade at least.

Referring to Figs. 15 to 18, these show the ideal curve of efficiency, based on the theory of planes as recommended by Mr Froude, and Rankine's ideal jet efficiency, both plotted on a basis of thrust. The actual results obtained on experimental screws of the characteristics given in Table V. are indicated. They take the same form; efficiency invariably falls off after the slip reaches 20 per cent. It may also be noticed that the form of the curve approaches more nearly to Rankine's than Froude's, and, on the assumption that the former more accurately represents the ideal, the writer of the paper, from which these diagrams are taken, published in the transactions of the American Society of Naval Architects of 1906, has framed a formula representing the efficiency that has already been reached in practice, viz.—80 per cent. It appears in a very convenient form, showing readily the influence of dimensions and thrust on efficiency, and is easily handled. Fig. 18 is plotted in view of turbine practice, to show the effect on efficiency, thrust and speed being constant, due to increase of diameter, 10 per cent. being secured in this particular case by doubling this dimension. Since the efficiency of the turbine is limited by rotation of screw, this curve is very instructive. A few remarks only may be made with regard to cavitation. It is accepted generally that acceleration and thrust are the factors involved, and perhaps form of blade, yet, as a result of experiment, Constructor Taylor found that "one model tried exhibited signs of cavitation at 5 knots, distinct evidence at 6 knots, and pronounced at 7 knots, but at a very much lower thrust than that at which it began to show cavitation at 6 knots, being about one half." This phenomenon requires a great deal more research work before any dogmatic statement can be made as to the causes and period of its appearance. At any rate, it cannot concern the problem of Atlantic performances for some considerable time. It is to these performances that the writer wishes specially to refer—how can they be improved? It is suggested, since high reciprocating engines are unpopular, that by the employment of the turbine, taking full advantage of its capabilities, increased power, coupled with the increased efficiency it intrinsically possesses, a vessel of the length of the "Campania" can be driven economically and continuously across the Atlantic at a speed of 25 knots. What that means to the shipowner in first cost and upkeep little need be said. A design, however, has been prepared on these lines which can achieve this result, no difficulty having been experienced in providing ample room for the machinery and coal stowage on the weight the necessary power requires.

Table I. indicates not only that this is possible, but many alternatives are within the range of achievement without radical departure in form from current practice. There appears to be no sound reason whatever for preventing the turbine doing the work its existence demands. It has been shown that speed is subordinate to stability, and that this has become to-day the determining factor in the design, associated with light, quick-running machinery, with relatively small screws; and on these lines the future of the Atlantic service appears to be directed.

Finally, if it be true that stability is a measure of power in the sense previously mentioned, and therefore speed in a steamer, it is in a greater degree the case in a sailing yacht. Although, as has been shown, displacement is best disposed depthwise, yet, when power is to be applied to yachts of relatively small dimensions, it is very questionable whether the British methods, hitherto adopted in the "America" Cup races, warrant their continued adherence. The slight differences, length and surface being constant, on wave-making resistance, in favour of relatively deep yachts are more than counterbalanced by the greater stability, which means sail area, obtained by the wide, shallow boat of the American designer—bringing with it the continuous success the courageous departure from tradition deserves. A change of design is demanded on our part. When these cup races cease to be personal, and become international, it may well be that without changing a single clause in the Deed of Gift, the greatest maritime nation the ages have ever seen, may produce at last an enthusiast who will with a perfect contrivance, instinct with life, herald the dawn of the time so eagerly looked for; when, sailing with outspread glistening wings across the Western Sea, wafted by favourable winds and guided in the hour of trial by the traditional splendid seamanship of our sea-girt isle, realise the dream that has long been ours, and proudly and majestically bring back from the land of golden sunsets, over the expanse of the trackless ocean, the cherished prize to the shores it need never have forsaken.

There need only be said that throughout the paper acknowledgment has been made of the various sources from which information has been gleaned, but special thanks are due to my assistant, Mr Hendin, for his assistance in the preparation of the diagrams.

TABLE V.

Comparison of efficiency curves of model propellers with theoretical curves of efficiency.

Fig. 15.

Propeller.	Pitch Ratio.	Breadth Ratio.	Mean Width Ratio.
1	1·0	3	·125
2	1·0	4	·075
3	0·6	2	·200
4	0·8	2	·200

Fig. 16.

Comparison of theoretical efficiencies by the jet and by Froude's methods (omitting friction) with experimental efficiency of model.

PARTICULARS OF MODEL.

Diameter	16″
Diameter of hub	$3\frac{1}{8}$″
Thickness of centre blades at the root	$\frac{9}{32}$″
,, ,, ,, ,, Tip	$\frac{3}{32}$″
Mean width ratio	·125
Pitch Ratio	1·0
Total developed area	40·6 sq. in.
Developed area ÷ disc area	·2012

Fig. 17.

Comparison of efficiency curve

$$E = \frac{3 \cdot 2}{3 + \sqrt{\frac{\cdot 91\,T}{V^2\,d^2} + 1}}$$

with certain propeller efficiency curves developed by experiment.

Propeller.	Pitch Ratio.	Breadth Ratio.	No. of Blades.
1	1·1	2	4
2	1·1	4	4
3	0·9	4	4

Discussion.

Mr **Edward H. Parker** (Member) said that this paper, with the accompanying diagrams, could only have been presented in the form it appeared after considerable labour on the part of its Author. Opinions differing from those expressed in the paper might exist in the minds of readers, and that, after all, was only to be expected in dealing with a subject so complex as the propulsion of ships, involving problems, upon which, in the absence of experimental data, even experts were compelled to express themselves with reserve and caution. Mr O'Neill said, "In extending the length, a time came when the skin and wave-making resistance became equal." The relation of surface friction to wave-making resistance varied considerably with variation of beam, draught, and coefficient of fineness, and the speeds at which the two were equal might be very wide apart, even in vessels of the same length. The proportion of the total resistance due to surface friction, in different types of ships, was, roughly speaking:—

	Full speed.	10 knots.
In battleships, - -	55 per cent.	79 per cent.
,, cruisers, - -	55 ,,	84 ,,
,, torpedo craft, -	43 ,,	80 ,,
,, fine passenger vessels,	55 ,,	82 ,,
,, cargo vessels, -	60 ,,	73 ,,

Keeping breadth and draught the same, the curves of resistance in terms of length, for constant speed, were sinuous, the humps and hollows growing less with increase of length. In consequence of this, there might be more than one length of ship where surface friction and wave-making resistance would be equal, and had Mr O'Neill carried his investigations further, this variation of resistance would have appealed to him. Under certain conditions it might be advantageous, purely from the standpoint of resistance, to select a certain length shorter than another, and to alter beam and

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draught. With a given type ship at high speeds, there was, of course, a length below which it was impossible to go, the limiting condition being the point where the curve of weight of hull, machinery, equipment, etc., crossed the curve of displacement. That point might not be the minimum on the curve of total power, and the designer might be precluded, for reasons over which he had no control, from adopting a length which would yield the best possible results. The curves which Mr O'Neill had presented were interesting, but their interest would have been enhanced had they been carried through a greater range of dimensions and speeds. The results of Col. Rota's investigations, as given on Plate III., and the deductions therefrom, bore out the conclusions of earlier investigators of the resistance of ships, that, in similar forms, keeping length and draught fixed and disposing displacement breadthwise, the power varied in a general way as the beam; but with length and breadth constant and disposing displacement depthwise, the power varied much less than as the draught. From experimental trials with models and the results of practical observations of the performances of steamers, it was generally admitted that length was necessary to attain a given speed economically. For the reason that the longer the form of a vessel tending to produce waves the longer would the waves produced tend to be, and as each wave had a definite speed appropriate to its length, and increasing with the length, the greater would be the speed of the ship before she experienced pronounced wave-making resistance. Increase of length meant an addition to the surface and clearly an enlargement of surface friction, at low speeds telling in favour of the shorter vessel, but at higher speeds the total resistance would be less for the longer vessel, in virtue of diminished wave making. As a practical example, he cited the case of an Admiralty design for a cruiser of fine form, in which the length was increased from 300 feet to 315 feet, or 5 per cent.,

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by displacing the cross-sections a proportional amount on either side of 'midships. The beam and draught were kept the same, while the ends were fined a trifling amount. The results of the experimental trials showed that below 13 knots the power of the longer form was increased, due to surface friction, at 13 knots the curves of power crossed, and above that speed the power steadily decreased until at 17 knots—the designed speed—there was a difference in favour of the longer form of 16 per cent. The importance of length as a factor in propulsion at high speeds was shown at a glance by the total power curves of Fig. 4. It was a peculiar feature of Fig. 5 that the curve for ship 5 differed so much in rate from the other curves, but this might be due to greater length and the relative difference of transverse to diverging wave making in this ship. In the preparation of Fig. 12, a constant efficiency of 50 per cent. had been assumed for four different vessels at various speeds. If the actual ratios of E.H.P to I.H.P. had been available, and used in plotting these curves, their characteristics might have been considerably modified and their relative values changed. For the ratio of E.H.P. to I.H.P. varied in different ships, and in the same ship at different speeds, the propeller having something to say in what its value should be. Mr O'Neill said, "Care must be taken that the longitudinal distribution of displacement be unchanged, as experiment shows that dimensions and block coefficient remaining constant redistribution of displacement affects wave making"; but it should be borne in mind that under certain circumstances it might be possible to redistribute displacement in such a manner as to lessen wave making with advantage. On the question of form, Mr O'Neill referred to Atlantic liners, "being widely divergent, yet, with equal surfaces, secured equal speeds with equal powers." That might be so, for any badness due to form, in any one case, might be counteracted by extra goodness in propellers or machinery and *vice versa*. It was not quite evident from the curves in Fig. 9

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that the present speeds of Atlantic liners, under existing conditions, "could be attained on shorter lengths"; although it might be true that variations of form "involved relatively small gains," but only in certain cases and under certain conditions. Taking the published figures for the displacement and power at 25 knots of the "Mauretania," as 38,000 tons, and 68,000 I.H.P. respectively, and assuming an efficiency of 50 per cent., the E.H.P. would be 34,000. From Fig. 9, the E.H.P. for the given type ship at the same speed and displacement was about 30,000, and the length 645 feet. The corresponding beam and draught would be 105 feet and 40 feet respectively, dimensions which, under conditions ruling at present, were prohibitive. Compared with the "Mauretania," the figures for the type ship were:—

	L. B. D.	Displacement.	E.H.P.	Block Coefficient.
"Mauretania,"	760′ × 88′ × 33·5′,	38,000	34,000	·487
Type ship,	645′ × 105′ × 40′,	,,	30,000	·594

In order to fulfil the requirements of the problem carried out in the design of the "Mauretania," the dimensions of the type ship would have to be materially altered; her length would have to be increased, and breadth and draught diminished. Brought to the dimensions of the "Mauretania," the displacement of the type ship would be about 31,000 tons, and one was forced to the conclusion that her form would require considerable modification before hoping to better the performance of the "Mauretania" at sea.

Mr J. R. JACK (Member) observed that the points dealt with in this paper were, in themselves, of very great interest. While Mr O'Neill had dealt fully with figures of foreign origin, he had omitted to do justice to some things that had been accomplished nearer home. He (Mr Jack) referred to the relationship between resistance and size which had been investigated many years ago by one of their own past presidents, Dr.

Inglis, who then showed that, if the resistance varied as the sixth power of the speed it became independent of the absolute dimensions,* and this accounted for the peculiar property pointed out by Mr O'Neill, namely, that starting with a small vessel for a given speed, an increase of dimensions first produced a diminution of resistance which presently reached a

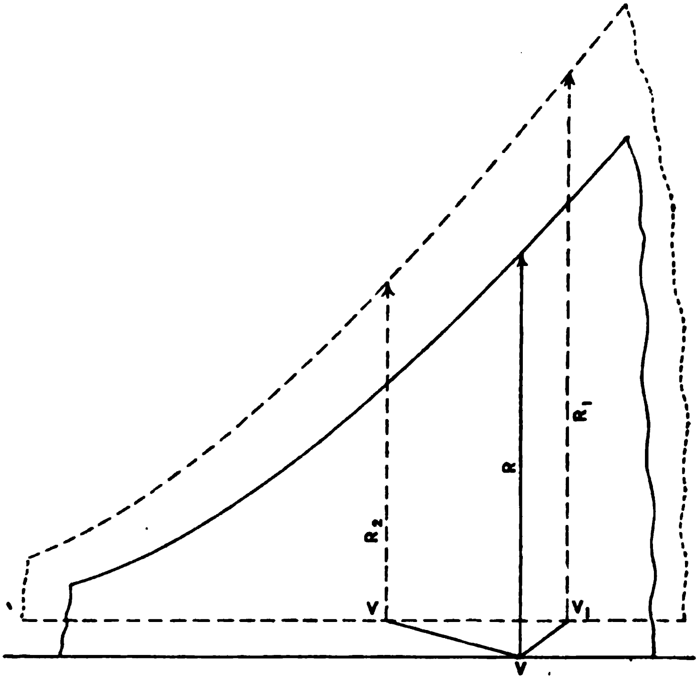

Fig. 19.

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* Let the full line, Fig. 19, represent the curve of resistance of a type ship, and the dotted line the same for a similar ship, whose dimensions were p times those of the type ship. The latter curve was not in the same plane as the former, but in one parallel to it, the normal distance between the planes representing the difference of size. At any speed V, the resistance of the type ship was R; the corresponding speed of the other vessel would be $V_1 = Vp^{\frac{1}{2}}$, and

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minimum and then increased again. With regard to the differences which Mr Parker had pointed out, he thought that probably one reason for discrepancies in Mr O'Neill's curves was that, judging by the Table, the vessels were by different builders, and it was extremely unlikely that exact data had been obtained for all of them. If the figures used were those got from a newspaper report, or even from a technical paper, the results were likely to be inaccurate, either from accident or design, and anything based upon them would be likewise incorrect. On page 243, there was a notable point raised with reference to the gain due to using turbines in place of reciprocating machinery. Mr O'Neill put the limit of this speed at 23 knots, but if this had happened in any particular case there was something very far wrong with that particular turbine, because, at very much lower speeds, for vessels of ordinary dimensions, the gain due to the adoption of turbine machinery was considerable. There was a gain both in the weight of machinery and in its seating. A very interesting point was raised regarding the differences of form between the lines of No. 15 and the recent Cunarders, without apparently any great difference in corresponding resistance. He thought the explanation of it was that, if one took two vessels of totally dif-

the corresponding resistance $R_1 = Rp^3$. Suppose the dotted curve to have the equation $y = ax^n$ (which would be approximately true for such a short piece as that between V and V_1) the resistance would vary as V^n,

$$\therefore R_2 = R_1 \times \frac{V^n}{{V_1}^n} = Rp^3 \times \frac{V^n}{(Vp^{\frac{1}{2}})^n}$$

$$= \frac{Rp^3 \times V^n}{V^n \times p^{\frac{n}{2}}}$$

$$= Rp^{3 - \frac{n}{2}}.$$

In the particular case when $n = 6$, $R_2 = Rp^{3 - \frac{6}{2}} = R$, therefore the resistance was independant of p, and a cross curve having values of p as abscissæ, and R, R_2, etc., as ordinates would be level between R and R_2.

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ferent forms, but of the same dimensions and displacement, and plotted off their resistance curves, it would be found that at *one* speed the two curves would cross, and it was possible for a large number of intermediate forms to exist whose curves of resistance would cross, not exactly at the same point, but in the region of it, so that at the speed where the crossing occurred there was a range of possible forms having practically the same resistance. Of course, at a lower or a higher speed, form might have an enormous influence on the result. Such a question had come up between two actual vessels, and it was found on investigation that at the designed speed one form had 40 per cent. more resistance than the other. Mr. O'Neill stated that it had been shown that speed was subordinate to stability, and that this had become to-day the determining factor in design, but he was afraid that while this was what one would like to have, it did not always occur. Frequently a proposal was put forward which, on investigation, was found to be deficient in stability, and if the owner were approached with the request for permission to increase the beam, the designer was informed that several other shipbuilders had assured the owner that the beam was sufficient for the stability desired, although on the completion of the vessel this prophesy was not fulfilled; and Mr O'Neill was to be thanked for bringing forward the question of stability which was too often deliberately ignored. Towards the close of the paper, Mr O'Neill referred to the "America" Cup races. He (Mr Jack) had been particularly interested in the later challengers, both during the stages of design and construction, and differed from Mr O'Neill concerning the difference in form between the British and American vessels. That this was great in the times when a challenger of the "plank on edge" type went out to meet a centre-board skimming dish, he readily agreed, but both of these types were totally extinct, and the forms now presented comparatively little difference. He hoped also that the Cup challenger would not become an international problem, as it would then be handed

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over to the Admiralty. A modern challenger was a very costly toy, even when designer and builder were careful that no money should be wasted, and if such a vessel were dealt with by the Admiralty, and their usual methods adopted, he did not think it could be carried to completion without putting a penny on the income tax. In the handling of the boats, which was a very important factor in the final result, their American friends were to be congratulated. Certainly in some of the cases Britain had the better boat, and all that was wrong was that it did not come in first, because of the skill with which the defending yacht was handled. The solution of the problem, under present conditions, was an extremely simple one, the better boat in all cases was simply the bigger boat, time allowance being on a basis not sufficiently great to neutralise the advantage of greater rating. This rating was length plus the square root of sail area divided by 2. The length for a vessel having one mast was limited to 90 feet, but there was no limit on the sail area, or other dimensions, and the question simply became, Who would build the bigger boat, with the bigger sail area, and the bigger mast? That meant an engineering problem of considerable complexity, because the forces were not determinable, and all that could be done was to fix the strength of, say, one important part from previous experience, and make the strength of the other parts to correspond with this. All weight possible must be saved, which meant cutting down the factor of safety, or, as it had been more aptly termed, the "factor of ignorance." On this basis, he thought the Americans had the advantage, because they were more willing to take chances and to cast aside old-fashioned ideas, and although they sometimes cut their margins down to a dangerous extent, with disastrous results—as, for example, in the case of the Quebec Bridge—there was no doubt that, in many other cases, their courage had met with a deserved reward. To support the necessarily large sail area demanded considerable beam, and he hoped the next designer,

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whoever he might be, would look upon this factor with the same broad mind that Mr O'Neill had shown, and if he did so, he thought his chances of winning the Cup would be particularly good.

Mr John Neill, B.Sc., remarked that on referring to Fig. 13, it would be seen that curves were given connecting i.h.p., revolutions, and speed, for the same ship with two different propellers. If one considered the point at which i.h.p. and speed were equal in the two cases, at about 17·4 knots, it would be noticed that propeller E was running at a greater speed of revolution than A, although on referring to the particulars given on page 248, it would be found that propeller E was greater in diameter and pitch, and only slightly less in surface than A. It was generally recognised that if a propeller of greater diameter and pitch were fitted, the speed of revolution would be diminished. On the other hand, the decrease in surface would tend to make the speed of revolution increase, but the effect of change of surface was relatively less than change of diameter and pitch; therefore, the resultant effect should have been decreased speed of revolution. He would be pleased if Mr O'Neill could offer some explanation of this, and wished to know if it could be explained by any other change in the propeller, either in the material or in the thickness of the blades. Again, Mr O'Neill stated that propeller efficiency, as taken from Taylor's curves, remained practically constant, but he could not see that this was possible. At the higher speeds there had been a decrease in the i.h.p., therefore there must have been an increase in the propulsive coefficient. This propulsive coefficient was the product of three efficiencies—engine efficiency, hull efficiency, and propeller efficiency. The engine efficiency must have remained constant, and in the light of present information on hull efficiencies, it did not seem probable that such a small change in the propeller diameter would have caused any great change in the hull efficiency; therefore, practically the whole of the change in

Mr John Neill, B.Sc.

propulsive coefficient must have been brought about by change in propeller efficiency. He would be pleased if Mr O'Neill could offer any explanation on that point.

Mr R. T. Napier (Member) thanked the Author for the pleasing novelty of a paper dealing with model experiments. In the time of Mr William Froude more publicity was given to such experiments. Regarding the five conclusions quoted on page 237 of the paper, he ventured to think that these did not do much beyond confirming what the Author, along with other designers of steam vessels, already knew. Regarding conclusion No. 5, Mr Froude showed, thirty years ago, that, for the same speed, vessels differing considerably in length and displacement could have the same wave resistance; he further traced this fact to its cause. The wave resistance was then arrived at, and he presumed it was still, by deducting the calculated resistance due to skin friction, from the total resistance gained by experiment, the data for skin friction being got by hauling thin plane surfaces on edge through the water. There seemed to him an element of uncertainty in the assumption that the friction per square foot of the oblique surfaces of a ship was the same as that of the planes tested, but no verification seemed possible. The Author was of the opinion that various large steamers now on the Atlantic could have been profitably driven at higher speeds had more power been provided. In this he quite agreed with him, believing that block coefficients did not require to be as low as ·5, in order to get any Atlantic speed yet attained. A steamer 100 feet long running at 10 knots was exactly comparable, so far as wave-making resistance was concerned, with a steamer 625 feet long running 25 knots. No model experiment was required to determine the power for the former, and the need for such experiment in the case of the latter was not apparent. Atlantic steamers were now well over 700 feet in length, and the difficulty in the problem of driving them did not lie in estimating the necessary power, but in getting that power on

Mr R. T. Napier.

board, in finding propellers suitable, and in getting a ship's structure rigid enough to keep vibrations within moderate limits.

Mr J. Foster King (Member) said he did not presume to enter that sphere of discussion which would be best reserved for experts in the theory of resistance as revealed by tank experiments, but he could not help giving expression to the feeling that Mr O'Neill would probably have saved himself, to some extent, from a good deal of criticism had he avoided a certain looseness of expression, and been more precise in the definitions necessary for comparisons which were expressed in curves. The title of, and the first sentence in, the paper might be taken as an example. He thought that probably Mr O'Neill was less desirous of raising a discussion upon the details of the various analyses of skin and wave-making resistance and their relation to dimensions, speed, and power, than of suggesting that because theory showed that the most economical way of utilising power, in order to obtain increased speed, was to increase length. This idea was, perhaps, too prominently before the eyes of ship designers to permit them to view in just proportion the economic possibilities of other factors. The chief value of the diagrams seemed to be less in their particular application, than in the emphasis they lay upon the fact that, for each length of ship, they showed considerable ranges of variation in speed and displacement which might be obtained without rapid increases in proportionate power; and the support which they thus gave to the view that more might be done to obtain better results from big passenger steamers by attempting, on a larger scale, much that had already been successfully done in channel and other craft, by means of light hulls and fast running machinery. Experience had already been obtained of sea-going steamers of from 300 to 350 feet in length, having speeds of from 18 to 20 knots, which were doing their best work most satisfactorily, and showing perfect stiffness and strength on weights

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of hull and machinery which must be regarded as remarkably small. This brought him to the paragraph he particularly wished to touch upon, where the opinion was expressed that there was not much room for economies in weight of hull in the type of vessel now becoming general, except by the introduction of high tensile steel. Without entering into the merits or demerits of increasing the tensile strength of steel, he ventured to differ from Mr O'Neill as to the possibilities of economising weight in the structure of large passenger steamers; in fact, he held, and had already publicly expressed the view, that in no type of steel ship had there been so little advance in structural design, or in which there was more room to seek for economies in weight than in big passenger steamers of high speed. There was no possible doubt as to the economic effect upon design of every ton of permanent weight eliminated from such vessels, and of every reduction of dimension which could be obtained without undue sacrifice of coal to the speed-power problem; and he thought Mr O'Neill had done right in bringing this aspect of the case so prominently before the Institution, and in emphasising the possibility of obtaining desired results through smaller dimensions, by directing a large share of attention to weights of hull and machinery, and to the flat parts of the power curves.

Mr P. A. HILLHOUSE, B.Sc. (Member) said that the preparation of Mr O'Neill's paper together with the diagrams and Table which accompanied it must have necessitated an immense amount of work, and that the thanks of the Institution were certainly due to the Author for the labour that he had expended on its behalf, although he doubted if the practical value of the results would be found entirely commensurate with the work which had been involved. The general problem appeared to be that of determining the best way of attaining a given speed upon the Atlantic. Now, if a given Atlantic speed were required, one of the first things to determine was the most suitable length of the vessel. A vessel of small displacement and short in relation to the speed intended would meet with excessive wave-making resistance. An increase of length would reduce the wave-making resistance more than enough to make up for the additional skin frictional resistance, so that a greater displacement could be driven with less horse power. If the increase of length and displacement were carried still further, the required total power would be found to increase, though in a lesser proportion than the displacement. In other words, for a given speed a large ship required a large horse power; a smaller ship less horse power; but a very small ship more horse power on account of undue wave-making resistance. No one attempted the very small ship, unless it was absolutely necessary to do so. Even if attempted, it might be found impossible to find space or displacement for machinery and coal. The medium ship, the one having the least E.H.P., was recommended by Mr O'Neill, but it was not necessarily the most economical, as the ratio of horse power to displacement was greater than in a larger vessel, and the ratio of coal comsumption to paying weight greater still. In order to illustrate these general principles, Mr O'Neill had prepared a large number of curves, which were in three groups, based respectively on a paper by M. Rota published in the "Bulletin de l'Association Technique Maritime" No. 11, 1900; on Mr Froude's paper to the Institute of Naval Architects, 1904; and on the performances of four vessels whose names were not stated. Plate III. was a reproduction of M. Rota's Plate IV. Referring to Fig. 3 of this Plate III., Mr O'Neill said that the wave-resistance curve for 20 knots ascended to a maximum, and also that a period apparently arrived when wave augmentation ceased; but in order that any curve might show a maximum value, it was necessary that its tangent should be horizontal, the curve falling away on both sides of the highest horizontal part. The

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curves of Plate III., however, showed no such rise and fall. The period spoken of as valuable to the shipowner when wave augmentation ceased, and increased displacement could be driven without increase of power, did not appear in the curves, and there was no evidence upon which to base the statement that, at higher limits of displacement such a period would apparently arrive. In introducing Figs. 4, 5 and 6, Mr. O'Neill said, "Following out the previous idea respecting the behaviour of the curves when extended, these forms have been enlarged to the displacement of 37,000 tons," but the idea underlying the enlargement as carried out in the paper was quite different from that upon which M. Rota's curves were extended. M. Rota extended only one dimension at a time and kept the same speed. Mr O'Neill used the law of comparison and increased all three dimensions simultaneously, and the speed as the square root of the length. Extension of M. Rota's curves, "according to the previous idea," would have meant, for example, the extension of the base scale of displacement in Fig. 1 to 37,000 tons, by increase of length only, which could only be done from further model experiments. Each of M. Rota's enlargements produced a new model, while Mr O'Neill's gave the same models on a larger scale. M. Rota's curves corresponding to Mr O'Neill's Figs. 4, 5 and 6 were drawn in accordance with Mr. Froude's "constant system" of notation, published about two years earlier, and were, therefore, independent of actual dimensions. All that was necessary to make these curves apply to any displacement was an alteration of the horizontal and vertical scales—the scales representing speed and power. Although such alteration of scales could not alter the nature of the data, there were a number of differences between the two sets of curves. For example, in Fig. 5, curves 5 and 7 crossed, but did not do so in the original diagram. Mr O'Neill said that for No. 2 ship, Fig. 4, the skin and wave-making resistances

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would be equal at 18 knots. M. Rota's curves showed skin resistance to be about three times the wave-making resistance at that speed. Mr O'Neill said that No. 3 was at a minimum at 20 knots. Such a minimum meant a lowest point, with the curve rising on each side; which in turn meant an increase of wave-making resistance as the speed was reduced below 20 knots, or more resistance at less speed, but M. Rota's curve showed no such minimum. For this vessel, No. 3, Mr O'Neill said that a reduction of length appeared to be desirable; but the 24 to 30 knots quoted for the 37,000 tons vessel corresponded to about 18 to 22 knots for the 6000 tons basis vessel of M. Rota's curves, and Fig. 1 showed that any reduction of length from the 6000 tonner at these speeds meant less displacement and more power. In enlarging M. Rota's vessel of 6000 tons to a displacement of 37,000 tons Mr O'Neill presented to his readers a series of vessels, whose lengths in some cases ran up to 960 feet, breadth in other cases to 122 feet, and draught to 52 feet, the block coefficients in all cases being ·51, and the speeds from 23½ to 30½ knots. Mr O'Neill said "The practical realisation of these data here presented is manifested by the appearance on the Atlantic of such vessels as the 'Baltic,'" etc.,; but there was surely a vast difference between the "Baltic" of ·7 block coefficient and of about 17 knots speed, and the vessels above described. Mr O'Neill also claimed that these White Star and Cunard intermediate vessels confirmed Mr Johns' recently published results in so far as they referred to vessels whose lengths were twice the squares of their speeds. But the "Baltic" was about 710 feet long, and twice the square of her speed was 578, and she, therefore, did not come into that category at all. He would like to ask the Author whether any two of the vessels named had lengths equal to twice the squares of their speeds, the same surface, 20 per cent. difference in prismatic coefficients, different forms, but equal lengths, speeds, and powers. If not, they could not be adduced

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in confirmation of his reading of Mr Johns' curve. Actually Mr Johns' curve showed about 11 per cent. increase of wave-making resistance for the same displacement between ·52 and ·62 prismatic coefficients, and about 50 per cent. increase if the displacement was allowed to increase with the prismatic coefficient. In the same paper, Mr Johns quoted a formula by Mr Taylor in which wave-making resistance was made directly proportional to block coefficient instead of independent of it. Mr O'Neill concluded that in these cases form had no influence on the results. The speaker had particulars of two vessels of the same dimensions whose lengths were twice the squares of their speeds, and with the same draught, displacement, block coefficient and speed, but which were of very different form. One of these vessels required about 30 per cent. more horse power than the other, a result which showed that form had a very considerable influence on the results. In his paper, Mr O'Neill introduced some new functions for stability. He claimed that stability measured the power available and the weight of machinery, and, later, that it determined displacement. It was, perhaps, a pity that these assertions were not accompanied by definite explanation, as otherwise they were unlikely to meet with general acceptance. He also stated that "speed is always possible of attainment when all the other determining conditions are fulfilled." With that he (Mr Hillhouse) agreed, one determining condition, doubtless, being that there was enough power to attain the speed. That agreed with the Author's further contention that greater speeds could be attained in Atlantic liners provided the power their dimensions invited was present. Mr O'Neill said that depth was the most desirable way of disposing displacement, but M. Rota's table for vessels of 6000 tons showed that length was better, vessel 4, the longest of the series, being always better than any of the broader or deeper vessels, and that in only three cases out of eight was a deep vessel better than

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a broad one. Mr O'Neill further said, "It is along these lines that the merchant navy has broadly developed." Draught, however, was about the only dimension which was usually restricted, and he was not aware that increase of draught had been more marked than increases of length and breadth. Referring to the curves based on Mr Froude's paper, the Author said, "In addition, had curves at speeds below 24 knots been plotted, from their very nature it could be safely predicted that the pronounced wave-making resistance at high speeds on small displacement would rapidly decrease in intensity on expansion of dimension, to again increase by a further augmentation of displacement of ship." As a matter of fact, curves at 22 knots *had* been plotted by Mr O'Neill on Plate VI., and they did not show this feature. Throughout the paper the Author was somewhat contradictory as to the value of form. He said that form in certain cases had apparently no influence on the results, that wide variations of form in liners and Channel steamers gave the same results, and that variation of form involved relatively small gain; but, on the other hand, he admitted that longitudinal distribution of displacement affected resistance, and stated that the curve of areas and water-line form must not be changed. He also gave curves based on Mr Froude's paper, which showed great variation of E.H.P. for different forms at the same displacement and speed. He referred to Mr Chase's paper on submarines, in order to show that there would be little or no wave making at a certain speed on the surface, because there was none at the same speed when submerged; but the submarine when submerged would meet with more skin friction than when awash, and considerable conning tower resistance. The absence of these resistances in the awash conditions would allow of a good deal of wave making without bringing the total power above that when submerged. With reference to Table I., he would be glad if Mr O'Neill would say which figure showed the possibility of a 25-knot "Campania," and

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he would also ask whether he considered the 8600 tons vessel, of column 5a, a vessel 360 feet in length by 74 feet in breadth and 21½ feet draught, with a block coefficient of ·528, and 64,000 I.H.P. for 25 knots, "one of the many alternatives within the range of achievement without radical departure in form from current practice?" He would further ask whether the speeds quoted were trial speeds or sea speeds, and whether the Atlantic liners based upon Mr Froude's data were to have rams and long immersed counters as in the originals, or if not, had any length correction been made. Mr O'Neill appeared to have overlooked one of the simplest methods of reducing E.H.P. indicated by Mr Froude's curves, namely, that of increasing the ratio of length to transverse dimensions. For example, considering Type 1a and increasing all the dimensions equally from the original, 350 feet by 57 feet by 22 feet vessel of 6100 tons, a vessel about 562 feet by 92 feet by 35 feet would have 25,280 tons displacement, and 26 knots trial speed with 30,030 E.H.P. But if the length were increased to 720 feet, the beam reduced to 81 feet, and the draught to 31·25 feet, the same displacement could be driven at the same speed for only about 24,200 E.H.P., a saving of about 11,660 I.H.P. Mr O'Neill's paper was nevertheless a very interesting one and had the merit of redirecting attention to many important points in connection with the speed-power problem.

Mr J. G. Johnstone, B.Sc. (Associate Member) said the Author had considered a few of the prominent problems that lay strictly in the domain of ship design, namely, the resistance problem, the speed-power problem, and propellers, etc. The first part of the paper dealt with the question of resistance. Those who were acquainted with this subject knew that the modern theory of resistance was based upon two laws, one affecting the wave-making resistance, and the other affecting skin friction. Instead of stating these laws, which explained all the peculiarities that were evidenced when the results of a

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given form were developed, the Author described how the curves of resistances varied up and down, but the descriptions could only apply to the special cases under consideration, and he (Mr Johnstone) thought that Mr O'Neill might have saved himself from some rather vague statements had more reference been made to the laws governing the variation of resistance. For instance, Mr O'Neill talked of the *relation* of wave-making resistance and skin friction. That was wrong, as there was no relation at all between wave making and skin friction. The law of comparison which governed wave-making resistance was independent of the law governing skin friction. A convenient method of studying this subject was to consider a surface of wave-making resistance. There were three things to consider—speed, resistance, and size or displacement. With these three as variables, one could have a surface which was termed the surface of wave-making resistance. One of the interesting points that could be observed by this method of study had been already mentioned by Mr Jack, namely, that if the rate of variation at any point of the speed-resistance curve was greater than the sixth power, then the wave-making resistance at that point in the corresponding resistance displacement curve decreased as displacement was increased. The peculiarity of decrease in the wave-making resistance as size increased was evidenced in some of the curves submitted by the Author, and he (Mr Johnstone) thought that it would have been of great value if more consideration had been given in the paper to the circumstances under which this peculiarity occurred. With regard to the remarks on propellers, reasons had been already deduced, by a previous speaker, to prove that the fault of propeller B might lie in its inefficiency. The figures for the efficiencies given by the Author were almost the same for the two propellers, but it would be seen that he had measured the efficiencies at slips of from 7 to 13 per cent. It was most likely that these slips were observed or *apparent* slips. But it was necessary in comparing the results with

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those of Mr Taylor's experiments to measure the efficiencies at the *real* slips. Now the real slip might be as much as from 27 to 33 per cent. over the range of 7 to 13 per cent. *apparent* slip, the difference being due to the effect of the wake, and, therefore, it was quite possible that had the efficiencies been measured on this basis, which was the proper one, considerable differences would have been noted in the propellers selected for comparison. The Author stated that stability determined displacement. Every one knew that the consideration of stability was of great importance in ship designing; but he differed from the Author in the above statement. For example, taking two vessels, the one a large vessel, 600 feet long, and the other a small vessel, 100 feet long. These vessels could be serviceable and seaworthy with, say, one foot of initial stability, or as it was usually termed metacentric height, in each case. With the same stability their displacements would be vastly different. Or, consider a case in which the design would be considered satisfactory if the stability were anything between 6 inches and, say, 3 feet. Two designs could be prepared, each embodying the extreme condition stated, by varying the proportion of breadth and depth; but it would in nowise follow that the design giving the smaller amount of stability had necessarily a smaller displacement. Even if it had a smaller displacement, it might be the worse form to propel. It could, therefore, hardly be said that stability determined the displacement.

Mr JOHN ALEXANDER (Member) said he would like to ask Mr O'Neill if he knew of any experiments on the friction of water over surfaces travelling at from 50 to 150 feet per second? It was well known that below a certain critical speed the friction was proportional to the velocity, that velocity was probably about 2 or 3 feet per second, but above that speed it increased as the square of the velocity. It was, therefore, reasonable to expect that at a much higher velocity, they might have another critical speed above which the friction increased as the third or fourth power of the velocity. The velocity of the tips of the propeller blades of a ship like the "Lusitania" must be not less than 140 feet per second, and if the friction increased as the square of the velocity the power lost in friction alone would be about from 5000 to 5500 I.H.P. If, however, the friction increased as some higher power of the speed, then much more power might be lost in friction. Referring to the formula for efficiency of propellers, if the diameter were infinitely large the efficiency would be 80 per cent., in fact, the efficiency increased as the diameter increased, and he thought the formula might be modified to include the efficiency reducing effect of friction.

Mr JOHN WARD (President) said the subject of Mr O'Neill's paper was alike interesting to members engaged on the practical side of shipbuilding, as well as those on the theoretical and scientific side, inasmuch as the interrelation between theory and practice was the line along which further professional achievements and successes must run. The ocean route which had hitherto given most scope and appealed most strongly and successfully to shipowners and builders alike had been the Atlantic, and in the steamers built for that evergrowing trade, the combination of the essentials named by Mr O'Neill had been most successfully demonstrated and confirmed. Mr O'Neill paid his hearers the compliment of thinking the subject was as clear to them as it was to himself, but much of its merit was, he feared, lost to the average student through this assumption. In the first portion, however, his paper dealt with effect on horse power of variation of each given dimension. An increase of length was, of course, equivalent to a diminution of speed, for Froude long ago established that for wave-making resistance, corresponding speeds were proportional to the square root of the length, and the fall in the total power curves in Fig. 1, which at first took place (as th length and displacement increased) was due to the fact that the larger vessels were really going at what

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were to them *lower* speeds, and this gain more than counteracted the increase of surface friction due to greater surface. The effect of increased breadth was well known, and as the curves in Fig. 2 were nearly straight, it was evident that for small variations of breadth, horse power might be taken as directly proportional to breadth without serious error. The peculiarly reflex shape of the curves in Fig. 3 was noteworthy, showing that at first as the draught was increased the increment in power was not proportional to this increase, surface friction being the principal factor, but when the draught became very great the increase in power became *greater* proportionately than the increase in draught, due probably to an increase in the height of the wave series. He believed that some builders of torpedo craft had experienced trouble through lack of knowledge of this peculiar property of increased draught. If speed were the only factor, or even the dominant factor in the design of a vessel, naturally the advantage would be taken of the property, so well brought out by Mr O'Neill, that, at certain positions on the curve, increased displacements could be driven at constant speed without increase of power, but this involved a proportionate increase of all dimensions, and it was not often possible to increase the draught, so that here practice parted company with theory to a considerable extent. Mr O'Neill made a good point when he drew attention to the tact that stability was (or should be) the controlling element of the combination, as safety should be the first consideration of all designs, and it was to be regretted that, in many cases, there was a tendency to cut down unduly the beam of ships. With regard to the statement that "reduction of stability and displacement makes for the attainment of speed," that depended on circumstances. One could frequently increase beam and at the same time fine the coefficients in less proportion, so that displacement was increased, thus increasing the stability in virtue of the larger water plane area, yet reducing resistance in virtue of the finer

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coefficients, more than it was increased by the greater beam. Mr O'Neill raised an interesting and important point in regard to endurance, especially in machinery having high rotational speeds. With good design and ample lubrication there was no reason why high revolutions should be detrimental to endurance, and he quite agreed that engineers could, and probably would, travel much further in this direction than they had yet done In dealing with the propeller problem, one entered a sea of very troubled waters. While every contribution was of value as throwing more light on a very dark subject, he did not think the time was yet ripe for anything more than a "working hypothesis." The laws controlling propeller efficiency were yet far from being discovered. While Mr O'Neill's results had not been put down in the form which was most familiar to naval architects, they showed a good deal of work and study on his part, and would doubtless be of value to many members of the Institution, and he deserved their best thanks and commendation for his contribution to the work of this session.

Mr O'NEILL, in reply, said he had appreciated the very valuable remarks of the speakers, which had, he felt sure, considerably enhanced the value of the paper. The thanks of the Institution were due to Mr. Parker for his exposition of the theoretical side of the subject. One of the chief objects aimed at in the paper was to draw attention to the relation or ratio between the two resistances which together make up the aggregate. The examination of the curves shown enabled the designer to alter dimensions, so as to obtain the most economical results, which could not be determined by the examination of the E.H.P. curve alone. The great part played by surface friction throughout was shown by the approximate figures given by Mr. Parker for various types of ships. The characteristics of these curves were capable of general application and extension. The paper confined itself, however, to one phase of the sinuosity, being that portion representing speeds and displace-

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ments at present in vogue, or likely to be sought in the near future. Mr. Parker mentioned that for a given type ship at high speeds length was fixed by the position of the point where the curve of weight of hull, machinery, equipment, etc., crossed the curve of displacement. This was true; but it must be admitted that weight of machinery represented a large proportion of the total weight, and if by any means power could be obtained on lesser weight, and surface friction decreased at the same rate as increase of wave-making resistance, shorter ships, provided the space permitted for the installation of machinery, could secure equal power-speed results. At certain well-chosen speeds equal power-speed results could be secured with varying dimensions and form. The fact that any form undergoing further fining and extension secured greater economy proved nothing new or surprising. The chief point he desired was to secure the best results with the fullest form at a given speed, and, in this particular, those equipped with reliable data had very great scope in choice of dimensions. As an example of the converse to the fining process cited by Mr Parker, he presented the following vessels based on experimental results, which showed clearly that shorter and fuller vessels could achieve equal power-speed results. The displacement was constant, and the speed 19 knots in both cases.

	Dimensions.	Pris Coeff.
Vessel "A,"	455' × 53' 7" × 26' 3"	·6.
Vessel "B,"	560' × 66' 4" × 19' 9"	·55.

An intermediate ship of equal displacement and speed of the following dimensions:—500' × 59' 3" × 22' 10" with prismatic coefficient of ·58 required 5 per cent. less power. At 20 knots the power required for this vessel was the same as for a vessel 525' × 62' 3" × 21' 6", with a prismatic coefficient of ·57, and also another 560' × 66' 4" × 19' 9", with a prismatic coefficient of ·55; so that with a reduction of length of 60 feet, accompanied by an increased prismatic coefficient, these dimensions possessed the cherished attribute of not largely departing from traditional practice. The subjoined Table showed, at a speed of 22 knots with displacement and block coefficient constant, equal power-speed results for the following vessels:—

	Dimensions.	Percentage of Total Resistance.	
		Skin.	Wave-making.
1.	493′ 0″ × 66′ 0″ × 34′ 0″	68	32
2.	504′ 0″ × 87′ 6″ × 25′ 6″	65	35
3.	526′ 0″ × 80′ 6″ × 29′ 0″	70	30
4.	586′ 0″ × 89′ 6″ × 23′ 6″	76	24
5.	592′ 0″ × 63′ 0″ × 33′ 0″	72	28

In reference to the assumption of 50 per cent. propulsive efficiency in plotting the curves of Fig 12, he quite agreed that this varied at different speeds in the same vessel, and in different ships. The E.H.P. unfortunately was not at present available, but he had found that in dealing with war vessels, 50 per cent. represented generally the efficiency at full speed, although it was greater at a lower speed; the curves had therefore a value at the higher limits. Mr Parker seemed to attribute the equality of results notwithstanding difference of form to the machinery, and in this there was a great amount of truth. What he (Mr O'Neill) had in his mind, however, was form, pure and simple, disassociated from propulsive mechanism. The acquiesence of Mr Froude on this very point could be found in the Transactions of the Institution of Naval Architects for 1905. He had also seen, quite recently, evidence that hollow lines at high speed detracted from performance, and with round lines an even better result could be obtained. Mr Parker's reasoning on a vessel of the displacement of the "Mauretania" was sound; but the type ship chosen was at the higher limit of the curves. He preferred, however, the adoption of dimensions which would give lesser displacement and power. He was sorry that Mr. Jack considered justice had not been done to those nearer home who had added largely

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to the knowledge of the fascinating aspect of ship design. Such, however, was not his intention. In preparing the paper he assumed that those interested were fully conversant with the past literature of the subject. It was gratifying to find that the investigations of Dr. Inglis were in perfect harmony with the deductions of the paper. Regarding the accuracy of the curves in Fig 12, he might say that they represented developments of vessels built and engined by one firm. The E.H.P. curves for these vessels were not available, so the assumption of 50 per cent. propulsive efficiency was made as fairly accurate over the range of speeds plotted. He verified Mr R. E. Froude's statement respecting the propulsive efficiency of war vessels at the higher speeds, and fortunately the published curve for the "Lusitania" justified this efficiency as generally true for latest turbine practice at speeds from 23 to 25 knots. Mr Jack demurred to the conclusion arrived at as to turbine efficiency, but in comparing similar vessels with respect to equal powers and speeds, he found no perceptible gain until after 25 knots was reached; he was pleased, however, to learn that Mr Jack's experience was happier. With reference to the weight of machinery and its seating, the paper made a special point of the gain accruing to the employment of the turbine. Mr Jack was perfectly right in his explanation regarding the differences of form between the lines of No. 15 and the new Cunarders. At certain speeds great variations of form were permissible without affecting power and speed, whilst between the chosen speeds wide differences of resistance appeared. Too much stress could not be put upon the necessity of considering, as vital, the element of stability, and he was in entire agreement with Mr Jack on that matter. In designing ships it should be insisted on that stability received careful attention. There seemed to be no defence for its absence on any ground whatever, even including consideration of cost. With regard to the "America" Cup races, he feared Mr Jack had not quite caught his meaning as to the international character of

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the races. He had always considered that the designing talent of the country was not utilised in the matter; and unless there were competitive designs submitted to competent authorities, then one designer's ideas were merely represented. Mr Neill's remarks on the propellers were interesting, but he would find, however, on closer examination, that it was unnecessary, in order to explain the different behaviour of propellers A and E, to introduce differences of material or thickness of blade (which as a matter of fact were the same), both of which would very appreciably affect results, nor any variation of engine and hull efficiency. Sufficient explanation could be found in examining the elements of the propellers themselves as expressed by pitch ratio and blade factor, associated with slip ratio. Thus, thrust being constant at 17·4 knots, and assuming similar blade factors and pitch ratios, A would require a greater number of revolutions than E to secure the same result, due to its lesser diameter; but owing to its more efficient blade factor equal thrust would be secured at a lower rate of revolution—the pitch ratio value affecting the result but slightly. Propeller E, however, had a greater and more favourable pitch ratio associated with a lesser blade factor, involving increased slip and increased revolution to obtain equal thrust result. Generally speaking, Mr Neill's deductions were sound. The importance of slip ratio and blade factor had only recently been fully appreciated, since the investigations of Mr Froude and Mr Taylor. Referring to Mr. Neill's concluding remarks regarding the increased total efficiency with propeller E, being due to increased propeller efficiency only, on the assumption that engine and hull efficiencies were constant, these assumptions were unsound. Any change in dimension and speed of rotation affected the *wake*, concerning which more information was needed; whilst propeller efficiency reacted on engine efficiency in so far as it affected revolutions. The higher the revolutions of a machine, within limits, the more efficient it was—so that increased engine efficiency was secured by the higher piston speed

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permitted by the larger diameter propeller and relative small blade factor. This higher piston speed involved greater slip, and secured equal propeller efficiency of A. Regarding the other pair of propellers B and E, variation of blade factor and pitch ratio explained completely the difference of result. He was glad to be assured from Mr Napier's remarks that the five conclusions quoted on page 237 were already generally known, as he feared, from the observations of other speakers, that the subject was still wrapped in obscurity. Mr Froude certainly, thirty years ago, did show results of experiments establishing the fact that vessels dissimilar in length and displacement had the same wave-making resistance. These experiments showed the effect due to the introduction of varying middle body merely, keeping the ends constant, but by no means exhausted the inquiry. The method of ascertaining the wave resistance was as stated by Mr Napier, and his remarks concerning the uncertainty of estimating the skin friction carried some weight. No branch of the inquiry was more unsatisfactory than this one, and research work was still needed to establish definite information. Regarding the attainment of Atlantic speeds, he was in agreement with Mr Napier, in the view that higher speeds were possible with fuller forms. Those who were fortunate enough to have reliable data knew perfectly well that, it was possible to drive vessels of similar displacement but varying prismatic coefficients at certain chosen speeds with equal powers. Mr Napier stated a fact when he said that the 100 feet vessel was comparable with the 625 feet one at the speeds named, in so far as wave-making resistance was concerned, since the speed length ratio was the same, but this merely restated the law of mechanical similitude in another way. Mr King happily interpreted the spirit of the paper aright, notwithstanding the obscurity of its title. Although the paper stated that future economies would probably be found by the introduction of high tensile steel, yet it must not be understood that this was the only direction in which such

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economies could be obtained. The fixing of scantlings of ships was not entirely in the hands of the designer. From his own experience, covering a number of years in dealing with various types of vessels, he was convinced that unless some radical change in the system of construction was adopted, and the "factor of safety" modified, little could be hoped for in the direction of reduction of scantlings. He found himself, however, very much in harmony with Mr King's remarks as to the small structural advance made in large passenger steamers of high speed. Any assistance that could be given by Registration Societies would be heartily welcomed by the profession. If, at the same time, smaller vessels of less weight, and consequently less relative stresses, associated with light, quick-running machinery, could secure the end sought, shipbuilders would rejoice. Mr. Hillhouse failed to appreciate sufficiently the preponderating influence of skin friction at relatively low speeds as generally known to students of the subject, and made clear incidentally by the curves. Practical designers of the Atlantic liners referred to made, and were still making, full use of this knowledge. The paper distinctly differentiated between residuary and skin resistance. With the proviso, as mentioned in the paper, that if skin friction were constant, the vessels whose lengths were twice the square of the speed would secure equal power-speed results. Regarding Mr. Hillhouse's remarks concerning the Atlantic liners quoted, he would ask him to again read the paper carefully. He appeared to have lost sight of the fact shown so far back as 1877, by Mr Froude, that residuary resistance at relatively low speeds was constant over a very wide range of prismatic coefficient, and it also held at relatively high speeds in vessels of well chosen lengths. This was in harmony with other investigators' conclusions, and justified Mr Johns's curves as published in the Transactions of the Institution of Naval Architects, of 1907, where the value of *b* was constant from ·52 to ·72. Which was to say, displacement being constant, residuary resistance

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was also constant, when $\frac{V^2}{L} = \cdot 5$, over this range. If Mr Hillhouse referred to Professor Hovgaard's paper of this year, in which the results were given of some of Mr Taylor's experiments with a series of six models, each of 1000 lbs. displacement, and having the same length, same ratio $\frac{B}{D} = 2{\cdot}923$, and same midship section coefficient ·926, but with varying "cylindrical" coefficients ranging from ·48 to ·68, or an increase of 20 per cent., he would find the curves crossing when $\frac{V}{\sqrt{L}} = 1{\cdot}25$ from which he could draw his own conclusions. Mr Hillhouse mentioned that the methods of M. Rota and his (Mr O'Neill's) were different, and objected that "following out the previous idea" was unjustified, to which he answered—"the previous idea" referred to was contained in the opening sentences of the paper, and was long anterior to the birth of M. Rota's curves. He pointed to Fig. 3, Plate III., to show that no rise and fall occurred at 20 knots, and elaborated his remarks by reference to the application of tangents. Practical designers, however, without descending to minutiæ, could appreciate the character of the residuary resistance curves at both 18 and 20 knots of Fig. 3, which, practically constant over a 30 per cent. range of displacement, justified the general statement. He could not think that Mr Hillhouse was really serious in saying the curves did not show that increased displacement could be driven without increase of power, for surely, if he referred to Fig. 1 of M. Rota's curves, he would see that a considerable increase of displacement could be driven without any power increase, say, at 22 knots. Again, Mr Hillhouse considered it necessary to explain how simply data could be made to apply to any displacement by merely an alteration of scale; but the laws governing skin friction and wave-making resistance were dissimilar—a fact omitted to be mentioned by Mr Hillhouse—and to apply the "curves of constants," corrections

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for skin friction, due to variation of length, had to be made, and even then total resistance only was known, and not its elements. The curves given had at least the virtue of showing these. Mr Hillhouse thought he discovered in the manipulation of the curves a complete alteration of their natural characteristics, because at 18 knots the 37,000 tons vessel did not compare, in so far as the relative values of the two components of total resistance were concerned, with the 6000 tons vessel of M. Rota at the same speed. These should be compared at corresponding speeds, and it would then be found that the natural characteristics could be reconciled. It would have been interesting had Mr Hillhouse given particulars of the two phenomenal low-speed vessels mentioned by him, whose dimensions, draught, displacement, and block coefficient were the same, but with a great difference in form, the difference in horse power, at the same speed, presumably I.H.P., being 30 per cent. One was constrained to ask the name of the designer, and if these vessels were engined by the same company. Deductions from results involving engine and propeller efficiency required careful and cautious handling. He (Mr O'Neill) also had particulars of two liners of similar dimensions, length, draught, displacement, and fineness, one propelled by reciprocating engines and the other by turbines. At sea speed, the power required for the turbine vessel was 20 per cent. greater than for its reciprocating competitor, due, not to any difference of form, because they were both developed from the same model experimented with by Mr Froude, and should have the same total resistance, but to differences in efficiency of the machinery. The acceptance of the controlling influence of stability might not have received the concurrence of Mr Hillhouse, which was to be regretted, but it was gratifying to find that other speakers recognised its importance. It was unnecessary to draw attention to Mr Hillhouse's invitation respecting the 8600 tons vessel of Table I., column 5a, as "one of the many alternatives, etc.," as in

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this case it was the minimum displacement, and 35,600 tons the maximum which required equal power to secure equal speed, and this was actually true. The impossibility of finding space and weight for machinery on the lower displacement would be evident to the casual observer. In the discussion on the "Lines of Fast Cruisers," published in the Transactions of the Institution of Naval Architects for 1903, no less an authority than Sir Philip Watts stated that:—"Regarding the size of Atlantic liners, they are slow vessels compared with our cruisers," and that "the 'Campania,' with 53,000 I.H.P., could reach 25 knots without alteration of form, but with suitably shaped hollow lines could be driven at 25 knots with 35,000 I.H.P.—these speeds obtainable in a comparatively smooth sea." Further, Sir Philip was of opinion that, it was "comparatively immaterial at the speeds she usually maintains whether she has a straight or hollow water line," so that if Mr Hillhouse would search diligently the figures of Table I., he would ultimately find suitable dimensions without "radical departure from current practice" agreeing somewhat with the above. Mr. Hillhouse deprecated the apparent contradictory statements as to the value of form, but unfortunately disassociated the various statements from their surroundings. Taken in conjunction with their contexts, the views expressed were perfectly reconcilable. Mr. Hillhouse referred to a difference between M. Rota's curves and those which appeared with the paper. Fig. 20 was a copy of the original curves of resistance of models 5 and 7, following the method of "constants," from which it would be seen that they did intersect. Curve 5, it would be observed, showed a pronounced hump. Regarding the ratio of I.H.P. to displacement, which Mr Hillhouse thought told adversely against the smaller vessel, the ratio of I.H.P. to displacement in the new Cunarders was as 2 to 1. In the "Campania," modified as suggested, the ratio was slightly less, and in the vessel herself very much so at maximum speed, so that even on coal consumption

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grounds and paying weight, the smaller and initially cheaper ship suffered nothing in comparison. Mr Hillhouse made a gratuitous assumption that he (Mr O'Neill) had overlooked a "simple way" of reducing E.H.P., and gave two ships of equal displacement, one of excessive length securing a great reduction of power. He omitted to point out, however, that the vessel thus evolved to secure this economy of power, at the sacrifice of every other element of the design, had a block coefficient of ·476, surely a great departure from current practice, and totally unfit for any known service. Had the relative values of wave-making resistance and skin friction been appreciated, 100 feet could have been taken off the length of this ship, and the block coefficient increased to ·58 without any effect on power and speed. Mr Johnstone's remarks were very interesting, and, as he pointed out, those acquainted with the subject knew that the theory of resistance was based on two laws, but seemed to think that, by merely stating this, finality had been reached. It certainly would be very gratifying to know that the subject of ship's resistance was exhausted, the laws governing the variations of resistances, both wave-making and frictional, being established, but he feared Mr Johnstone was too sanguine. The curves of resistance given in the paper only applied to the special cases, he thought, and

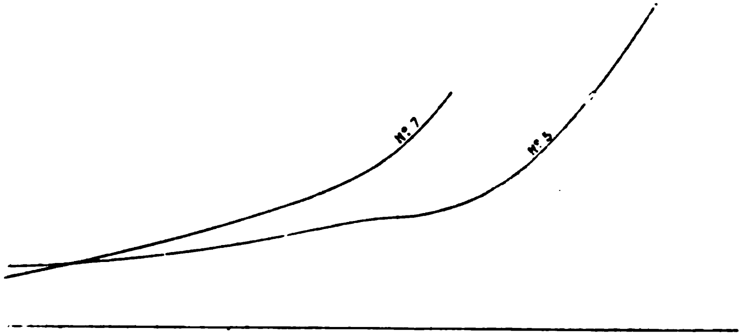

Fig. 20.

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had no general application. Further, Mr Johnstone regretted all the labour that had been expended, and considered some vague statements would have been avoided had reference been made to the laws governing the valuation of resistance, but he modestly refrained from stating these laws. Mr. Johnstone also stated there was no *relation* between wave-making resistance and skin friction, and quoted from the text-books concerning the traditional surface of wave-making resistance, involving three variables. One might very reasonably venture to ask what the relative values of these variables were? What relation did they bear to each other? Having this surface of wave-making resistance, must not skin friction be introduced before any practical use could be made of the information?' If that were so, then it seemed to be really necessary to know the *relative* values of both wave-making resistance and skin friction, and their relation to each other to discover possibilities of design. He was glad that Mr Johnstone appreciated the fact that a period arrived which permitted increased displacement with decreased resistance, and recognised the evidence thereof in the curves, as the previous speaker failed to find any evidence at all of such behaviour. He personally considered the model experiments of Mr Froude and Mr Taylor purely academic. They possessed only qualitative and not quantitative value. When it was established that the law of mechanical similitude could be applied to propellers, when they were under precisely similiar conditions as to immersion and relation to ship, then only could experimental results be applicable in practice. Even when all the information was available, the procedure in the case of the "Mauretania" showed that practical designers attached no real importance to tank propeller experiments. He was afraid Mr Johnstone had been rather hasty in his remarks on stability as affecting displacement. He would find it was possible that the determining factor in both the 100 feet and 600 feet vessels was metacentric height. To develop from the type ship of 100 feet to 600 feet involved equations in

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which metacentric height could remain a fixed value in both vessels. This was quite a different thing from saying stability was proportional to displacement. It was still true, as stated in the paper, that "reduction of displacement makes for both the realisation of stability and speed," since water line area remaining constant, by reduction of weight of machinery, securing a corresponding reduction of displacement, increased stability must result; accompanied by an easier driven ship if the reduction of displacement was suitably made. He was sorry to be unable to assist Mr Alexander, as he was unacquainted with experiments on the friction of water over surfaces travelling at the rates he mentioned. With him, he thought that it would be extremely valuable if the formula for efficiency of propellers could include the effect of friction, to which end it was to be hoped experimenters who were fortunately placed would direct their attention. He could only express to Mr Ward his thanks for the honour he had done him in contributing to the discussion. Mr Ward's analysis of the curves lucidly explained the reason for the happenings to performance due to variation of dimension, and he was especially pleased at his reference to the greater proportional power required when the draught became very great. He was also in accord with Mr Ward in reference to stability. It was quite possible to increase stability by increasing the area of water plane, either by augmenting beam or filling out the ends and fining, the coefficient, but the point he specially wished to draw attention to was, not that reduction of stability and displacement made for the attainment of speed, but that reduction of displacement made for both the realisation of stability and speed. This statement hinted at reducing the weight either of hull or machinery, or both, to which Mr Foster King made reference. Mr Ward's remarks concerning endurance were valuable, and he (Mr O'Neill) was pleased to find that he was not alone in the belief that high rotation of machinery was not detrimental to efficiency. Whilst he agreed that the propeller

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problem was still enshrouded in darkness he had hope that a high-speed propeller, enabling the full efficiency of the turbine to be attained, would yet be devised.

On the motion of the PRESIDENT, Mr O'Neill was awarded a vote of thanks for his paper.

The vote of thanks was carried by acclamation.

Correspondence.

Prof. **HERBERT C. SADLER**, D.Sc. (Member), considered that the problem of speed and power of ships was always one of great importance, and he was sure that all welcomed any further light upon the subject. For a given speed, service, and type of machinery, the ultimate choice of dimensions did not, however, permit of very great latitude. In most services draught was a fixed quantity, and this, in connection with stability and sea-going qualities, more or less fixed the beam. In actual cases, therefore, one was usually forced to length in order to obtain speed. The curves shown in the paper were all for fine vessels, and in this type there was not much room for general change in distribution of displacement, especially when dimensions were fixed. As, however, the Author had touched upon the question of distribution of form, the accompanying curves might be of interest to members of the Institution, although they applied to fuller types. A series of experiments had been carried out in the experimental tank at the University of Michigan, U.S.A., upon the effect of distribution of displacement only, the length, breadth, draught, and displacement all remaining constant. The two extreme curves of sectional areas for the two types were shown in Fig. 21, and in general represented a vessel with no middle body and rather full ends, and one with parallel middle body and rather finer ends. The curves of resistance in pounds per ton of displacement were given and plotted to a speed-length ratio base. The effect of the fine ends, especially the fine bow in both forms, might be seen by comparing the curves I. and I.a for

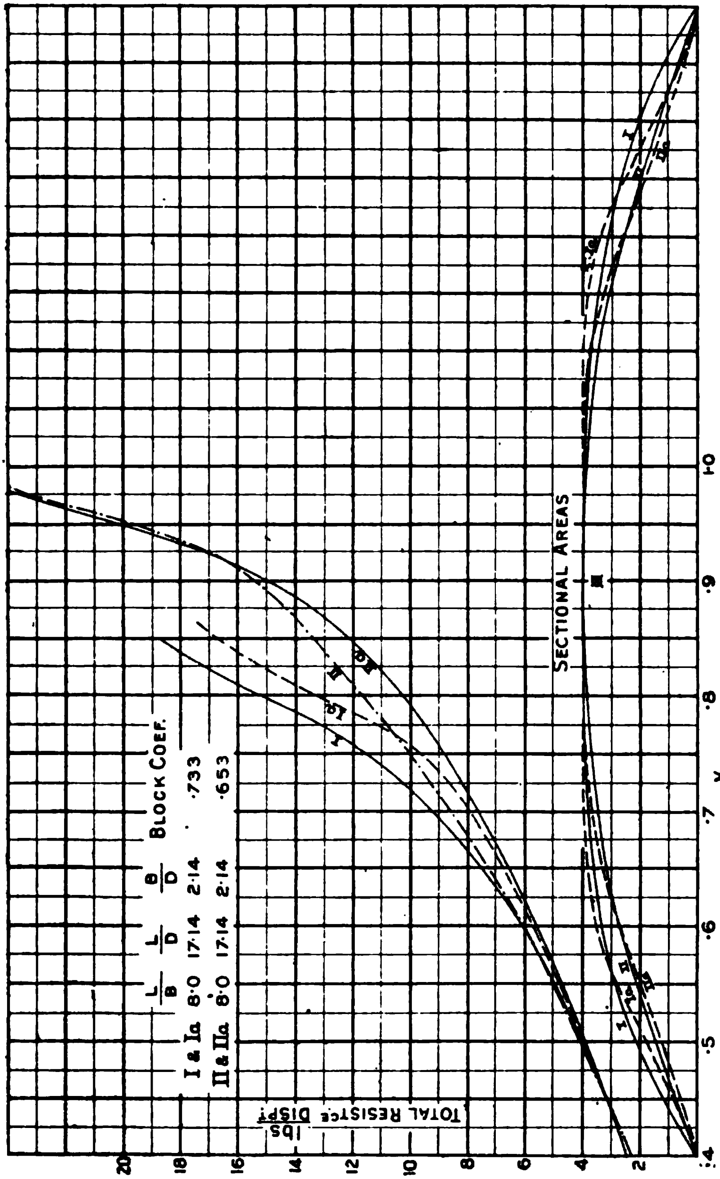
TOTAL RESISTCE / DISPT lbs
SECTIONAL AREAS
L/B L/D B/D BLOCK COEF.
I & Ia 8·0 17·14 2·14 ·733
II & IIa 8·0 17·14 2·14 ·653
I
Ia
II
IIa
$\frac{V}{\sqrt{L}}$
·4
·5
·6
·7
·8
·9
1·0
2
4
6
8
10
12
14
16
18
20

Fig. 21.

Prof. Herbert C. Sadler, D.Sc.

a vessel of ·733 block co-efficient, and the curves II. and II.a for a vessel with ·633 block coefficient. In the case of No I., the difference in resistance at about the maximum economical speed amounted to about 20 per cent. in favour of the vessel with the fine ends and parallel middle body; and in the finer form, the difference was somewhat less, but still appreciable. Further experiments upon the same lines were in progress for different types, and until complete it was not safe to draw general conclusions. This much might be said that, with a given set of dimensions and displacement, it appeared to be advantageous to adopt a fine entrance and long middle body, rather than a fuller entrance and no middle body. So far as the after body was concerned, the easier form appeared to give slightly better results. The above was submitted as showing that improvement in design was still possible, even when everything else was constant.

Engineer-Lieut. WALTER S. DAMANT, R.N. (Member), observed that Mr O'Neill in his very interesting paper said that the turbine had the advantage over the high-speed reciprocating engine with regard to endurance. He should like to suggest that the very rapid adoption of the steam turbine for marine work, which followed the overcoming of its initial difficulties, retarded the further introduction and improvement of the forced lubrication high-speed reciprocating engine for marine work. More than one of H.M. torpedo boat destroyers were equipped with forced lubrication reciprocating engines, and not only had the wear and tear of working parts been almost nil, but the extraordinary small consumption of lubricating oil had effected a very great economy. It, therefore, was to be regretted that the adoption of forced lubrication in the mercantile service had not had the opportunity of development in reciprocating machinery. The type of forced lubrication referred to was that fitted by Messrs Palmer in H.M. torpedo boat destroyer "Ure."

Mr O'NEILL, in reply, said he was pleased to note

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Professor Sadler considered that, although for a given speed, service, and type of machinery, the choice of dimension was limited, and owing to restriction of draught increased length was resorted to in order to obtain speed, stability and sea-going qualities were necessary factors. He ventured to think, however, that the two essential fundamentals to be considered in practical design work were contained in weight and stability. No doubt those who came into actual contact with ship design were aware that with authentic data it was possible to construct curves representing "equation of weights" and "equation of stability" suitably plotted. By the aid of this information very widely different dimensions could be chosen to fulfil the fundamental conditions of metacentric height and weight, this latter containing as one of its components the proportion assigned to power involving speed. The curves Professor Sadler had been good enough to supply confirmed the statement made in the paper that, redistribution of displacement on fixed dimensions affected resistance, and were specially valuable since they dealt with large block coefficients. The necessity of further experiments being made for different types before general conclusions could be drawn was evident, and it was to be hoped that with the facilities at his command he would prosecute further research work in that direction. Incidentally it might be remarked in connection with these curves that the resistances were equal for vessels II. and II.a when $\frac{V}{\sqrt{L}} = \cdot 925$. The vessel represented by II. having round lines, and that of II.a hollow ones, confirmed previous researches and practice. This block coefficient fairly represented Atlantic practice, and clearly showed that displacements being equal similar power-speed results could be assured irrespective of the character of the entrance or distribution of displacement within the assigned limits. The round lined ship would every time not only secure the speed result on trial, but maintain it at sea better than the hollow-lined vessel. The corresponding lengths of the vessels at 20, 22, and 25 knots were respectively

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467 feet, 566 feet, and 730 feet, being well within actual practice. Another confirmation as to the constancy of resistance at the lower limits of the curves was shown when the length was twice the square of the speed. Further experimental information in his possession, abundantly confirmed since he had written the paper, enabled him to make the additional statement that when $\frac{V}{\sqrt{L}} = 1{\cdot}25$, length, breadth and depth ratio, midship area coefficient, and displacement being constant, total resistance was equal for a range of prismatic coefficient of from ·50 to ·70 There was, therefore, a considerable choice of form for designers available. With reference to Engineer-Lieut. Damant's remarks, regarding endurance of the high-speed reciprocating engine, there was no doubt that, had some similar scheme been adopted in the mercantile marine the reciprocating engine would have been able to have demonstrated its capability of high endurance, and would have had an effect in retarding the introduction of the turbine engine. It was to be hoped, however, that forced lubrication would be further extended in merchant marine practice, especially as its introduction in torpedo boat destroyers and other war vessels had clearly shown its enormous advantage.

REINFORCED CONCRETE AND ITS PRACTICAL APPLICATION.

By Mr. M. Kahn.

Read 18th February, 1908.

Various engineers in Great Britain have already used reinforced concrete to so great an extent that it would seem unnecessary to dwell upon any lengthy arguments advising the use of this material in buildings and other constructions.

Its efficiency has been thoroughly demonstrated, and it is now recognised as a permanent method of construction, proof against the deteriorations to which other materials are subject. The fire at Baltimore gave evidence of its being fireproof; the earthquake at San Francisco showed it, to a great extent, to be proof against earthquake; innumerable instances have convinced users that it is rust proof; and the Pantheon at Rome proves it practically everlasting.

A reinforced concrete structure, cast as a monolith, is more rigid than steel, where rigid connection can only be secured at great cost. The corresponding strength obtained from this cause is one of the reasons for the economy secured in its use, and in the hands of capable designers, girders and other structures can be made as strong in reinforced concrete as in structural steel. Finally, what is most advantageous about it is that its strength continually increases with age.

An engineer, in deciding upon the use of any building material, after satisfying himself as to its suitability and efficiency, inquires as to its probable cost. In all important structures, and in all buildings where steel framing might be used, reinforced concrete will prove an economical structural material. In this country, however, there are many places where it would be of no advantage whatever to have a steel or concrete frame building, so far as the external walls are concerned, on account of the thickness of the walls required by the building bye-laws. If the external walls of the building are to be built in a structural frame, the filling-in should be made of thin panels, and where reinforced concrete is used, these panels need not be more than 5 inches thick. If, on the other hand, brick panels are used, a 9-inch thickness will suffice. As a rule, it is necessary to secure permission from the local authorities whenever it is desired to erect a construction as outlined.

It is erroneous to say that reinforced concrete will always prove the cheapest method of construction. As already stated, there are instances where it is not so cheap, and engineers soon recognise such cases. Middle-sized and small residential buildings, small manufacturing buildings, and the ordinary one-storey type of building, will show very little saving when reinforced concrete is used in their construction. A low retaining wall 6 feet high would be cheaper in brick than in reinforced concrete, inasmuch as it would require a comparatively thin brick wall to withstand the strain, but a retaining wall, say 10 feet high, could easily be constructed in reinforced concrete cheaper than in brick. Isolated girders and roof trusses high in the air will invariably prove cheaper in steel than in reinforced concrete; but a steel structure, after having been built, will always require a certain amount of upkeep, and the maintenance charges thus entailed will have considerable influence on the total cost. In brief, though the material under discussion may not always be the cheapest form of construction, it is generally the most economical when all things are taken into consideration, such as the additional safeguard against fires, with a corresponding efficiency in one's plant, the reduction in fire insurance premiums, and also the reduction in maintenance charges.

One of the reasons for the popularity of reinforced concrete lies in the fact that the constituents from which it is made can easily be obtained in almost any locality. In every part of England there are cement mills, and it is never necessary to look far for sand and crushed stone or ballast. These materials being found near the site produces a considerable decrease in the freight charges of building materials. The only remaining constituent which need be brought any distance is the reinforcing steel, but such steel will only be about 20 per cent. of the weight of the material which would be used in an ordinary steel structure, and consequently the freight is reduced in accordance therewith.

In the selection of materials, the question is often asked whether preference should be given to either crushed stone or ballast. Engineers are wont to object to the use of the latter, on the ground that the surfaces are generally round and too smooth. It has often been demonstrated that round, smooth ballast gives just as strong a concrete as crushed stone. This statement might be limited by the fact that in the early stages, say at the end of two weeks, crushed stone concrete will be found to be a little stronger than ballast concrete, but at the end of 30 days, ballast concrete is just as strong as stone concrete, and from that time on its strength begins to surpass it.

Ballast is often considered unsatisfactory as a fire-resisting material. At a fire test made recently, it was found that ballast concrete would not go through the ordeal; but the ballast used in that test was uncrushed, and portions of it were of considerable size. Large stones when heated to a certain temperature will fly apart, owing to the internal strains existing therein, but small stones, heated to the same degree, will not disintegrate. If the ballast used in that test had either been crushed, or screened to pass a ¾-inch mesh, the floor slab in question would have successfully withstood the test. A similar test was made by myself for the New York City Fire Department, in 1904, using crushed ballast concrete, with satisfactory results.

With reference to sand used in concrete, some engineers specify that it shall be sharp and coarse. It is, however, very probable that these specifications will soon be eliminated. It has been recently proved that a moderately fine sand will give a stronger concrete than sharp, coarse sand. In the selection of this material, however, it is necessary to discover whether it contains chemicals which might act on the cement. Sand taken from beds in contact with impure water, kills the action of the cement, and should be condemned. Pit or bank sand is a very satisfactory kind to use. The cement should be of the very best grade, and should be subjected to many mechanical tests during the progress of the work. There is no necessity to dwell upon this material, as the products now being turned out by the various leading English mills are of such excellent grades that very little difficulty should be experienced in securing a proper quality. In this respect English cements are probably the best in the world. They are fully 100 per cent. better than American, and many times better than Belgian cements.

The handling and mixing of concrete is a feature which, to a great extent, governs its cost. Many engineers object to the use of machine mixers. The use of a good batch machine mixer is advisable, however, on every large construction. When the concrete is mixed by hand it is turned from six to eight times, but when a machine mixer is used, the concrete is turned at least twenty times in a much shorter period, and at a considerable saving in expense. In truth a good machine mixer should actually be specified, provided the size of the construction and the amount of concrete to be mixed, warrant the expense of installing such a plant. In general it will be found that in all constructions involving a quantity less than 400 or 500 cubic yards the concrete will be more economically mixed by hand than by machine, but in larger constructions the reverse is true.

Fig. 1 shows a mechanical mixing plant consisting of a machine mixer, steam boiler, and engine, all mounted on a truck, which enables the mixture to be discharged directly into its final position. On a parallel track runs a truck which discharges the materials directly into the mixer. This plant, which was installed at a cost of less than £800, mixes and places 125 yards of concrete per day at a cost of 9d. per yard. The price of mixing and placing concrete by hand under similar conditions would have been 2s. 6d. per cubic yard, so one can readily determine how soon the plant would pay itself.

At the construction of the Bournemouth Gas Company's premises, the concrete was mixed by a stationary mixer, and hoisted and placed by a trolley running up an incline. Probably the best arrangement for hoisting concrete is that in which a self-dumping bucket is raised up a tower and automatically tipped at the required level. The cost of such an arrangement is about £150, and the saving over other methods of hoisting is about 5d. per cubic yard.

One of the most important matters in connection with reinforced concrete is that concerning its inspection or supervision. An inspector who is too fastidious can do quite as much harm by over-inspection as one who does not sufficiently perform his duties. An inspector should be the intermediary between the owner and the contractor, and it should be his duty to see that everything runs smoothly, his main object being to keep the interests of the contractor in line with those of the owner, thereby securing the best results. An over-anxious inspector is apt to disgust the contractor, causing him to lose interest in the construction, with the result that poor work must follow. It is assumed, of course, that good materials and workmanship are always to be demanded.

The following instructions for inspecting ferro-concrete construction, written for the benefit of my inspectors, may be of interest:—

"Centering and supports must be properly braced and cross-braced in two directions. False work or centering should be removed with great care, and without injuring the construction by dropping heavy sections thereon. No centering should be removed in less than three weeks. A good rule governing the length of time for the centering to remain in position is two days for each foot of span, that is, a span of 12 feet should remain centered for 24 days, and a span of 16 feet should remain centered for 32 days. The supports should under no consideration be removed in less than three weeks. No centering need remain in position longer than 45 days, no matter how great the span. Temporary shores should be placed under all main girders which might be subjected to heavy loads during the course of construction. Where centering supports come on soft ground, a heavy plank or timber should be placed underneath them to prevent their being forced into the earth. Reinforcing steel should be free from oil and paint. A slight film of rust is not objectionable, but all loose scales should be cleaned off with a stiff wire brush. Where Kahn bars are used as reinforcement the diagonals should be bent up to an angle of 45 degrees with the main tension bar.

" Samples of materials used should be subjected to mechanical tests. Only clean water, free from acids and strong alkali should be used in the mixing. The resultant should be that known as a wet mixture rather than that termed a dry mixture. No concrete which has once begun to set should be deposited thereafter in the forms. Sections which have recently been concreted should not be travelled over. Concreting should never be carried on in freezing weather. In case the concrete, after having been deposited, should become frozen, the centering should never be removed until it is absolutely certain that all the frost has disappeared."

Lack of time prevents the consideration of these instructions in more detail, but a similar set of instructions can be drawn up by any engineer in charge of this form of construction. Probably one-half of the responsibility of a reinforced concrete structure depends upon the inspector in charge, and it is important that he should be as familiar with the class of work as the foreman who is to carry it out, and, at the same time, he should bear in mind the objections to his being too theoretical in his inspection; the practical man will secure better results. Since the Royal Institute of British Architects thought that reinforced concrete, as a structural material, was of sufficient value to devote to it the attention and research of a special committee, which committee summarised the general principles for designing reinforced concrete, and published formulæ recommended by them, there is no necessity for me to burden this paper with any mathematical problems. Nor is it necessary to attack the methods of calculations employed by the patentees of the various systems, unless such calculations are based purely upon empirical formulæ. Empirical formulæ should not now be used, for sufficient progress has been made in scientific research to establish definite results, and though various authors who do not employ empirical formulæ differ widely in their methods of calculation, it will usually be found that there is very little difference in the result, no matter what method is used.

The theory and calculations which I adopt are practically the same as those adopted by the committee appointed by the Royal Institute of British Architects. However, in using these formulæ it must be borne in mind that no method of designing beams, based only on the calculations of the bending stress, can be correct. Such a design assumes that the concrete will, within itself, resist all the shearing stresses, and all internal tensile stresses resulting therefrom. That concrete is incapable of doing this is now generally recognised, and in proper designing, provision is made for overcoming all internal stresses whether they occur at the end of a beam in the web, or at the centre of the beam in the bottom flange.

In a beam uniformly loaded, the maximum tensile stress on the steel will occur at the centre of the span, where the bending moment is greatest. At the same time, the maximum shearing stresses on such a beam will occur near the points of support. The ultimate resisting value for concrete to shear is about 300 lbs. per square inch, and if the total shearing stress on any plane exceeds 300 times the area of that plane, failure is bound to occur therein. This is shown by Fig. 2, which is produced from a photograph of a test conducted by the United States War College on a reinforced concrete floor slab. It will be seen that failure occurred, not at the centre due to the bending moment, but near the supports, due to the internal shearing stresses.

It is interesting to observe the direction of the planes wherein the failure took place. They all curve from the supports at the bottom towards the centre at the top. This might appear to be accidental, but an explanation of it is readily apparent when Rankine's theory of the principal lines of stress in a beam subject to bending is called to mind. Comparing this test with Rankine's theory, the planes of failure in the former are nearly identical with Rankine's curves of principal compressive stress. Such curves at all points are at right angles to the lines of principal tensile stress. Concrete being weak in tension, the various particles will fail in directions parallel to the lines of principal tensile stress, and the plane formed by the failure of these particles will lie in the lines of principal compressive stress. Reinforcement could be adopted, which would embody small rods curving along the lines of principal tensile stress. A beam thus reinforced would be constructed with a minimum amount of material for the maximum strength, but such a system of reinforcement would necessitate the use of a multitude of small rods, the impracticability of handling of which is readily apparent.

The next step in reinforcement would be to have a main tension member running horizontally in the beam, using auxiliary reinforcements, or arms, in the vertical plane, to provide for the shearing stresses existing at the ends of the span. Such auxiliary members should be inclined so as to cross the planes of rupture at nearly right angles. An angle of 45 degrees seems to be the desired one, for laying theory aside for the moment, and referring to the test, it would appear more logical to have auxiliary members crossing the planes of rupture at right angles, when they will prove more effective than if placed vertically. I should like to call attention to the fact that the concrete surrounding the reinforcement in this test was the first to fail and break away, leaving the steel bars exposed.

Probably the best comparison of values between vertical and inclined auxiliary or shear members can be seen in Fig. 3, which represents a beam with inclined auxiliary members. The arrows indicate the direction taken by the forces in transmitting the loads to the supports. The dotted lines are shown as compressive forces, and the full lines as tensional forces. Note that the tensional forces running obliquely towards the support can be decomposed into vertical and horizontal components, the vertical one pulling up on the steel, and the horizontal one tending to throw an extra tension into the steel reinforcement.

The same figure shows a beam with vertical shear members, in which the compressive forces run diagonally towards the supports, instead of vertically as in the previous instance. Inasmuch as the compressive forces, which are taken up by the concrete, now run diagonally, they, too, will have horizontal components, which will tend to make the vertical shear reinforcement slip along the bar. Of course, in reinforced concrete the steel is surrounded by concrete, which, it can be assumed, takes up this horizontal component to the diagonal force; but this concrete in question, being farthest from the neutral axis, is strained to the greatest extent, and is already overworked, therefore in calling upon it to do this extra work, an improper demand is made. Proof of this lies in the fact that in the test already referred to, Fig. 2, the concrete surrounding the bars was the first to fail and break away, leaving the bars exposed, to which point attention was specially called. Therefore, in a test to destruction, when loose shear members are used, the concrete will fail to transmit the stress in the stirrup to the main tension member, as there will be no concrete around the bars to perform this function. The result under test will be failure by shear, and in truth this was actually demonstrated at the testing laboratory of the French Government, a couple of years ago.

When a beam is loaded internal stress arches will, of necessity, tend to carry the load towards the supports, and each arch should have some abutment to take care of its horizontal thrust. This result can only be obtained by having some rigid connection between the shear reinforcement and the main tension rod.

In a beam where vertical shear members are used, and placed loosely around the bar, it will be readily seen that the shear reinforcement, in order to be effective, should be rigidly secured to the bar, so that the arches will not tend to cause the members to slip along the tension rod. It follows from the above, that in a properly reinforced concrete beam, the three fundamental principles of reinforcement are—*firstly*, the concrete should be reinforced in a vertical as well as in a horizontal plane; *secondly*, that the shear reinforcement should be inclined at an angle of 45 degrees in preference to being vertical; *thirdly*, that all shear members should be rigidly connected to the main tension member.

At the present time many systems of reinforced concrete are being used in Great Britain, each of which has its advocates. Fig. 4 illustrates three typical examples of reinforcement. The upper one is that invented by M. Hennebique, of France. Here will be seen the main tension bar, which consists of a round rod, and also the vertical stirrups made and placed in the concrete by the workmen during the progress of construction. In order to be efficient, they must be accurately placed and held in position until the concrete is rammed round them. This necessitates careful supervision, for if the stirrups should be improperly placed, they might just as well be omitted altogether.

The second example is the system invented by M. Coignet, of France. In this system a main tension bar is used in the bottom, and also a small rod in the top. The inventor uses

Fig. 1.

Fig. 2.

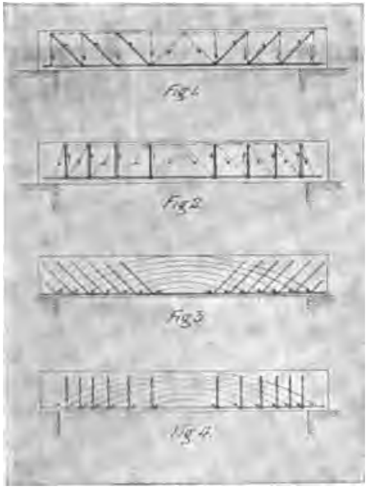
Fig 1.
Fig 2.
Fig 3.
Fig 4.

Fig. 3.

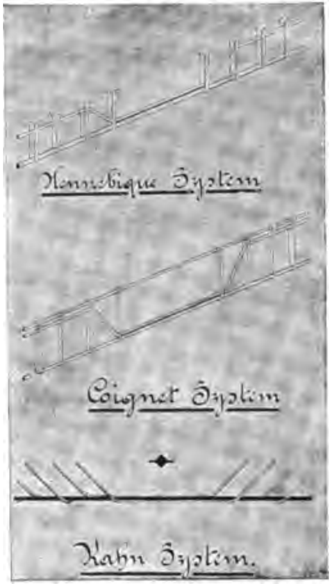
Hennebique System
Coignet System
Kahn System.

Fig. 4.

Fig. 5.

Fig 6.

Fig. 7.

Fig. 8.

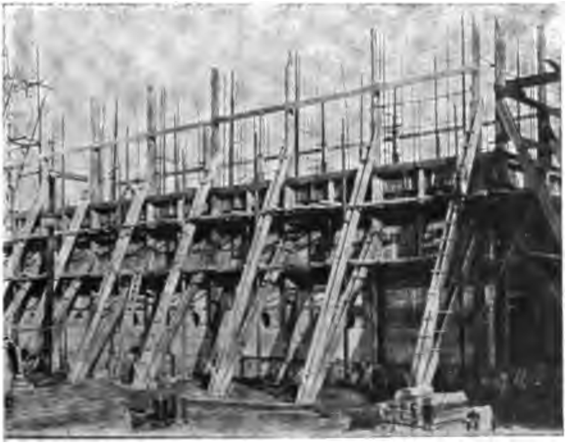

Fig. 9.

Fig. 10.

Fig. 11.

Fig. 12.

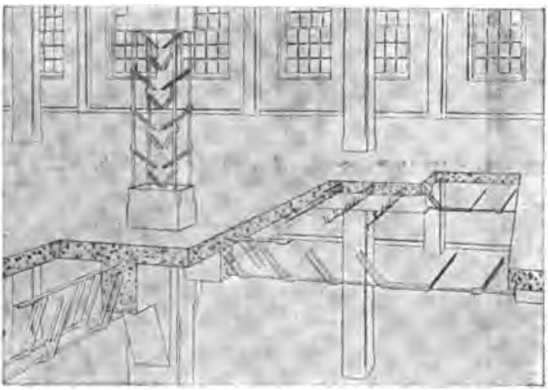

Fig. 13.

Fig. 14.

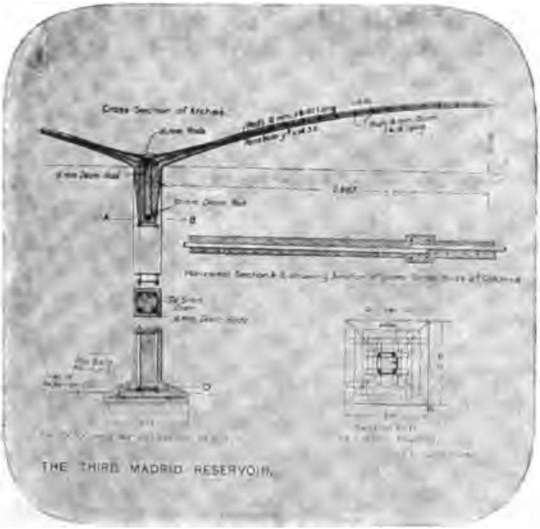

Fig. 15.

vertical stirrups, and bends them over the top bar. As in the previous system, so in this one, all the loose pieces must be put together by the workmen at the site, and the same supervision is required.

No attempt was ever made to have the stirrups rigidly connected to the bar until within the last four years, when the Kahn bar was invented. This is shown in the third example, and consists of a main tension bar, on which diagonals are rigidly secured. A square bar is rolled with two wings projecting from opposite angles, as shown in the cross section, Fig. 4. These wings are struck up from the bar to form stirrups, but are left attached to it by shoulders, which are not sheared away. In this way the stirrups are part and parcel of the main reinforcement. Where the bending moment is at a maximum, the full section of the bar is there to resist it, while towards the points of support, where the bending moment diminishes, and shear increases, the surplus metal not required in tension is turned up to take care of the shearing stresses, which here are at a maximum. This means that there is a distinct saving in material where this bar is used, for in all other systems, whatever tension reinforcement is used in the centre of the beam it must run through to the end, and all the stirrups used to provide against shear must be made of other metal. In the Kahn bar, however, the stirrups, or shear members, are made from metal which would, under other circumstances, be wasted. The bar, with its wings struck up by standard dies at the works, comes to the site ready to go into the concrete. No work need be done on it by operatives, either in the placing of the stirrups, or holding them in position while the concrete is being placed. This entirely eliminates any error on the part of the workmen in properly placing the stirrups, for when a Kahn bar is put into position, all the stirrups must also be in position, unless they are maliciously torn off. Such a form of reinforcement greatly relieves the duties of the inspector, as it is not necessary for him to watch the placing of every stirrup. This placing of stirrups is probably the most complicated part of reinforced concrete work; the entire success of the structure depends upon it, so one can realise how carefully it should be attended to.

It will further be noticed that the shear members, or stirrups of the Kahn bar, differ from both previous examples in that, instead of being vertical, they are inclined at an angle of 45 degrees, and this system seems to embody all the necessary fundamental principles of reinforced concrete.

In the selection of reinforcing material, it is not necessary to go into the matter of shape or form of reinforcement. A round bar is as good as any deformed bar, providing proper provision is made for all internal strains. This statement must be true, as all the theory of reinforced concrete is based on the assumption that the tensile stress of the reinforcement is transmitted to it only by the adhesion of the concrete, and that by embedding a plain, round rod a certain distance within the concrete, its full tensile strength can be developed. Were it not so, millions of pounds worth of structures, built on these assumptions, would fail to fulfil the conditions for which they were designed. For a considerable length of time mechanical bond bars were used to a great extent in the United States, but the use of such reinforcement is now being abandoned, and engineers seem to be coming back to the use of plain, round rods.

Probably every engineer recognises the extensive field wherein reinforced concrete can be used. It immediately recommends itself for use in all harbour works and water-works in general. Buildings of every description have already been, and are being, built with it, and engineering problems of the most complicated character are successfully carried out by its adoption.

Fig. 5 gives a view of the Lake Park Bridge, which has a clear span of 108 feet, designed for ordinary light load traffic. It is interesting to note the decorative effect which can be produced by reinforced concrete, as the appearance of the bridge harmonises so well with the surrounding landscape. No attempt has been made to make it appear otherwise than a reinforced concrete bridge, all imitations of stone work being carefully omitted.

A view of an aqueduct in course of construction at Blackburn is given in Fig. 6 which shows the centering and reinforcement in position, ready to receive the concrete. This aqueduct is to carry a roadway which will be sandwiched between a creek underneath and the Leeds and Liverpool Canal.

The Richmond viaduct is probably the largest structure of its kind in the world. It is 2800 feet in length, and rises to a height of 70 feet above ground level. It is built on a $1\frac{1}{2}$ per cent. grade, and a 7-degree curve, which necessitated complicated details. The entire structure is built on the Kahn system of reinforced concrete. Fig. 7 shows a test which was made on this viaduct upon completion. A locomotive weighing 78 tons, followed by two trucks with a total load of 134 tons, was run over the entire structure at various speeds. According to specification the deflection was not to exceed $\frac{1}{1000}$ part of the span in any case. As a matter of fact, the maximum deflection obtained was $\frac{1}{2000}$ part of the span on a girder 67 feet long.

Fig 8 illustrates the town quay erected for the Southampton Harbour Board. This quay is entirely erected in reinforced concrete on rather unique principles. The problem was to reconstruct a steel and wooden quay without hindering the owners from carrying on their work. A period of four months was given to execute a piece of work which would take, under ordinary circumstances, one year. It was accomplished, however, by erecting the quay in pieces on another site, and afterwards putting it together in the final position. Eight months were spent in preparing the parts of the quay, and four months in erection in its final position, in other words, saving to the owners eight months' working time.

Fig. 9 shows a view of the Swanscombe coal pocket during course of construction, with the centering in position. It was all bolted together, and erected in such a manner that it could readily be taken down and used in a series of coal bunkers which were constructed by the owners. It might be added here that the cost of centering is probably the most important feature to be studied in the design of reinforced concrete constructions. The centering amounts to practically one-fourth of the total cost, so a little study on the part of an engineer in laying out his structure in order that the centering can be used several times, will result in a considerable reduction in the ultimate cost of the work.

An interior view showing the construction of the roof principals at the Hammersmith Public Baths is shown in Fig. 10. These principals are interesting on account of the fact that they are designed as arches, of 55 feet span, and are carried on stanchions 20 feet high. No tie rods or abutments were used to take care of the horizontal thrust of the arches, the columns being designed to resist this as a bending force. The galleries which run around the building are cantilevered from the galleries which support the roof arches.

Fig. 11 illustrates a test which was carried out on the floors of the Farwell, Ozman and Kirk hardware storage house. The building was designed to carry a load of 5 cwts. per square foot, and being nine storeys high, the ground floor columns were called upon to carry very heavy loads. A typical floor panel was erected on the ground, and was carried by four piers to represent the four columns. Although the floor was designed to carry but 5 cwt. per square foot, nevertheless this isolated panel was tested to 2 tons per square foot, and under this great weight the deflection was only $\frac{3}{32}$ of an inch. The span of the girders was 16 feet clear, and the floor slab was of equal span. From the test it will be seen that though the specification called for a safety factor of 4, nevertheless when designed in reinforced concrete, the construction really possessed a safety factor of 8.

Fig. 12 gives an exterior view of a cold storage warehouse, clearly showing the American skeleton type of construction. The walls of this building are but 9 inches thick, being merely panel walls. The Government is adopting this type of construction, and a building has just been completed for H.M. Office of Works at Birmingham. A second building is under consideration with the same method of construction. In accordance with a report submitted by Sir Henry Tanner to the House of Commons, this form of construction produces a saving of over 20 per cent. in the total cost.

Fig. 13 shows the general application of the Kahn system to various parts of building construction. The concrete is shown broken away leaving the reinforcement exposed. Over all points of support inverted bars are used to produce the effect of continuous action. Attention might be drawn to the simplicity of construction where bars, having their shear members rigidly attached, are used. The columns in the sketch are reinforced with the same bars, one in each of the four corners having their diagonals turned inwards. This produces a regular latticed-column effect. Objections are sometimes raised to the use of bars having shear members rigidly attached as column reinforcement. Personally, I cannot see the difference whether the shear members are loose or rigidly attached as far as ease of construction is concerned; in fact, I believe the construction is much simpler when rigidly attached shear members are used. At any rate there is a distinct advantage as far as strength is concerned. In the buildings for H.M. Office of Works at Birmingham this system is used in the columns throughout.

Fig. 14 illustrates the construction of a floor where Kahn bars are used as a reinforcement. It is interesting, as it shows all the five stages of the work. First the centering in the foreground, then the first layer or fire-protection of concrete, then the reinforcement placed in position, next the main body of the concrete, and finally the granolithic finish, which is laid immediately after the main body of the concrete. This is done to secure a perfect bond of the granolithic finish to the floor, and although being a trifle more costly, it certainly gives a better construction. When the reinforcing bars are placed correctly in this system all the shear members are in their correct position without further ado, and instead of having a half dozen men to place the reinforcement as is necessary in the loose stirrup system, only one man is required to do the work. This shows clearly the great amount of labour saved by the contractor in handling this system.

In view of the large number of structures which have been erected in reinforced concrete, it might be asked—What is the percentage of failures as compared to the number of successes? This would be a logical question, and it is proposed to deal with it accordingly. That failures do occur is more or less obvious, but one of the objects of this paper is to show, *firstly*, why they occur; and, *secondly*, the means of preventing them. As a general statement, most of the failures which have occurred have been due to carelessness or ignorance on the part of supervisors or workmen engaged on the particular construction referred to. This being so, it would appear a simple matter to provide means for obviating the same, more especially as failures due to faulty design are but rarely heard of.

An accident occurred at a building being erected for the Kodak Company at Rochester, New York, and a brief statement of the causes governing the accident may be interesting. The building referred to was to be constructed of concrete in a limited time. The foreman in charge, being desirous of hastening the execution thereof, one rainy day, instructed some outside workmen to remove the centering from under the floor, the concreting of which had been completed some 30 days previously. Instead of seeing that his instructions were carried out, he allowed the men to remove the centering without paying the attention to them which the importance of the work required. The result was that centering was removed from work which had only been completed 10 days before. The accident was solely attributable to this, and the foreman was to blame for improper attention to his duty.

The lessons to be drawn from this accident are, *firstly*, that the foreman must be capable of carrying out simple instructions implicitly; *secondly*, that centering dare not be prematurely removed, or indeed removed at all under any circumstances, except under the personal supervision of the foreman; *thirdly*, that the removing of centering is just as important as the construction of the floors, and should be as carefully supervised.

A simple method of preventing such failures would be the attachment of a small label to the centre uprights supporting each girder form. On this label could appear a notice to the effect that the centering should not be removed until a certain date, the date, of course, being left blank, to be filled in by the foreman as required, but to be not less than 30 days after the concrete is laid. This simple precaution would add considerably to the safety of reinforced concrete structures, at no material increase in cost.

This particular accident is mentioned because it is illustrative of the majority of failures which have occurred. As previously stated, accidents due to faulty design are but rare, but that they do occur is evident from the accident which happened at the Madrid reservoir, which has a capacity of 106,000,000 gallons.

A drawing showing a cross section of one of the bays of the roof of this reservoir, which was designed on the lines of parabolic arches of nearly 20 feet span, with a rise of 2 feet, is shown in Fig 15. With a span of 20 feet, the thickness at the crown of the arches is only 2 inches. It is assumed that when the roof is uniformly loaded over the entire area, the thrusts of the various arches will counteract each other, thus allowing the arches to carry their load. Theoretically, the structure is correct, but in designing it, the engineers appear to have forgotten that with an area such as this it would not be possible to place the entire load on at once. As a matter of fact, in order to place the load, it was necessary to start at one end and work towards the other, loading some of the arches before the others, with the result that thrusts in the abutments were produced, which were transmitted to the unloaded arches, thus causing them to buckle upwards, doubtless because of the thinness at the crown. No lateral stiffness could be depended upon from the columns, which were too small in diameter for their length.

In testing the structures the engineers used sand about 2 feet deep on a strip 13 feet wide over the entire width of the reservoir. This weight of sand was safely carried overnight, but the following day one of the bays collapsed, with the result that the thrust previously referred to caused the collapse of all the adjoining bays, until the whole structure fell in like a pack of cards. The lesson to be learned from this failure is that though a design may be theoretically correct, consideration should also be given to the method in which the structure is to perform its work.

An arch, when designed to carry a uniformly distributed load, will do so if the load is placed upon the entire arch at the same time, but if, for one reason or another, the eccentric loading of an arch is necessitated, it should be designed to provide for contingencies of this sort.

However, the failures in reinforced concrete bear but a very small percentage of the number of successes. Over 2700 buildings, involving a total expenditure of more than £10,000,000 sterling, have been constructed on the Kahn system, and only four accidents have occurred. Figures of this kind should prove the safety of reinforced concrete, more especially as even the small percentage of failures referred to, could be eliminated with the exercise of ordinary intelligence and supervision. For this reason, when an accident takes place, care should be taken to avoid condemning any particular method of reinforcement before the actual circumstances are known. It is possible that the best design, and the best method of construction, when placed in the hands of careless workmen, will result in disaster. Hence the emphasis which has been laid upon the details of construction work.

In brief, I would state that reinforced concrete is, in my opinion, the best form of construction when properly handled, and the worst when improperly handled. Such being the case, it behoves the owner and the architect to ensure that only the best class of contractor is employed on his work. Reliable contractors can only afford to carry out work which will ensure them a fair amount of profit, and if, by the adoption of reinforced concrete, the owner is saved 10 per cent. of the cost of construction, it is advisable to grant the contractor any extra saving, so as to ensure his giving a construction which will prove satisfactory in every respect.

When owners and engineers realise this point, and act accordingly, reinforced concrete will then reach that position in the category of structural materials where it justly belongs.

Discussion.

Mr C. P. HOGG (Vice-President) observed that the use of concrete reinforced by steel bars or rods was gradually extending, and Mr Kahn had shown in the paper how it had been applied in a great many different cases. Mr Kahn, he thought, had made good his claim that his system was, perhaps, more scientifically designed than some others in general use; at least so far as simple means were concerned. He was not sure, however, that the system was any better in the case of continuous beams. Mr Kahn said that many engineers objected to the use of machine mixers. He himself was not one of them, and he did not know any engineer of experience in concrete work who did object to machine mixing of concrete. There were one or two machines of the continuous delivery order that did not make good concrete, or, rather, unless the materials were put into these machines with great regularity, they could not possibly give good concrete; but the ordinary machine certainly did make a very much better concrete than that obtained by hand mixing, for the simple reason that the machine turned it over twenty times against probably three or four times by hand. What

Mr C. P. Hogg.

retarded the introduction of reinforced concrete, to a large extent, was the difficulty in getting contractors to take sufficient care. It required great care to make good concrete suitable for acting as a beam when reinforced by steel, and the directions or instructions which were given by the Author for the benefit of inspectors would be very useful to anyone contemplating the introduction of reinforced concrete. It might interest the members of the Institution to know that the new buildings for the Institution, in Elmbank Street, were built on a raft of reinforced concrete. When the site was cleared and borings taken, sandy clay was found, varying from 10 to 16 feet in thickness, overlying boulder clay. It became a question how to get the foundations down to the boulder clay? Several systems of piling were contemplated and ultimately it was determined to adopt a raft of reinforced concrete, which, he was happy to say, had been entirely successful.

Mr W. M. ALSTON (Member of Council) said he was endeavouring to gain some experience of reinforced concrete by constructing a piece of wharf in Glasgow Harbour. The work was not being executed according to Mr Kahn's system, but under the Hennebique system. In driving the piles he had been rather disappointed that they did not stand the hammering of the ram so well as was expected. He would be glad if Mr Kahn would give his experience regarding what his piles would stand. One had often heard glowing descriptions of how piles had been driven, but he suspected that in those cases they must have been driven through material of a soft character. He took it from the paper that Mr. Kahn's system had been applied more particularly to buildings than to engineering works. Reinforced concrete was one of the latest materials of construction, and there was no doubt that it was making great strides on the Continent and in America, and now in this country. He was glad to find Mr Kahn making such a frank acknowledgment of the merits of British cement. Cement was a fundamental ingredient, and Mr Kahn

Mr W. M. Alston.

said that the English cements were probably the best in the world, and that they were fully 100 per cent. better than American, and many times better than Belgian cements. One of the troubles the engineer had was to prevent these inferior cements being forced upon him. In the making of concrete, Mr Kahn considered that fine sand was better than coarse, sharp sand, but he (Mr Alston) had been brought up in the belief that sand should be clean, coarse and sharp. In his own experience, exception had often been taken to sand for being too fine. Perhaps Mr Kahn, in his reply to the discussion, would give some indication of the cost of reinforced concrete structures. Taking the cube of a building in the manner common to architects, it would be interesting to know what its cost would be per cubic foot, and with engineering structures what generally was the cost per cubic foot as compared with structures in pitch pine or one of the hard woods.

Mr F. A. MACDONALD said the most interesting portion of Mr Kahn's paper was that which was devoted to the types of steel reinforcement used in reinforced concrete work, and having special reference to that type of bar which Mr Kahn himself had patented. Mr Kahn stated that "no method of designing beams based only on the calculations of the bending stress could be correct. Such a design assumes that the concrete will within itself resist all the shearing stresses." That was true, because the resistance of concrete to shear was feeble. The designer must, therefore, not only reinforce the concrete beam with steel placed horizontally in the direction of the beam, and sufficient to meet the maximum bending moment, but, in addition, must provide further reinforcement, so placed as to meet internal shear in the most satisfactory manner. It was to that auxiliary reinforcement that Mr Kahn called special attention, with reference to the type of reinforcing bar which he had patented. For the purpose of illustrating the importance of this auxiliary reinforcement in a composite reinforced concrete beam, let a material be substituted for the

Mr F. A. Macdonald.

concrete which did not possess any affinity for steel, such as, say, wood. If in that beam of wood a hole were drilled in the longitudinal direction near its soffit, and thereafter a steel bar of the same diameter, which could be moved in the wood, was placed in the hole, one had a reinforced beam, differing only from a reinforced concrete beam on account of the fact that the wood had no affinity for the steel. It was clear that if a beam so formed were loaded, no tangential forces could be transmitted from the one material to the other, and that the reinforcing of the beam would have but little influence on its ability to carry load. But if uprights in metal were fixed on the bar in vertical planes which could be embedded in the wood (as could be done in concrete) in such a manner that the fibres of the wood and the metal were in contact, then the wood and the metal would no longer act separately under load, but would act together, and their combined resistance to flexion would be much increased. That illustration was given to indicate the absolute necessity of auxiliary reinforcement in a reinforced concrete beam. All competent designers in reinforced concrete had recognised that, and various methods had been adopted, such as curving upwards part of the main tensional reinforcement towards the supports, locking vertical stirrups round the main tension bars, and other devices, and that those methods were efficient was proved by the many important structures which had been erected on that basis of design. Mr Kahn had, however, gone a step further and, theoretically at least and provided that other conditions were satisfactorily fulfilled, he thought it was a step in the right direction. Mr Kahn's patented section of reinforcing bar consisted of a central square with projecting continuous wings on two angles, which, when sheared and turned up, formed diagonals of shear members rigidly attached to the central bar, which formed the main tensional reinforcement. The whole advantage lay in the fact that the shear members were rigidly attached to the central bar, and could, to that extent, be relied on to form a series of abutments in the concrete web of the beam which provided for the theoretical internal stress arches. He would, however, add that the purchase of a specially-designed bar was by no means the passport to safety in reinforced concrete work, for whatever might be the predetermined positions and sectional area of the shear members, their resistance must vary according to the shearing stresses. In all cases the designer should closely investigate for shear, and if it were found that the predetermined shear members did not satisfy his calculations, then he should supplement them as might be necessary for each particular beam. On the question of beam design in reinforced concrete, he would summarise by saying that the section of the bar in question would form an excellent tool in the hands of a capable designer, but theoretical skill and practical experience were, and would always remain, the main factors in the successful design of reinforced concrete work. In connection with columns and piles, the method which he (Mr Macdonald) adopted in reinforcing was to tie together the main bars by frequent steel wire ties. Spiral winding might also be adopted. In a reinforced concrete column, tested to destruction, the concrete, owing to tension, really burst apart, and he thought that some system of tying or hooping was desirable in order to directly counteract that tendency. Mr Kahn had referred to an accident which took place some time ago in Madrid, and it would be interesting to know if the extreme lightness of the whole structure—he stated that the arch was only 2 inches thick at the crown with a free span of 20 feet, and that the columns were too small in diameter for their height—did not result from the work being submitted to competition, in consequence of which the lowest offer was accepted. An arch with a free span of 20 feet and a thickness of 2 inches at the crown seemed to him to be cutting matters far too fine, even if theoretically correct. It was, of course, always desirable to have competition among contractors, on definite plans, so that favourable

Mr F. A. Macdonald.

terms might be secured, but once the engineer in charge of the work had decided on the type and system of construction, he should adhere to that type, and see that a full margin of safety was adopted. Although various methods of calculation for the individual members of a structure might be used in reinforced concrete work, it would be found that the results differed but little, and when once the general planning of the work had been definitely decided upon, any economy realised by one system over another in structural details was at the expense of the margin of safety, and not in the real interest of the work. With reference to the examples of work, he thought the Author's statement hardly reflected the enormous importance to which this type of construction had already attained in Great Britain. In England the use and spread of reinforced concrete in recent years had been phenomenal. It had been adopted by the Board of Works, the Admiralty, and the War Office. The new extensions of the General Post Office in London were being entirely constructed in reinforced concrete at a cost, he believed, of, roughly, £150,000. Huge warehouses had been erected in that form of construction by such prominent corporations as the Manchester Ship Canal Co., the Mersey Dock and Harbour Board, the North-Eastern Railway Co., the Great Western Railway Co., and many others, too numerous to mention. Even in Scotland its use was by no means unknown, and such diverse works as elevated reservoirs, bridges, piled jetties, grain silos, and factory buildings could be seen in and around Glasgow. On every side the merits of that class of construction were being recognised, and he would conclude by stating that he most cordially agreed with Mr Kahn that no other form of construction presented so many undoubted advantages, when properly handled.

Mr H. DE COLLEVILLE replied to the discussion on behalf of Mr Kahn, and said that, had Mr Kahn been able to be present, he would have replied to the various questions raised by the speakers in a more instructive manner than he could. In

Mr H. de Colleville.

dealing with continuous beams, the Kahn system offered the same advantages as with non-continuous beams, in this respect that shear members were rigidly attached. If necessary, the bars which were in tension were tied on the reverse side of the beams to those in the centre of the span, and connected together in such a way that the beams were absolutely continuous. It was somewhat difficult to determine the cost of engineering works and buildings, because in many instances one did not know what the cost was of ordinary building methods. When a tender was submitted to an engineer or architect, he did not, as a rule, guarantee any information as to how the price compared with those of other methods of construction. The Company with which he was connected had constructed warehouses in this country for 3½d. per cubic foot. Sometimes, as in London, that was exceeded, but he did not think that his Company had ever completed a structure exceeding 4½d. per cubic foot. Bridges and such like structures did not lend themselves to cubing. There was, no doubt, a great advantage in using reinforced concrete for bridge work, especially in places where access was difficult, and where the freight of heavy girders would mean a great cost. In parts of Scotland where abundance of stones were available, reinforced concrete would be exceedingly cheap for bridges. His firm had repeatedly tendered for bridges in reinforced concrete, and very successfully so against steel and other systems. He had been confronted, particularly among architects, with objections to the introduction of mixers, and he was glad to hear that such objections would not hold good in Scotland. Architects were sometimes rather slow in moving, and the amount of concrete that was used in building works was very small, as compared with engineering works, and no doubt that was why they favoured hand mixing. In piling, he was always careful to tie the rods at the upper end of the piles, and also at the lower end, using stronger wire at the ends than at the middle. He thought that was the recognised practice

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in skilful piling. His Company had not had any broken piles. With respect to fine *versus* course sand, he thought that the idea of using coarse sand was largely due to the selection of sand for cement testing. The British Standards Committee recommended coarse sand for tensile tests of cement briquettes. When Mr Kahn talked about fine sand in preference, he referred to the tests of concrete for compression. Care during construction was certainly an important point, and work in reinforced concrete could not be successfully done without skilled designers and good supervision. The advantage of having shear members fixed to the bar, so that they could not be displaced avoided a great deal of supervision. The spacing of the shear members could be varied by using various bars in one beam, each bar of different length, in such a manner that the position of the shear members was alternated as required.

The PRESIDENT (Mr John Ward) said that the delivery of Mr Kahn's paper had passed a most instructive and helpful hour. If there had been a little extra time, Mr Kahn would probably have shown them the latest proposed application of the material, viz., that the armour plating of battleships of the future should be made of reinforced cement. Mr Kahn had shown by his lantern slides that there were many uses and advantages to which this wonderful material could be put, but in the event of it being tried for battleship armour, it would come under the heading with which Mr Kahn's paper concluded, viz., "Failures." About 18 months ago, he (the President) had visited a very large printing work in Brooklyn, built entirely of reinforced concrete; indeed, with the exception of the hand rails of the stairs leading from one flat to another, there was not a particle of wood in the whole building. Mr Kahn had come specially from London to read his paper, and he was sure the members present would accord him a hearty vote of thanks for his valuable addition to the records of the session.

The vote of thanks was carried by acclamation.

Mr H. F. Porter.

Correspondence.

Mr H. F. Porter (Philadelphia) said that the paper by Mr Kahn was, on the whole, a sane and comprehensive exposition of a subject commanding a large share of the attention of the engineering world to-day. It reflected the more orderly view of the application of reinforced concrete, which, while recognizing its limitations, was more truly appreciative of its vast possibilities. Enthusiasts in times past had advanced extravagant claims as to the superior economy of reinforced concrete as a building material. And all things properly considered, for a structure destined to last for an indefinite period, and where " most fireproof " was the slogan, such was the case. For minimum insurance rates, and zero maintenance and depreciation charges, weighed in the balance with a higher initial cost against any other known type of construction, swayed it decidedly in favour of concrete. But if intending builders were looking for a great saving in first cost they were doomed to disappointment, for reinforced concrete, properly designed and executed, was not a sovereign panacea for a sparse bank account. There was one instance where it would be cheaper in first cost, namely, a factory or warehouse of large floor area, say, 20,000 square feet, with heavy floor loadings—200 lbs. per square foot and upwards—and above six storeys in height, would run perhaps 10 per cent. less in reinforced concrete than in first-class timber-mill construction, and about 40-50 per cent. less than a fire-proofed steel and brick construction. This resulted from the reduced relative cost of the centering, the reason for which would be perfectly apparent on a moment's reflection. It had been his experience that a surplus of fine sand might seriously impair the strength of the concrete. A proper proportion of fine sand was undoubtedly desirable, but there should be also correct amounts of coarser particles on an ascending scale to melt into the grading of crushed stone. By carefully grading the sand, from very fine to very coarse, a concrete of greatly increased strength might be obtained. Mr. Hobart, Consulting

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Sand-lime Engineer, Cleveland, Ohio, was at present reducing the results of a series of tests on this very point, and his findings were expected to be of considerable import. Machine mixing was undoubtedly to be preferred to hand mixing for jobs of any size. He, in fact, always expressly specified it. Two important points were to be noted in this connection; *firstly*, provision must be made for the introduction into the mixer of the proper amounts of materials in the proper order; and, *secondly*, that the batch be given the proper number of revolutions to insure thorough incorporation of the ingredients before being discharged. Indifference, carelessness, and irresponsibility were the obstacles in the first place, and the desire to hurry matters in the second. The troubles in the first instance might be eliminated by the adoption of automatic charging devices, which would unfailingly mingle the proper amounts of the ingredients, and the trouble in the second instance could be obviated solely by careful inspection. By using a gravity mixer both problems would be solved, for when once properly adjusted it was only necessary to keep the charging bins full, and the apparatus would do the rest. The use of so-called continuous mixers, of the pug-mill type, was not recommended, for the reason that the mixture was liable to run streaky, through not being thoroughly incorporated. Too much emphasis could not be laid on efficient inspection. It was the soul of success. It required technical training, tempered by sound, practical experience, and balanced by a temperament at once active, alert, faithful, and uncompromising. The duty of an inspector should be to harmonize practical perfection with reasonable economy, thus merging the interests of owner and contractor. Inspection should include investigation of the centering, to see that it was strong and true, and all braces and clamps secure; that the moulds were thoroughly cleaned of all foreign matter, and wetted before the deposition of concrete; that old concrete surfaces were cleaned of scum and laitance, freshened up with a tool, and wetted and grouted be-

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fore fresh material was deposited; that the proper reinforcement was in its designed position, and suitably maintained until locked firm in the stiffening concrete; that every deposition of fresh concrete was properly handled and properly tamped, to avoid batches of partially mixed concrete getting into the moulds, stone pockets forming, or masses of untamped concrete allowed to stiffen up. All materials should of course be inspected prior to use, for quality and cleanliness, and special attention given to the cement. There should be at all times an abundance of tested cement on hand, well guarded by a dry, ventilated shanty. These were some of the things to be dealt with, and the success of the job was largely measured by the faithful exercise of intelligence in inspection; for just as "eternal vigilance is the price of liberty," so expert supervision was the price of success. It was strongly advisable not to concrete in weather where the temperature, even at night, was liable to drop below 32 degrees F., unless provisions were made for holding the temperature of the concrete safely above freezing point until it had a good, hard set, or until, in the process of crystallisation, all the surplus moisture imprisoned in the mass was absorbed or evaporated. Perhaps the chief obstacle to success in winter work was the difficulty in keeping bosses and workmen alert. The tendency was to draw into themselves, suffering from the cold, and become indifferent to the fate of fresh concrete. The men must be kept comfortable. Carrying on operations under tents, with plenty of open grate stoves distributed about, both in the tent and underneath the floor, so as to keep the temperature at a favourable point above and below, alike protecting the work and the men. But this meant considerable extra cost. This method was used with entire success in the erection of the Butler Building at St. Louis, Missouri, the largest concrete building in the world. If concreting were required to be done in the open at freezing temperature, the materials should all be warmed and hot water used; and the freshly deposited concrete as soon as tamped

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covered with suitable insulation. Manure should not be used for this purpose unless the wet surface was protected from close contact by boards or tar papers; straw was very good. Perhaps the handiest and cheapest means was to cover with straw ticks. Outside courses, lintels, and columns, should have extra heavy forms, and preferably double forms with a space between packed with manure. The concrete, after deposition, might freeze, and finally freeze dry, or thaw out with the first warm spell and continue setting. It should then secure its hard set before a freezing temperature again seized it, for alternate thawing and freezing effectually ruined the concrete. This danger was very real, for concrete once chilled before it had got well started on the hardening process, set up very, very slowly, and might stay soft and damp for weeks. The centres should not be removed until it was very sure that the concrete was set up hard and strong and was not merely hard from frost. It was necessary even to keep concrete—though laid in warm weather preceding a cold snap—that had not attained a large percentage of its strength, free from moisture as from melting snows, rain, or water from the overhead work. The effect of freezing of the little moisture that was bound to penetrate the surface, was to disintegrate the surface to the depth of penetration. The worries and expense of winter concreting were sufficient to effectually discourage it, and unless the case was very urgent it was far better to await milder weather. In this connection it might well be noted that too much heat was quite as bad as too much cold. The concentrated rays of the summer sun were especially bad, baking up the fresh concrete as if it were mud, with the same effect, namely, to interrupt it with cleavage planes or shrinkage cracks in all directions. It became, therefore, quite important to afford shelter from the sun in hot weather. A tent or movable awning might be used, or the surface covered with a layer of wet sand. The best work was accomplished when the temperature was between 40 degrees and 50 degrees F., and safe from the direct rays of the sun.

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Often cold weather concrete was ultimately the hardest and best. The subject of reinforcement, as treated by Mr Kahn, was perhaps open more to debate than any other issue. He (Mr Porter) quite agreed that a reinforcing bar with rigidly attached diagonals was perfectly good reinforcement for isolated, freely supported, rectangular beams. However, in most instances, where an installation was monolithic, the beams might reasonably be regarded as of T-sections, and as continuous members, whether so recognised by the building codes or not. The logical method of reinforcing against these practical conditions would seem to be to place the steel as near as practicable in a position in the beam, simulating the curve of bending moments for continuous action, or the catenary curve. Then every tensile stress would be assumed by the steel in the most efficient, and therefore most economical, manner; and the concrete would act merely in compression, resting on the steel as a saddle, confining it to its proper line of action and fire-proofing it, and, moreover, furnishing a stiff, rigid floor. This required sufficient end anchorage of all steel, which might be simply realised by splicing bars of adjacent spans, or lapping them at all critical points sufficiently to develop their full strength. Round bars then became the natural reinforcement, for they were entirely safe, were easy to handle because of their roundness, embedded themselves nicely in the soft concrete, and were cheapest in first cost. He had obtained some interesting results following this method, both in low cost and great strength of structure, and felt abundantly assured of its correctness. In all events, whatever the method, full provision should be made for the disrupting forces which were bound to occur over all supports. The members should be so well tied together over all supports that failure would be nigh impossible, and if it did occur it would be very gradual, like the sinking of the bottom of an old basket. If proper provision had been made for these continuity stresses in the failure cited, namely, the Kodak building at Rochester, New York, the collapse would probably not have

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occurred. He happened to be in a position to speak authoritatively in regard to this particular case, and could say that, while premature removal of the forms was assigned as the cause, this only showed up a number of other faults, among which were lack of inspection and intelligent supervision, and lack of provision for continuity in the design. Had the members been properly tied together across the supports, failure would have been practically impossible, as the concrete had been in position for nearly two weeks before orders were given to strike the centres. With his method, where an absolute tie was always had across every support, and the reinforcement was at all times in position to assume all tensile stresses, centres had been struck with entire safety in from a week to ten days. In the case of the Frank H. Fleer & Co.'s new factory, in course of construction in Toronto, the roof centres were all removed after the seventh day, in weather of temperature from 30 degrees to 40 degrees F., without sign of deflection, although slab spans were 12 feet and beam spans 15 feet. The advantage of this method in permitting earlier removal of forms, and hence their use over again the sooner, would appeal to any having experience in this work. It should be noted that, although theoretically not required, vertical stirrups were used in this method. Their purpose was threefold; *firstly*, to tie slab and rib together and develop the T-section, the tendency being for the rib to separate from the slab in the longitudinal plane of the under side of the slab, especially if soffit and slab were not poured at the same time; *secondly*, to carry the main reinforcing as in a saddle; and, *thirdly*, to furnish support for the slab bars, to compel them to assume the catenary form. Fig. 16 illustrated this application. Suitable separates were used to hold the beam bars in proper position, and spacers of spring wire for spacing the slab bars. By alternating the points of lapping, practically a continuous run of steel was secured throughout the structure, every stress was taken care of, and the strength was not dependent on the bond or high compressive strength of concrete; all

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by using only plain round bars, which could always be obtained most readily and at lowest cost.

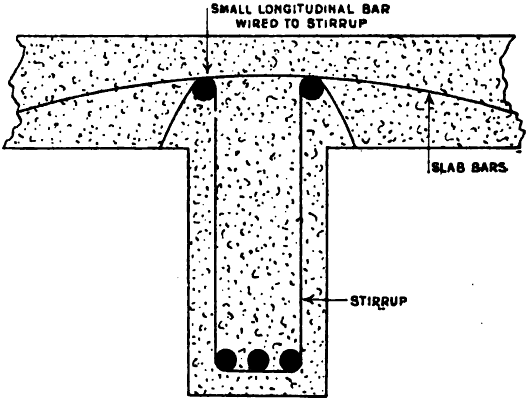

Fig. 16.

Mr KAHN in reply said that he did not know where Mr Porter got his information concerning the Kodak building, that no continuity bars were used over points of support, and that this was a source of weakness in the construction. As a matter of fact, the continuity bars were used, and Mr Porter was in error. There was no weakness whatsoever in any part of the building, as the tests by the eminent engineers, Messrs. Thatcher, of New York, and Marx, of Cincinnati, conclusively proved. They also submitted a report to the owners which was afterwards published, stating that the building as designed was sufficiently strong to perform its work, and to this report he respectfully called Mr Porter's attention.

ELECTRIC PROPULSION OF SHIPS, WITH NOTE ON SCREW PROPELLERS.

By Mr HENRY A. MAVOR (Member).

SEE PLATE IX.

Held as read 18th February, 1908.

THE electrical engineer is on the outlook for new worlds to conquer. He has placed his mark on all other branches of engineering, and it does not seem too much to expect that he may also have a share in the further development of marine engineering.

No great advance takes place without a preparation for change.

The applications of electricity have been conspicuous examples of this rule. The end of the first thirty years of the history of the practical use of electricity for the transmission of motive power is approaching. Two generations of steam engineering preceded its advent, and prepared the way for rapid development. On land, steam engineering and electrical engineering have exercised a powerful mutual influence, and the development of the steam turbine has been a direct outcome of this interaction.

The use of the steam turbine for propelling ships is already strongly influencing marine engineering, and this would in itself justify a re-examination of the problem from a new standpoint.

The use of steam in a turbine involves essentially a speed of rotation far above what is customary in reciprocating engines. Formerly existing methods have involved direct application of the energy of the prime mover to the propulsion of the ship, and these methods are closely related to the comparatively slow speed of rotation of the reciprocating steam engine. It is not surprising, therefore, that the steam turbine, when applied to marine propulsion, should be materially modified, and that the marine steam turbine is a compromise in which some sacrifice of economy has been made for the sake of avoiding a greater loss due to the characteristics of the propelling apparatus.

Within the limits of practice, the efficiency of the steam turbine is increased by increased speed of revolution; while the efficiency of the propeller is decreased by a corresponding change.

Fast-running turbines and slow-running propellers are respectively highly efficient instruments, but hitherto there has been no proper method of coupling them together. The underlying principle of the proposals here made is the use of a high-speed turbine running at a uniform velocity for all speeds of the ship, and driving a dynamo from which electric power is taken to a variable speed motor or motors coupled direct to the shafts of propellers of maximum efficiency.

The dynamo and motor here occupy an intermediate position, as indeed they do in all cases, between the power and the work, and in effect constitute a gearing which can submit to modifications of its own characteristics, to meet the characteristics on the one hand of the prime mover and on the other hand of the machinery to be operated.

It is precisely in this region that electricity has found a place in engineering on land, and it is now proposed to examine the possibility of its use at sea.

If such a possibility can be established, and practical applications made, no doubt the methods of applying the power will be subjected to modification; but this reaction has been on land of very slow growth, and little has yet been done in the way of making special machinery to take full advantage of the properties of electric transmission.

For this reason it is not necessary to enter into any questions involving material modification of the ship or the methods of operating it.

For present purposes, in considering electric motors, attention may be confined to two types which have proved themselves capable of the most extended adaptation.

The use of alternating currents for electric distribution is developing very slowly in Great Britain. The reasons for this are various, the most important being that continuous current had established itself as a commercial success before the advent of the multiphase systems. But even in new countries where development on the most convenient lines is free, the continuous current still holds the field for direct application of power, and in the application of electricity to transit, continuous current methods are still in the first position; notwithstanding the fact that the power stations are equipped with alternating current plant, the supply to the street cars is by continuous current, the conversion being accomplished in sub-stations.

A very important fraction of the total electric power generated in this country is used in this way, and this has tended to perpetuate the idea that alternating currents are not suitable for direct applications of power.

The superiority of the multiphase alternating induction motor in respect of compactness, endurance, and simplicity, together with the fact that nearly all large electric generators over about 1,000 H.P. are made for alternating current, is gradually leading to a more general adoption of this class of machine, and attempts have for some years been in progress to overcome its difficulties in practical application.

The chief of these difficulties is the low torque at start, that is to say, when the motor is at rest it requires artificial means to enable it to develop its full turning moment. These means are more complicated and costly than the equivalent apparatus for continuous current motors.

The ordinary multiphase induction motor also compares unfavourably with the continuous current motor in respect of its availability for changes in speed. The continuous current motor can now be made to give varying speeds through any necessary range without much loss of efficiency, the only consideration being cost. Hitherto the induction motor has not been able to meet this requirement. This latter disability is less serious than is generally supposed, because the cases requiring a smooth speed-change are comparatively few, and where they exist they have been in many instances dealt with by mechanical means.

Where very frequent starting and stopping have to be combined, as they often are with gradually varying speeds, something new must be attempted if the alternating motor is to take the field. The Author has been at work on this problem for some years with the result that he claims to have solved the problem, and that he can meet most of the demands which are likely to arise in practice and deal with some new fields of enterprise which have hitherto, for various reasons, remained closed to the electrical engineer.

Hitherto the use of electric motors for marine propulsion has been confined to small craft, such as submarines, and one or two small barges and other craft on Russian rivers and canals. A small electrically operated and propelled dredger has also been constructed in Germany.

The motors in these cases are continuous current machines.

The continuous current motor which is so convenient for small applications of power up to 100 horse power becomes less convenient over this size. Above 1,000 horse power it is not a very practical machine for power purposes, where starting and stopping have to be frequently accomplished, and it is not specially suitable for marine work. The multiphase induction motor on the other hand has all the properties to be desired in a marine motor except hitherto the facility of speed control. This problem may now be said to be solved.

Some years ago the idea of rotating the outer member of the motor, usually called the stator, occurred to the Author, and appeared to offer a solution of the starting difficulty, and this suggestion was made at a meeting of the Institution of Civil Engineers in 1904. The proposal was that the external member should be mounted so as to be free to revolve concentrically with the rotor or armature of the motor. The armature being connected to the load and the outer member being free to rotate, the outer member starts to revolve in a direction opposite to the working direction of the rotor, and having only its own inertia and friction to overcome, it quickly reaches synchronous speed. The motor is now in a position to develop its full load torque with full load current, and all that is necessary is to apply a mechanical or other brake to the external member, bringing it to rest gradually while the rotor starts and accelerates as the outer member or "spinner" comes to rest. The start can thus be made without excessive call for current and without jerk.

This idea soon developed into a proposal to modify the ordinary working speed of the motor, by so arranging the external member that it could be driven at any desired speed by gearing interconnecting both members, and an arrangement was worked out and patented for putting this idea into practical shape. It will be seen that by the use of a fast and loose pulley or friction clutch to transmit a part only of the power of the motor, the starting can be accomplished with a very small loss of energy. This method, although serving the purpose for which it was designed and giving a useful solution of the difficulty, did not appear to be the final stage. The idea of rotating the outer member and controlling its speed suggested the idea of controlling its motion independently of gearing or other arrangements which involved disadvantageous complications, and the simple apparatus now exhibited was evolved, which entirely gets over the difficulty of starting, and gives a change of speed in either direction. In this machine the outer member or spinner is made to act as the inner member or rotor of a second motor, the stator of which embraces the spinner. The machine is thus two motors concentrically arranged round the common axis. The three speeds which may be described as prime, secondary, and tertiary are attained without loss of efficiency, but if intermediate speeds are desired they are obtained by a slipping brake or external resistance in each case equally with a consequent loss of efficiency. This loss of efficiency is very small, and is less than the loss involved where series wound continuous current motors are used for speed variations; or intermediate speeds may be obtained by providing a separate supply of current to the external motor and changing its speed by change of periodicity of the supply.

The attainment of three speeds without any loss of efficiency in this class of motor is a very important improvement, because it at once renders it available for such work as steel rolling mills, haulages, hoists, calendering and printing machines, lathes and boring mills, and last, and perhaps the most important of all, driving vehicles either on or off rails, including vessels on the sea.

A proposition to apply electric motors to drive a ship involves primarily a consideration of the conditions with respect to the propeller and the prime mover. Naturally, the propeller with its shaft comes first, as upon its efficiency of transformation of energy depends the size of the prime mover. It is necessary to institute a comparison for any given ship of the normal propeller as used with existing machinery, and see what are the prospects of economy by the substitution of electric transmission for the direct connection between the engine and the screw.

At first sight it does not appear that any economy could be made by the introduction of two successive energy transformations, in the dynamo and motor respectively, to take the place of a direct transmission.

The maximum possible efficiency of these two transformations with the transmission shaft is not more than about 88 per cent.; while the efficiency of the direct transmission shafting is probably not less than ·95. There is thus a loss of at least 7 per cent. as a primary handicap against the proposal. This consideration may be taken as disposing of the possibility, by change of transmission, of any economy in ships of moderate size with slow-running propellers of upwards of 70 per cent. efficiency. If electric driving is to be introduced into such ships it must be on other grounds than propeller economy. The case is different on coming to deal with ships in which the power is large and the propellers are run at a high speed. Such cases are becoming common in vessels driven by steam turbines. A very short incursion into the study of propellers is sufficient to show the trend of the conditions which here emerge.

The subject has been treated in some detail in Professor Biles's book on "The Marine Steam Turbine," 1906, where are given the results of researches on propellers, and the methods generally adopted in the design of propellers are fully explained. The causes of loss of efficiency in turbine vessels due to adopting propellers too small for the best efficiency are also discussed in the same book.

A ready and convenient method of making comparisons without the detailed labour of designing groups of propellers is desirable in the present connection, and for this purpose the Author has developed a method.*

It will be seen that for any given ship, the designer who is at liberty to choose a large propeller for any given power has considerable advantage, as the efficiency may be as high as 70 per cent., and as low as 45 per cent. To say what improvement is possible in any case is by no means an easy matter, because the actual efficiency of any given propeller is often unknown; but the difference in efficiency between the probable bests, when the diameter can be changed, may be found approximately, and it is this which has been attempted. The introduction of an electric drive enables one to include in the

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*See "Note" in Appendix.

consideration all speeds of revolution of the propeller, both low and high.

In seeking for higher efficiency in the propeller, the limits imposed by practical considerations must, of course, be taken into account, such as the beam and draught of the vessel. On the other hand, the revolutions at which the propeller may be efficiently used are fixed by the diameter and pitch.

While, therefore, one may have ascertained what is the possible improvement in efficiency, one must, before claiming the possibility of such improvement, deal with the problem with the limiting diameter of the propeller as a first element in the calculation.

It is this consideration which makes any saving in propeller efficiency difficult in high-speed passenger steamers of shallow draught. The difficulty of improving the efficiency of ships of moderate size with slow-running propellers has been shown, so that the most attractive field of enterprise, from the propeller point of view, is in large ships of deep draught and high speed. Coming to the consideration of the prime mover, the scope of operations appears to be much wider.

If the ship is to be electrically driven, it will probably be found that the most convenient steam prime mover will in all cases be a turbine. The limit of speed of rotation, when the turbine is to be used for driving a dynamo or alternator, is of a different order altogether from the limit of speed imposed upon the turbine by its direct connection to the propeller. In some cases it will be easy to adopt an increase of ten times in the speed of revolution. High speed of the turbine means high efficiency, and therefore the turbo-electric generator with its motors compares favourably in economy, cost, and weight with the marine steam turbine directly connected to the propeller shaft, and therefore running at a speed lower than that called for by considerations of steam economy in the turbine.

The reversibility and speed variability of the electric motor driven by the turbo generator, run unidirectionally at constant speed, dispenses entirely with the objectionable heavy and costly go-astern turbines mounted on the propeller shaft.

The marine steam turbine has already fairly established its claim to economy in cases where the requirements of the propeller permit of a reasonably high speed of rotation relatively to the power used, and therefore a direct comparison may be made of the results to be obtained on a ship of large size driven direct by steam turbines, with what can be done by the application of electric gear.

The ship has in the first case a total of 17,000 horse power delivered to the three propellers, and a speed of 20¾ knots. The propellers are 8 feet 1½ inches in diameter, and the speed of revolution is 377 per minute. This example is worked out in detail in the Appendix, and it is there shown that the maximum probable efficiency of these propellers is 62 per cent., a figure which certainly does not err against the propeller in question.

An electric equipment would permit of the use of propellers of about 14 feet diameter at 140 revolutions per minute, and an efficiency not less than 70 per cent.—an improvement more than sufficient to cover the loss in the electric motors.

It is further to be noted that the slower speed propellers would be free from the risks of cavitation troubles, which arise when the resistance is increased on a propeller already producing a high value of thrust per unit area. No attempt is made to put a figure on the economy emerging under this head, but its importance is evident.

Turning now to the generators, it will be found that the steam turbo-alternator, as used on land in sizes corresponding to those now under discussion, can deliver an electric horse power to the motors for 12·2 lbs. of steam per horse power hour, allowance having been made for all intermediate losses, and for 4 per cent. for driving auxiliaries, no superheat being used, so as to make the comparison with normal marine practice. This figure is startlingly lower than anything which has been touched at sea. It is for full speed and power, but the comparison must also be made at low speeds and powers, and more particularly at the normal working speed of the ship.

It will be found that there is certainty of economy in this comparison, because of the higher speed of revolution of the turbine, which in the electric case runs at the same speed for all powers, while, of course, the direct connected turbine must vary its speed of revolution with the speed of the ship.

It is not possible to base any generally conclusive argument on these data, but there is evident encouragement to give detailed study from this standpoint to any particular case which may arise. The same limitation applies to weight and cost. In the example referred to an estimate has been made of the weight, with the result that it appears probable that the decrease in the weight of the steam equipment will more than compensate for the heavy slow-running motors and propellers, so that the weight will not be greatly changed. The cost will probably closely follow the weight.

Figs. 1, 2 and 3 illustrate a small 5 H.P. model of a three-phase alternating current "spinner" motor for ship propulsion. This motor is shown in elevation and part longitudinal section in Fig. 3.

The electric current is delivered from an outside source to the primary windings of the stator and spinner respectively, passing in each case through a simple reversing switch which determines the direction of rotation. The stator circuit also supplies a magnet, which, when no current is passing, releases a brake which brings and keeps the spinner at rest. When current is passing, the magnet lifts the brake and leaves the spinner free to revolve.

The three-speed motor provides a means of obtaining all the speed variations which are required on a ship. The intermediate speeds between the three normal speeds of the motor are obtained by variations in the speed of the generating plant, which are within the limits of practicability and economy. Each propeller shaft is provided with a directly connected motor on which there is co-axially superimposed a second motor for speed regulation. The regulating motor is mechanically connected and magnetically entrained with the first in such a manner that the speed variation may be effected as follows:—

For slow speed, by running the regulating motor in the reverse direction to the direct connected motor;

For intermediate speed, by running the direct connected motor alone, the regulating motor being stopped;

For full speed, by running the regulating motor in the same direction as the direct connected motor.

This arrangement requires no spur wheels or friction gearing. Each motor is controlled by a simple reversing switch without any other mechanism, and there are no power-wasting devices.

The advantages of the adoption of this system are well illustrated in the case of a ship of 17,000 horse power on three propellers at 21 knots maximum speed. At full speed the 17,000 horse power is provided by one turbo generator of 10,000 horse power which directly drives the direct connected motors, and by a generator of 7000 horse power which drives the regulating motors, the whole plant being run at full speed and full power. When the speed is dropped from 21 knots to 18 knots, the 7000 horse power turbo generator is stopped, and the coal consumption per horse power is the same at 18 knots as at full speed. When the speed is further reduced the 10,000 horse power may be stopped and the smaller unit again applied.

It will thus be seen that in addition to the economy attainable at full speed, there is a very great improvement in economy at all lower speeds, owing to the possibility of choosing a suitable size of power unit for each speed. This advantage

Fig. 1.

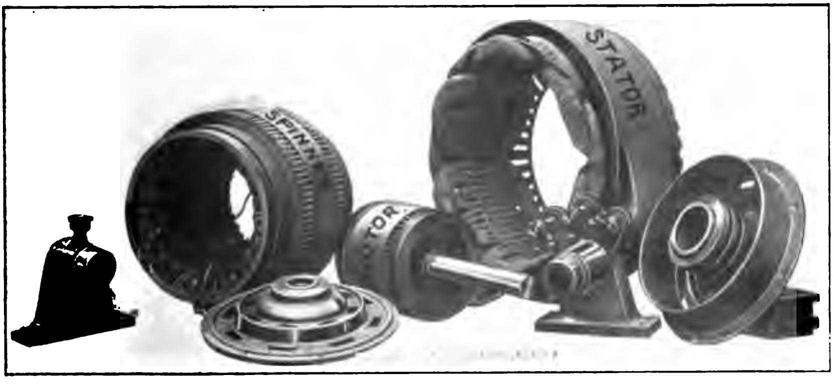
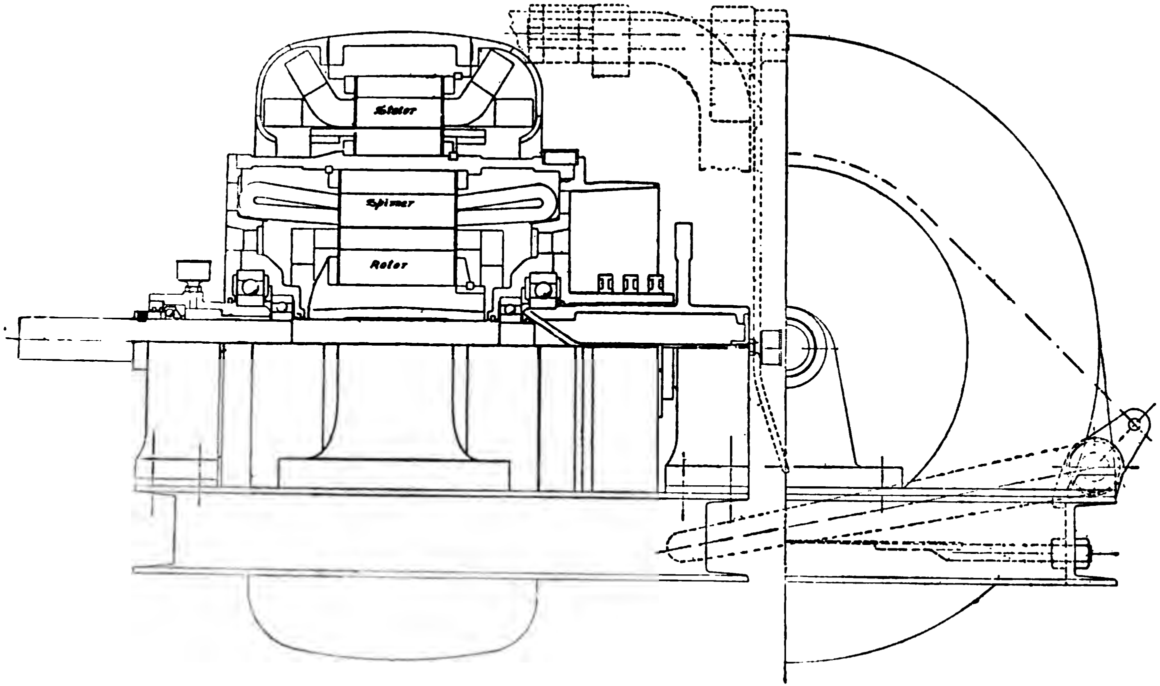
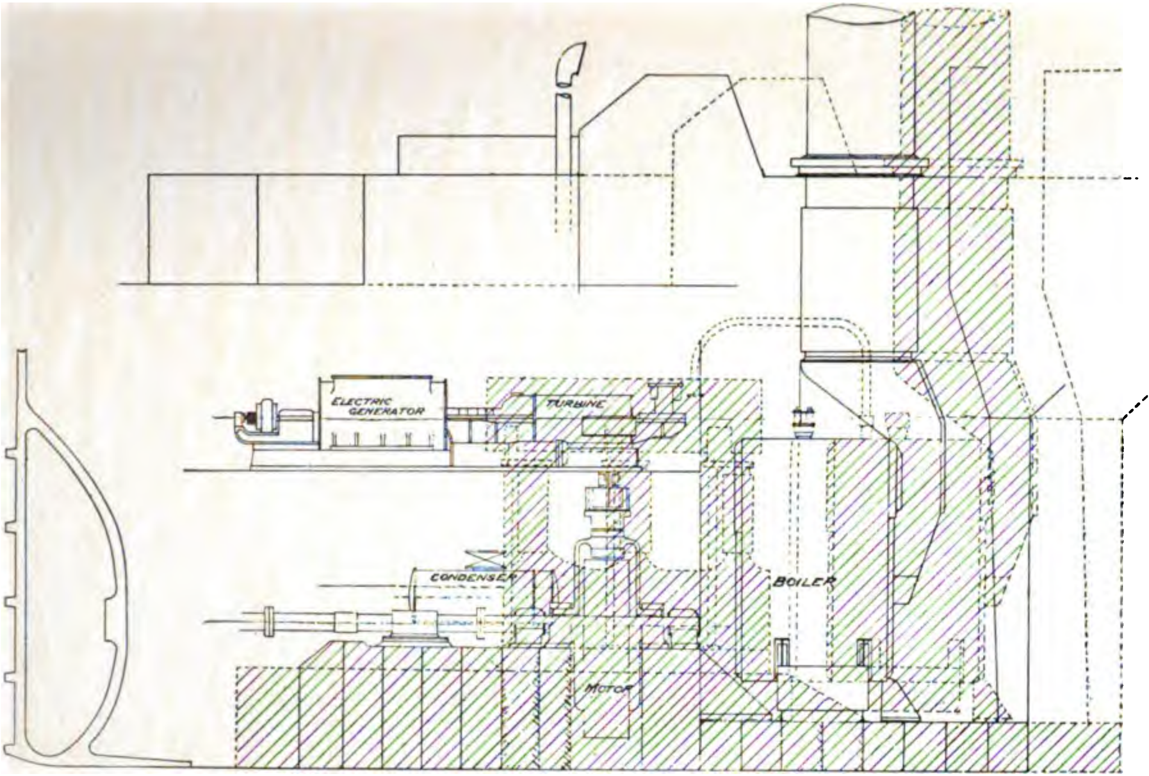


Fig. 2.

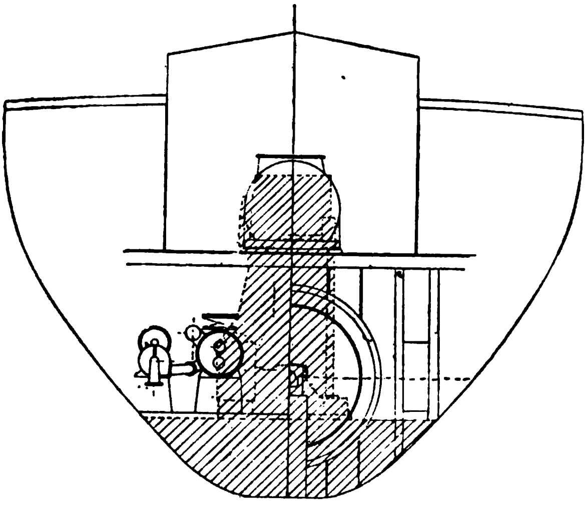


ELEVATION. SECTION.

Fig. 3.



LONGITUDINAL SECTION.
Fig. 4.



CROSS SECTION.

Fig. 5.

also appears in cases where the power required to drive the ship, at any given speed, is varied by the condition of weather or load; in short, the electric arrangements provide a means of approximating, at all working speeds of the ship, to the economy attainable on the trial trip at full speed. It is, of course, obvious that at very low speeds of the ship the economy cannot come within this region, but on the electric arrangements it is very much better than attainable by the ordinary means.

The model has been made with ball bearings, but it is not proposed to use these in the actual machine which will be arranged as shown in Fig. 4. The rotor circuit and the induced circuit on the spinner are permanently closed, being of what is known as the " squirrel cage " type, the simplest of all forms of winding.

Figs. 4 and 5 show the longitudinal and cross sections respectively of the engine room arrangement of a cargo vessel fitted with reciprocating engines of about 1200 horse power, and supplied with steam from two boilers. This ship is constructed under the patents of Mr Henry Burrell, who has been good enough to supply the Author with the drawings. The existing plant is shown in shade. The equivalent electric plant is shown in outline. The space occupied and weight are about the same in each case.

This paper is an incomplete treatment of the subject, but it may serve to elicit a discussion interesting to members of the Institution and others.

The Author acknowledges gratefully his indebtedness to Mr Thomas Bell, who specially directed his attention to this subject, to Professor Biles, who has for many months lent his knowledge and experience in preliminary discussions, and who it may be hoped will contribute to the public discussion, also to Mr Luke, Mr Cleghorn, and to Dr. Caird, all of whom have taken a lively interest in these investigations and proposals.

APPENDIX.

NOTE ON SCREW PROPELLERS.

The propeller is one of the many things on which Professor Macquorn Rankine turned the search light of his genius, and the writer was, early in his investigations, referred to an interesting paper by Mr W. McEntree on "The Limit of Propeller Efficiency,"* where he showed that a curve of "ideal efficiency," drawn in accordance with Rankine's suggestions, could be compared with the results of Taylor's experiments, which are well known to naval architects.

The present writer had found Rankine's conception of "Ideal Efficiency of Steam Engines" so useful in getting for steam engines exactly what is here wanted for propellers, that this method of treatment was very attractive.

Referring now to McEntree's paper on "The Limit of Propeller Efficiency," of 1906, his statement of the case may for convenience be modified so as to obtain a curve of ideal efficiency in terms of $\frac{\text{B.H.P.}}{d^2 v^3}$, extending the argument so as to include the effect of the wake, and also, in proceeding, to suggest the conception of ideal slip and ideal pitch.

Following are the definitions and symbols adopted:—

$A =$ area of the propeller disc $= \frac{\pi d^2}{4}$.

$d =$ diameter of propeller in feet.

$e =$ ideal efficiency $= \frac{\text{Useful work}}{\text{Gross work}}$.

$E =$ actual efficiency.

$g =$ acceleration due to gravity in feet per second per second.

$G =$ gross horse power delivered to propeller $=$ B.H.P.

$M =$ mass of the sternward column acted on by propeller per second.

$p =$ pitch ratio of propeller, $pd =$ pitch.

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* Trans. American Institution of Naval Architects, 1906.

p_i = imaginary pitch ratio assumed for ideal propeller, and deduced from the pitch ratios for maximum efficiency in Taylor's experiments on propellers of ·2 width ratio.

P = push or thrust delivered to the ship by the propeller in pounds.

R = revolutions per second of the propeller.

s is defined by $v_1 = \mathrm{R}dp_i\,(1 - s)$,

and is the carry of the ideal propeller relative to still water in which it is imagined to travel. *This is not equivalent to what takes place when a nut slides over the threads of an overhauled screw.*

s_a = the apparent slip of the actual propeller relative to the ground over which the ship travels when there is no wake, *i.e.*,

$$\frac{v_1}{\mathrm{R}dp} = 1 - s_a.$$

This is assumed as the probable best slip for maximum efficiency of actual propellers, and is deduced from the results of Taylor's experiments and their practical application to design.

s_ω is defined by $v\,(1-x) = \mathrm{R}dp_i\,(1 - s_\omega)\,(1-x) = \mathrm{R}dp_i\,(1-s)$, and indicates the changed ideal apparent slip theoretically occurring when a forward motion is assumed for the water in which the ideal propeller is imagined to move.

The suffixes indicate the values of x, which give the ideal values $s_{\omega\cdot1}$ $s_{\omega\cdot2}$ etc.

$s_{a\cdot1}$ $s_{a\cdot2}$ etc., indicate the probable actual values of the apparent slip, and these values are obtained by deducting the corresponding values of $s - s_{\omega\cdot1}$ etc., from s_a.
The suffixes indicate the values of x, which will give the apparent values of s_a.

s_p = the slip $= s_a - s$ which takes place on an actual propeller and corresponds to the slide of a nut jumping over the threads of an overhauled screw. To compensate for this slip involves an increase in pitch of the screw, as compared with that of the ideal propeller.

$$s + s_p = s_a.$$

x = ratio of speed of wake to ship speed over the ground in the same direction.

vx = speed of wake over the ground.

$v - vx = v(1 - x) = v_1$.

v = speed of the ship, or of the ideal propeller relative to still water or over the ground, in feet per second.

v_1 = speed of ship or of the ideal propeller relative to the water in which it moves, in feet per second.

v_2 = speed of the ideal sternward column over the ground, in feet per second.

$\left.\begin{matrix} w \\ w_{\cdot 1} \\ w_{\cdot 2} \end{matrix}\right\} = \dfrac{G}{d^2 v^3}$ when the water is in motion and wake ratio $x = \cdot 1$ $\cdot 2$, [etc.

$$\psi = \frac{\text{B.H.P.}}{d^2 v_1{}^3} = \frac{G}{d^2 v_1{}^3}.$$

W = weight of one cubic foot of sea water = 64 lbs.

The following is a

DEVELOPMENT OF RANKINE'S "IDEAL" FORMULÆ.

$$P = Mv_2, \quad M = \frac{WA}{g}(v + v_2), \quad v_2 = Rdps, \quad v_1 = R\,dp\,(1 - s).$$

$$\text{Useful work per second} = Pv_1.$$

$$\text{Lost work per second} = \frac{Pv_2}{2}.$$

$$\text{Gross work per second} = P\left(v_1 + \frac{v_2}{2}\right).$$

$$\text{Efficiency} = \frac{1}{1 + \dfrac{v_2}{2v_1}} = e.$$

$$\frac{v_2}{v_1} = \frac{R\,D\,ps}{R\,D\,p\,(1 - s)} = \frac{s}{1 - s} \;\therefore\; e = \frac{1 - s}{1 - \dfrac{s}{2}}. \qquad (1)$$

$$\text{Gross work in horse-power} = G = \frac{64\pi\, d^5 R^3 p^3 \left(s - \frac{s^2}{2}\right)}{550 \times 32{\cdot}2 \times 4},$$

and

$$\frac{G}{d^5 R^8} = {\cdot}00285\, p^3 s \left(1 - \frac{s}{2}\right)$$

$$= \frac{G}{d^2 r_1{}^3} p^3\ (1-s)^3,$$

$$\therefore \psi = \frac{G}{d^2 r_1{}^3} = \left(\frac{1 - \frac{s}{2}}{1-s}\right)\frac{s\,{\cdot}00285}{(1-s)^2}. \quad - \quad - \quad (2)$$

$$r_1 = r\ (1-x) = Rdp_i\ (1-s_\omega)\ (1-x) = Rdp_i\ (1-s),$$

and

$$\frac{1-s}{1-s_\omega} = 1 - x. \quad - \quad - \quad - \quad - \quad (3)$$

$$w = \frac{G}{d^2 v^3} = \psi\,(1-x)^3 = \frac{G\ (1-x)^3}{d^2 v_1{}^3}. \quad - \quad - \quad (4)$$

Let $w = \frac{G}{d^2 v^3}$, when $x = 0$,

$w_{\cdot 1} =$ „ „ $x = {\cdot}1$,
$w_{\cdot 2} =$ „ „ $x = {\cdot}2$, etc.

These equations have been applied to given values of s, and the results are stated in Table I. and plotted to the base ψ in Diagram 1, Plate IX., which also includes scales for converting ψ into w.

The efficiency being plotted to the base ψ the curves derived from Taylor's experiments (see Table II.) are plotted to the same base (see Diagram 2, Plate IX.), and it is found that the two curves, as has been pointed out by Mr McEntree, bear a constant ratio to one another throughout the range of the experiment. This ratio is for the ·2 width ratio, $\frac{80}{95}$, *i.e.*, the efficiency on Taylor's experiments is ·84 of the ideal efficiency of this width ratio.

An examination of Taylor's experimental data (see Table II.) of *maximum efficiency* with the relative slip and pitch plotted to

TABLE I.

FUNDAMENTAL EQUATIONS. 1. 2. 3 and 4.

s	$1-s$	$1-\frac{s}{2}$	$(1-s)^3$	e	ψ	$\cdot1=x$		$\cdot2=x$	
						$\frac{s}{\omega_{\cdot1}}$	$\omega_{\cdot1}$	$\frac{s}{\omega_{\cdot2}}$	$\omega_{\cdot2}$
·05	·95	·975	·8574	·974	·000162	$\cdot\dot{0}5$	·000118		·000083
·1	·9	·95	·729	·948	·000371		·000271	−·125	·00019
·15	·85	·925	·6141	·919	·000643		·000469		·000329
·2	·8	·9	·512	·889	·00100	$\cdot\dot{1}$	·000729	0	·000512
·25	·75	·875	·4219	.857	·001475		·001075		·000765
·3	·7	·85	·343	·823	·00212	$\cdot\dot{2}$	·001545	·125	·001085
·35	·65	·825	·2746	.788	·00300		·00219		·001535
·4	·6	·8	·216	·75	·00422	$\cdot\dot{3}$	·00308	·125	·00216

Diagram 1 represents these relations.

TABLE II

TAYLOR'S EXPERIMENTS. 3 BLADED PROPELLERS.

S	·2 W R			·275 W R			·35 W R		
	s	p	$S \times (1-s)^3 p^3$	s	p	$S \times (1-s)^3 p^3$	s	p	$S \times (1-s)^3 p^3$
·2	·14	1·318	·290	·168	1·436	·313	·16	1·47	·376
·25	·16	1·275	·307	·19	1.418	·378	·19	1·44	·397
·3	·1775	1·24	·318	·21	1·395	·402	·21	1·416	·422
·4	·2065	1·175	·325	·24	1·344	·434	·2425	1·362	·450
·5	·23	1·125	·325	·261	1·295	·439	·266	1·32	·455
·6	·251	1·084	·320	·278	1·248	·440	·284	1·28	·462
·75	·28	1·035	·310	30	1·172	·415	·307	1·23	·466
1·0	·317	·98	·300	·326	1·08	·386	·334	1·15	·445
1·25	347	·95	300	·347	1·006	·356	357	1·08	·423
1·5	361	·93	·300	·363	·95	·333	·347	1·016	·390
1·75	·3895	·90	·290	·3775	·90	·310			
2·0	·4065	·88	·283	·39	·866	·30			

the base ψ, as in the ideal curve, brings out the interesting fact that for the 3- and 4-bladed propellers the value

$$\frac{\text{B.H.P.}}{d^2 r_1^3} p^3 (1-s)^3 = \frac{\text{B. H. P.}}{d^5 R^3}$$

is very nearly a constant for each width ratio at all *maximum efficiencies*. The constant is for the 3-bladed ·2 width ratio propellers

$$\frac{\text{B.H.P.}}{d^5 R^3} = \cdot 000595.$$

As the B.H.P. required to drive the propellers for any given thrust is directly proportioned to the efficiency, the ideal B.H.P. will be inversely proportioned to the relative *maximum efficiency* of a similar propeller in Taylor's curve, *i.e.*, if the propeller in Taylor's curve takes

$$\text{B.H.P.} = d^5 R^3 \times \cdot 000595.$$
$$\text{Ideal B.H.P.} = d^5 R^3 \cdot 00595 \times \cdot 84 = \cdot 0005.$$

(It may here be noted that $\frac{\text{B.H.P.}}{d^5 R^3}$ is of the dimensions of a density,

$$i.e., \quad \frac{\overset{\text{Feet.}}{L} \quad \overset{\text{Lbs.}}{\frac{ML}{T^2}} \quad \overset{\text{Mins.}}{\frac{I}{T}}}{\underset{\text{Ft.}}{L^5} \quad \underset{\text{Rev. per Min.}}{\frac{1}{T^3}}} = \frac{M}{L^3} \text{ a density.}$$

Referring back to the fundamental equation (2) for ideal B.H.P. it will be noted that it includes the factor "W" = 64 representing the density of the water.)

On Diagram 1, it is assumed that as the result of Taylor's experiments (see Diagram 2, and Table II.) an ideal pitch line may be plotted to correspond with the ideal slip, and that a probable pitch line may be plotted for any other slip on the assumption that the constant $\frac{G}{d^5 R^3}$ is inversely proportional to the maximum efficiency.

The ideal pitch line has been put on Diagram 1 from the formula

$$\psi\, p_i^3\,(1-s)^3 = \cdot 0005,$$

This curve suggests the notion that under no circumstances can a low pitch ratio give an efficient propeller. Plotting also on Diagram 2, the values of slip in Taylor's experiments with three width ratios, it will be found that the slip follows generally the line of the ideal slip.

The curve "probable maximum efficiency," Diagram 2, is 90 per cent. of the efficiency for ·2 width ratio propellers in Taylor's experiments, and the value of $\frac{G}{d^5R^3}$ is therefore assumed to be for maximum efficiency,

$$\frac{\cdot 000595}{\cdot 9} = \cdot 00066 = \psi\, p^3\,(1-s)^3.$$

In plotting a curve, Diagram 2, of the probable slip for this group, the Author simply enclosed Taylor's experiments in an enveloping curve, because they have been adopted as giving the nearest values attainable of the proper slip for maximum efficiency, and from these values is derived the pitch curve for $\frac{G}{d^5\,R^3} = \cdot 00066.$

The curve of actual apparent slip could be deduced from that of ideal apparent slip by the following simple experiment.

The ship is moored, the propeller driven at R revolutions per second, and the velocity of the sternward column v_2 measured by means of a patent log.

Then the imaginary pitch ratio p_i is given by the equation

$$p_i = \frac{v_2}{Rd}$$

but

$$1 - s = \frac{v_1}{Rdp_i} \text{ and } 1 - s_a = \frac{v_1}{Rdp},$$

$$\therefore s_a = 1 - \frac{(1-s)\,v_2}{Rdp},$$

and if the torque horse power be also measured, the value ψ may be obtained.

COMPARISON OF PROPELLERS.

For comparison of propellers on this method the following data are required :—

$$G, \; r, \; d, \; p, \; R,$$

from which can be deduced $\frac{G}{d^5 R^3}$, $\frac{G}{d^2 r^3}$, s_a and approximations to the following from Diagram 1.

w and its suffix, by inspection of the apparent slip curves s_a and scales of w, the co-ordinate points on each can be found.

$$\psi = \frac{w}{(1 - x)^3}.$$

x is indicated by the suffixes to s_a and w.

s_p by difference between s_a and s.

e from Diagram 1, where e is plotted to base ψ.

E from same ordinate in Diagram.

$\frac{G}{d^5 R^3}$ approximately $= \frac{\cdot 0005}{E}$ for maximum efficiency.

The values are indicated thus † on the Diagram.

EXAMPLE A

$G = 5660.$

$r = \frac{20 \cdot 75 \times 6080}{60^2} = 35.$

$d = 8 \cdot 125.$

$p = 1.$

$R = 6 \cdot 283.$

$$\frac{G}{d^5 R^3} = \frac{5660}{8 \cdot 125^5 \times 6 \cdot 283^3} = \cdot 00064 = \psi \, p^3 \, (1 - s)^3.$$

·00064 is the actual value of $\psi \, p^3 (1 - s_a)^3$, deduced from the curve of efficiency E. This propeller has, therefore, been designed to give the maximum efficiency under the given conditions, and it probably does so.

$$w = \frac{5660}{8\cdot 125^2 \times 35^3} = \cdot 002.$$

$$1 - s_{ax} = \frac{r}{Rdp} = \frac{35}{6\cdot 283 \times 8\cdot 125 \times 1} = \cdot 685.$$

$s_{ax} = \cdot 315.$

The ordinate, which gives $s_{ax} = \cdot 315$, and the abscissa, which gives $w = \cdot 002$, are respectively in the scales $s_{a\cdot 05}$ and $w_{\cdot 05}$ *i.e.*, the points are halfway between ·1 and 0,

$\therefore x = \cdot 05.$

$$\psi = \frac{w}{(1-x)^3} = \frac{\cdot 002}{\cdot 85} = \cdot 00235.$$

$s_p = \cdot 08.$

$e = \cdot 81. \quad E\ \cdot 62.$

It is now required to find the dimensions of new propellers electrically driven to develop the same thrust. The thrust H.P. = 5660 × ·62 = ·3510 It is proposed that the propellers should have an efficiency of 70 per cent. ∴ G = 5010.

$$\frac{G}{d^2 r_1^3} = \cdot 0007 = \psi.$$

The wake value as before ·05,

$$\therefore w_{\cdot 05} = \psi \times \cdot 95^3 = \cdot 0007 \times \cdot 85 = \cdot 000595,$$

$$\text{and } d^2 = \frac{5010}{\cdot 000595 \times 35^3} = 196,$$

$$d = 14.$$

$$\text{If } \frac{G}{d^5 R^3} = \cdot 00064_1,\ R^3_1 = 14\cdot 5,$$
$$R = 2\cdot 44.$$

Discussion.

The AUTHOR said that it might be to the purpose if he made a short explanation of the motor, for the benefit of those who possibly had not had an opportunity of seeing it. He exhibited a rough cross section of the model which he had made, and which was now driving a fan, simulating as nearly as possible

Mr Mavor.

the conditions of a propeller. The model had been made for the purpose of enabling him to understand exactly what was happening under working conditions. It was easy to forecast, in a general way, that one could dispense with the usual starting devices. In the size in question they might be entirely dispensed with, and the current might be switched direct to the motor. For the purpose of ascertaining this definitely, he had arranged to drive the motor from a rotary converter of its own size. He took from the Corporation mains a continuous current, put it through a motor of the same size as the one shown, using slip rings, and collecting an alternating current from it to drive the alternating current motor, and he found that the small motor generator could start the motor under its normal conditions of load. In driving a fan or propeller, there was no load at starting, and he believed that with a turbo alternator the same could be done for a 5,000 horse power motor as he had here done with the small machine. To deal with the call for three speeds it was only necessary to have a reversing switch on the stator and spinner respectively. It would be evident from the diagram what the construction was. The intermediate spinner had on its inner surface the ordinary three-phase windings connected with the generator, and on its outer surface a squirrel cage rotor; while the stator or outer ring was provided with another winding connected with the generator. These elements might be interchanged in their respective relations to one another. Probably for ship propulsion it would be as well to put all the windings on the spinner part, so that it could be withdrawn for examination. He would like to record his thanks to the Honourable Charles Algernon Parsons, who was unfortunately laid aside by illness, for his kindness in giving the information for comparisons, and also to his firm for the tests at the Carville power station, which he had been kindly allowed to record in the Transactions of the Institution, as showing the best that had been done in steam economy

Mr Mavor.

in land practice. Messrs. Parsons' guarantees were the basis of the estimate of steam consumption given in the paper.

Mr W. B. SAYERS (Member) said the reason why he presumed to speak on this most important paper was that, in considering this problem, Mr Mavor's scheme was arranged to deal with very large powers, whereas he had already proposed a mechanical gear which, at any rate, to begin with, was better adapted for smaller powers. Before making any remarks on the electrical part of Mr Mavor's paper, he would like to show a model of this gear which was illustrated by Figs. 6 and 7, Plate X. Fig. 6 represented a part end view and longitudinal section of the gear in the same form as the model exhibited, but with ball bearings, reversing arrangement, plate brakes, and operating levers added; the gear being designed for motor vehicle work. Fig. 7 was a view and section of the wooden model exhibited. This model was constructed to show the principle on which the gear operated and was not in a convenient form for practice. In Fig. 7, K was the driving shaft; A the member driven at varying speeds, and to which connection must be made to the work to be done; E, E1, were satellite cranks pivoted at one end in the revoluble member B, which was one with sleeve B1 and brake wheel B2, the other ends of the satellite cranks being pivoted to the eccentrically moving member D, which was driven by the main crank J and pin I. The moving member, D, carried a ring of internal and a ring of external teeth, the external teeth geared with the internal teeth on the driven member A. The internal teeth geared with teeth on the pinion C1, which was in one with sleeve C1 and brake wheel C3. The operation was as followed:—If the brake F were applied, holding the member B stationary, the satellite cranks allowed the member D to be carried round with the crank J, but prevented it from revolving on its own axis. It, therefore, carried A round with it, by an amount equal to the difference between the number of teeth in D and A, the amount of relative motion between

Mr W. B. Sayers.

the teeth being at a minimum and the conditions being almost those of a through drive. If brake F were released and brake F1 applied, holding the pinion C stationary, the member D was revolved by the pinion C, and the member A was carried at a greater speed in the ordinary epicyclic fashion. He had called it a cycle-epicyclic gear, because at one speed every part of the driving member performed equal circles in its revolution, while at another speed each part performed an epicycle. He had suggested that it was suitable for high speeds, as in a steam turbine, because the amount of relative motion between the teeth, and the amount of collision, was at a minimum, or much less than in any other gear that he was familiar with. In an ordinary toothed gear there was a certain factor of collision, and one might have tables in which the speed of a gear was given as one factor in the power which the gear would transmit. He found a very much lower relative power as suitable for a given gear if the speed was high, just because the amount of collision and the shock which occurred between the teeth was much greater. Although he had made the proposal to use the gear on turbine ships with some temerity, he found that it was accepted as quite a reasonable thing, and, therefore, he thought that it might be of interest to bring before the members of the Institution that evening. At all speeds the gear very nearly approximated to the simplicity of a through drive. He thought it was reasonable for steam turbines in reducing the speed so as to get a good efficient propeller such as Mr Mavor had described. Turning now to Mr Mavor's very important and interesting paper, the first thing he would like to say was, that in looking into the practical operation of the motor built with Mr Mavor's device, which he had happily called a "spinner," he was in some doubt as to what would occur at a slow speed, when the spinner revolved in the opposite direction to the rotor, but on examining it he found that it must work as a generator. He did not know whether Mr Mavor had noticed that.

Mr W. B. Sayers.

Mr MAVOR—Yes.

Mr SAYERS—The spinner was a motor when the motor was running at top speed, and a generator putting power back into the main turbo generator when running at slow speed. Having noticed that, he could not help inquiring whether there was likely to be any need for the spinner for starting purposes. By means of the spinner, Mr Mavor got a number of speeds, but it appeared to him questionable whether the spinner was not an expensive contrivance, and for the case of driving a ship's propeller, it might turn out to be unnecessary. He was sure Mr Mavor would not mind him saying so, and if he was wrong, Mr Mavor would put him right. The propeller required very little power to drive it when it was running at slow speed. He understood that the torque was as the velocity cubed, and it seemed to him that it was a case where the squirrel cage motor could be started without any special contrivance. The squirrel cage motor did not give its full torque at starting unless with excessive current, but, on the other hand, the propeller did not require a heavy torque to start, so that in the ordinary way it seemed to him that the squirrel cage motor would start a propeller without much trouble. There was an exception to that, probably, where, in the case of emergency, it was necessary to reverse the direction. He presumed that if a ship had considerable way on it, the propeller would be driven by the water, and it would require a considerable torque to reverse it. It appeared to him that the operation in Mr Mavor's case would be to turn off the power, then reverse and get up the spinner speed, then stop the spinner and get the propeller up to the required speed, and, if maximum speed were wanted, to switch on the other current. He did not know whether Mr Mavor had considered that, with a very large power like 8000 or 10,000 I.H.P., no engineer, if he could possibly avoid it, would dream of switching off the full load right away. With a constant speed turbine and the best possible governing, the speed would

Mr W. B. Sayers.

increase 25 per cent. at least, if the load were taken right off, and unless one waited until the turbo had settled down, he would get a worse condition for restarting than if he had the ordinary pressure and speed on the generator. The steam had to be shut off, it was absolutely necessary, and it appeared to him that, that being so, a very good result might be obtained with a simple squirrel cage motor. Steam being shut off, the speed would fall rapidly, and at half speed the motor could be reversed, when, there being very little torque at the low speed, one would readily get the motor approximately synchronising, and the whole apparatus could be brought up to full speed. If that were possible, there were very considerable advantages to be gained. Such an apparatus on a ship would give a higher efficiency at the top speed or at full power, because, there being no intermediate spinner, no loss would be suffered in the second part of the motor, and the weight and cost would be reduced; but it seemed to him by no means certain that Mr Mavor, with the intermediate spinner, would be better off at other speeds. Taking the extreme case, slow speed, the main generator was running at the full speed, and was putting the current back into the turbo generator. Although the efficiency of the turbine was better at high speed than at low speed, it did not follow that it was so when running at half or quarter load. It was by no means certain that the efficiency would not be quite as good with the turbine running at a low speed and one transformation only. That was using only a plain squirrel cage motor.

Mr E. Hall-Brown (Member of Council) said he had had the pleasure of seeing Mr Mavor's model apparatus running at his works, and he had to thank him for putting the question of electric transmission forward in such an interesting form. He had no doubt that Mr Mavor's invention would find useful application in many directions, but he questioned very much if marine propulsion was one of them. He did not profess to be able to criticise the electrical side of the invention, and

Mr E. Hall-Brown.

anything he had to say in that connection was entirely in the direction of obtaining further and authoritative information. The first point he wished to raise was the question of efficiency of transmission. Mr Mavor had said that the possible efficiency of the two transformations necessary with electric transmission was not more than 88 per cent., which indeed seemed a very high figure, corresponding to nearly 94 per cent. for both dynamo and motor with no losses between, and he contrasted that with an efficiency of about 95 per cent. for shaft transmission. Now, the efficiency of shaft transmission, leaving out the thrust block and propeller shaft—which were common to both electric and mechanical systems, however arranged—was much higher than 95 per cent. and more nearly approximated to 99 per cent. No one doubted that a well-lubricated shaft, such as a tunnel shaft transmitting only torsion and thrust, and, consequently, having only the friction due to the weight of the shaft on its bearings, could be driven with about 1 per cent. of the total power transmitted. That corresponded to about 12 H.P. from an engine of 1200 H.P., or 100 H.P. from an engine of 10,000 H.P., figures which he thought were very ample, and which showed the high efficiency of mechanical transmission in the form of a rotating shaft—an efficiency which was not approached by any other system of transmission. He had pointed that out, not because it entered into the comparison between the two systems, but simply to show that anyone proposing to compete with shaft transmission had a difficult problem to face. The actual efficiency of shaft transmission did not, however, enter into the comparison in that case, because few engineers would care to place an important part of the machinery, such as the electric motor, elsewhere than in the engine room, and, consequently, the length of shafting required to transmit the power from the electric motor to the propeller would be, for all practical purposes, exactly the same as if the engines had been coupled direct. In the case of the cargo vessel's

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machinery, such as shown by Mr Mavor in Fig. 4, where reciprocating engines were replaced by a turbo electric set on Mr Mavor's system, the length of shafting, and its diameter. were practically the same for both systems of transmission, and, consequently, the efficiency of shaft transmission might be entirely left out of the comparison. The loss in adopting an electric system of transmission with an efficiency of conversion of 88 per cent. was, therefore, 12 per cent., not 7 per cent., and that 12 per cent. was, to use Mr Mavor's words, the "primary handicap against the proposal." The superior economy of the steam turbine, when working under the best conditions, might be sufficient to overcome even this handicap, but it should be remembered that the last word had not been said regarding the economy obtainable from the reciprocating engine. In fact, the very creditable economy obtained by the ordinary reciprocating engine in cargo boat work, together with the very moderate price at which these engines were produced, had, in his mind, prevented further developments in the direction of economy. Further, he was quite convinced that, for cargo boat propulsion at any rate, the reciprocating engine could be made to show an economy equal to that of any other prime mover, if owners were prepared to pay for it. There were, he believed, many firms prepared to take such a problem in hand. To come now to Mr Mavor's invention, he would have liked further information regarding the efficiency of the apparatus and the conditions for which that efficiency had been calculated. Taking the case given by Mr Mavor of a ship of 17,000 H.P., at 21 knots, with one turbo generator of 10,000 H.P. and one of 7000 H.P., he gave the three powers under his system as 17,000, 10,000 and 7000 respectively; lower powers being obtained by the usual methods. The corresponding speeds for the two higher powers was given as 21 and 18 knots respectively, and he presumed the speed for 7000 H.P. would be in the neighbourhood of 16 knots. That was not a great range, and he could not at pre-

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sent think of any problem for which a range of speed from 21 knots down to 16 knots would be a complete solution. The lowest speed was, he thought, too high for the ordinary cruising speed of a warship, and that was the one application of the arrangement which occurred to him. At the powers given above, the actual torque of the propeller shaft would be, roughly, in the ratio of 256 : 324 : 441 for the speeds of 16, 18, and 21 knots respectively. He did not put these figures forward as representing exact ratios, but they were near enough to fix ideas. It followed, therefore, that with Mr Mavor's invention, the motor which transmitted the power directly to the propeller shafting, and which had a constant speed relatively to that shafting—the variations in speed being obtained by varying the speed of the motor relatively to the ship—running at constant speed must transmit torques varying in the ratio of 256 : 441. If the ratio of highest speed to lowest was greater than 21 : 16, the ratio of torque to be transmitted would be correspondingly increased. He wished to ask whether an electric motor could be designed to work at these conditions, with a uniform efficiency of 94 per cent. If not, the efficiency of transmission would be reduced, and the comparison rendered so much the less favourable for Mr Mavor's system. In conclusion, for a cargo boat, with practically constant speed and power, when at sea, efficiency could be afforded for the short time reduced power and speed were required, and, consequently, if electric transmission were desirable, a constant speed ratio of dynamo to motor would quite meet the case. This would also apply to most passenger vessels. For vessels requiring to be driven for long periods at reduced power and speed, the actual efficiency which could be obtained might decide the matter, other things being equal, and it was this question of efficiency upon which he wished authoritative information.

Mr CAMPBELL MACMILLAN, B.Sc. (Member), said that before further discussion was embarked upon in regard to electric propulsion, it might clear the air if a comparison were made between the proposed speed control and a cascade arrangement. That might be better seen by considering a few modifications of the apparatus shown on the wall diagram. In the first place, the question was whether there was an advantage in what they were asked to adopt. It involved a relation between the spinner and the rotor at less than maximum speed of the driven shaft. When designing a large motor, one considered how the greatest possible speed could be utilised. They were forced by this arrangement to obtain a maximum speed from the combination, greater than the maximum speed for which each element was designed electrically. A cascade arrangement could be designed for both portions to run at the maximum speed required of the combination, namely, the speed of the propeller shaft, and to yield maximum power from each element at the same time. Perhaps the first objection to the cascade arrangement was that it was ruled out of court by the very low power-factor involved. It was always conceded that the cascade arrangement introduced low apparent efficiency, but since Mr Mavor had assumed the use of two different generators, these defects would disappear, and the cascade arrangement would again arrive in the front rank of possibilities. He would suggest an alternative line. Supposing there were two motors kept side by side on one shaft, each giving a torque equal to the torque of the spinner and rotor, the dimensions of each would drop down as the third power, and perhaps they might get 20 per cent. reduction off the diameter of the portion marked rotor on the wall diagram. Then there were two motors each capable of giving half torque and together giving the same total power, but they would be allowed to run at the full speed of the vessel's shaft corresponding to 21 knots, and not to 18 knots. These two motors could utilise the generators to obtain as many speeds as Mr Mavor obtained. Mr Mavor remarked that they were entitled to use an analogy made from the small

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motor in dealing with the probabilities of the large motor. He did not think that was admissible. There would probably be a much greater rush of current when changing speed. One could design a larger motor at much higher efficiency, and so unavoidably permit of a greater flow of current. In addition, in changing from a small to a larger motor, there were many other difficulties which cropped up and which would tell against this argument from analogy; for instance, Mr Mavor noticed that he would require to pass from ball bearings to ordinary bearings for the spinner, and when they went to such large powers an ordinary straight bearing became a very important problem indeed, and a more complicated bearing, for the spinner would introduce still more complicated problems. The same difficulty might occur in motors for steel rolling-mills. He did not know whether any figures had been given as to the possible sizes of motors for such purposes as Mr Mavor's marine scheme, but he thought that if the best possible designs for motors were looked into, dealing with the powers contemplated, it would be found that they were very large, and there arose a difficulty as to how they were to be arranged in the ship. As to the motor power with two turbo generators, one might be set out of action, but the turbines must be kept coupled together, because when one of the generators was turned into a motor, the turbine would be spun round, and there would be no speed control. In connection with Mr Hall-Brown's remarks, he thought they ought not to go back to the question as between reciprocating engines and turbines. If the turbine was desirable at all this should be frankly granted, and then a clear comparison could be instituted between electric driving and direct driving from the turbine. He believed a good case could be made out for electric driving. Mr Mavor's word must be taken for the comparison of weights that was instituted and the deductions drawn from this comparison. It would be interesting to have some details as to how one might expect

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to make up for the weight of the extra elements introduced. Once that point was settled further inquiry might be made into the electrical combinations. Another point that made the electrical problem simpler was, that in suddenly changing speed there would not be a very heavy torque to deal with, because there would be a large slip, and even a complete reversal might not introduce a very heavy torque. He hoped that the electric propulsion of ships would continue to interest engineers till a proper solution was arrived at, because there were feasible schemes not dependent entirely on one electrical solution of the problem. The whole question of electrical control was worthy of consideration.

Mr E. M. Speakman (Associate Member) thought this was the first occasion on which the electric propulsion of ships had been dealt with before any institution such as this, consequently a paper of such a nature would be very widely read by those gentlemen who were responsible for advising their companies as to what installation of marine propelling machinery they should adopt. Perhaps the paper had been submitted by one who was more interested in the electrical end rather than in the broader question of marine propulsion, but, nevertheless, the paper was one that would be received with a good deal of attention. When it was realised that the average horse power per annum produced in this country alone for marine propulsion was about 1,500,000, any serious proposal that was put forward for reducing either the cost of manufacture of that power, or of improving the efficiency of the propulsion of the 1,750,000 tons of steamships constructed per year, was one worthy of careful investigation. Consequently, when one took up Mr Mavor's paper he naturally looked for two or three facts that immediately affected the marine engineer and naval architect when engaged on estimating work. The first thing that he looked for was some statement regarding weight, and another as to economy compared with existing systems. In the example given on page 336 for

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a ship of 17,000 horse power, propeller dimensions and revolutions were given for the ordinary type of turbine machinery. Mr Mavor had made a comparison between that and a triple-screw installation with an electrically driven propeller. He could only say that, as far as turbine propellers were concerned, they seemed to him to be on the small side, and the probable efficiency given for them was undoubtedly too high. The paragraph went on to state that the electrical equipment would permit of the use of propellers of about 14 feet diameter at 140 revolutions per minute, giving an efficiency of not less than 70 per cent., which seemed to him to be a very high efficiency for any propeller. He did not know why there was a popular idea that the average efficiency of reciprocating engine propellers, or any propellers for that matter, should reach such a value, because he had not come across any experiments or results of trials of efficiency, on actual ships, that justified the idea of 70 per cent. He thought it was more likely to lie between 62 and 64 per cent. for a good propeller, and the efficiencies given by Mr Mavor required a good deal of reduction. As far as the question of weight was concerned, there was no statement in the paper as to the relative weight of the two installations. In connection with a 17,000 horse power steamer, Mr. Mavor stated that the power "is provided by one turbo generator of 10,000 horse power which directly drives the direct connected motors, and by a generator of 7,000 horse power which drives the regulating motors, the whole plant being run at full speed and full power." That corresponded to a turbo generator installation of 6000 kilowatts and 4000 kilowatts, and this would require an engine room that would be no toy at all. The turbines alone would be very nearly as large as in the case of the cylinders of the triple-screw installation, and as far as he could make out they would weigh very little less. The weight for 17,000 horse power at 370 revolutions per minute, with ordinary Parsons' triple-shaft marine turbines, would be about 250 or 260 tons; at least there was absolutely

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no reason why they should be any heavier. A 6000 kilowatt turbo alternator plus a 7000 kilowatt turbo alternator, supposing they revolved at 750 revolutions per minute, would weigh about 200 tons altogether, if not more, so that there would be a margin of about 50 tons between the direct set and the turbo generator set. Consequently, he thought that, as far as weight was concerned, there would be very little to gain in view of the increased weight of propellers and shafting, to which must be added the weight of the motors. He (Mr Speakman) had investigated several comparative systems, and had gone very carefully into the details of weight and efficiency, and he could assure Mr Mavor that as far as weight was concerned he did not think there would be any gain at all. Mr Mavor had stated a steam consumption of 12·2 lbs. per horse power hour, with a 4 per cent. allowance for driving auxiliaries, no superheat being used, so as to make the comparison with normal marine practice. That, he thought, was a very optimistic view for an ordinary turbo generator running without a superheater. Mr Mavor had also said, "Within the limits of practice, the efficiency of the steam turbine is increased by increased speed of revolution, while the efficiency of the propeller is decreased by a corresponding change." He did not think that very much would be gained by increasing the speed of rotation of the turbine, as the efficiencies did not depend only upon speed, but on several other things as well. Roughly speaking, as long as it was possible to get the blade velocity and corresponding number of rows of blades, the efficiency would not be greatly varied whether the turbine was running at 180 or 1800 revolutions per minute. A very good comparison was obtainable between the "Lusitania" and a 1000 kilowatt turbine, because in the case of the "Lusitania" the efficiency ratio was about 64 or 65 per cent., which was abnormally high, in fact, a ratio that one would be glad to get, even with a very high speed of rotation, out of a 1000 kilowatt turbine. One had to take the efficiency into account with

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various other things, so that when Mr Mavor said "In some cases it will be easy to adopt an increase of ten times the speed of revolution," he was sorry to say that he could not agree with him at all. He thought that if Mr Mavor got an increase of four times, he would be extremely lucky. In the case of a turbo alternator, it was not possible to go up very largely in revolutions, because one was led into abnormally high stresses in the generator, in fact, into exceptionally high stresses, so that one could not increase the revolutions any further. Another objection to Mr Mavor's system was that, which would probably be made by gentlemen connected with electrical work, regarding the possibility of getting a spinner to run properly between the rotor and stator, which seemed to him to be a difficult job. Mr Mavor would add a great deal of interest to his paper if, in his reply, he gave some definite idea and some definite figures as to the relative weights and efficiencies that he expected to get by this combination. He (Mr Speakman) certainly could not agree with him that there would be any saving from the purely steam consumption point of view, or from the point of view of weight and space, and he thought there would be very little from the propulsive efficiency point of view. Many engineers had been at work on this problem, and they had had the fullest data available as to the results that had already been obtained, and he could assure Mr Mavor that as far as weight was concerned the margin was a negligible quantity even in the installations that were unfavourable for direct driven turbines. The problem, however, was of considerable interest, and he would be glad to afford Mr Mavor any information as to the details of his (Mr Speakman's) investigations. Mr Mavor was the first gentleman who had submitted a paper on this subject, and he did not think he had made out a very good case for the system.

Mr J. A. RUDD (Member) considered that the thanks, not only of the Institution, but of the marine engineering world at large, were due to Mr Mavor for having brought forward this

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question—although thanks were, perhaps, all that Mr Mavor was likely to get. To his mind, it sounded the knell of marine propulsion by means of the turbine. It brought home the defects and deficiencies of the system, suggesting as a cure the multiplication of other and worse evils, and, as Mr Hall-Brown had indicated, it should have the effect of making the marine engineer look to his laurels in the production of reciprocating engines of the highest possible efficiency, and making the shipowner alive to the fact that, if he wanted economy he could have it, but he must be prepared to pay for it in the first place. If engineers were willing to go on sound lines, lines that had been established through many generations, they could get an economy with which the figures put forward in the paper did not compare at all. Hitherto marine engineers had gone very much upon a beaten track. They had adhered to one type of engine and valve gear, and it was rather an extraordinary thing, in view of the fact that coals had to be carried in valuable space and purchased abroad where they had been taken at great cost, that so little attention had been paid to the development of the reciprocating engine on the lines of economy. For land work more had been done in that direction. By way of comparison, he might mention that, whereas Mr Mavor spoke of a steam consumption of 12 lbs. per horse power per hour—he did not know whether indicated or brake horse power was meant—as low a figure as 8½ lbs. had been obtained, showing a further improvement of 30 per cent., beside which the suggestion of 12 per cent. and 7 per cent. contained in the paper faded into insignificance.

Prof. J. H. Biles, LL.D.—It would be rather interesting to know what particular engine was giving that wonderful result.

Mr Rudd—It was the Sulzer engine working with steam at 185 lbs. pressure and superheated to 300 degrees C., the power being 1000 kilowatts. In that case the steam consumption was between 8½ and 8¾ lbs. The engine worked with a

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drop valve, and while there was some difficulty in applying that type of valve to marine work, it pointed out one direction to which the marine engineer might turn his attention to enable superheated steam to be used. There was no doubt about the value of superheating, but piston valves and slide valves did not lend themselves to satisfactory working with superheated steam, and the problem was to apply a suitable type of valve that would. With development in that direction, and possibly also the application of the exhaust steam turbine between the reciprocating engine and the condenser, he believed that there was a great deal more benefit to be obtained in economy, in the reduction of weights, and the weight of coal to be carried, than by any method of indirect transmission that had been so far thought of. Mr Hall-Brown had pointed out that with direct transmission there was practically unity of efficiency, and there was, too, a very heavy handicap in introducing other means of driving between the engine and the propeller. Electrical composite driving, not exactly on these lines but on somewhat similar lines, had been tried in a boat some four years ago on the Lake of Geneva, the prime mover being a Diesel engine. In that case there were difficulties in the way of speed regulation and reversing, and the method adopted was a motor on the shaft with a magnetic clutch between the engine and the shaft. One speed was obtained with the clutch in operation and driving direct through the shaft, and another speed by running the engine with the generator on it driving the motor, the clutch being disconnected. That might, perhaps, be looked upon as the forerunner of the present proposal. He would just like to say that, perhaps his opening remarks might appear a little severe, but he had no intention of being so. This invention of Mr Mavor's showed very remarkable ingenuity indeed, and it must have involved a great amount of work and thought and an enormous expense in developing it. He believed that there were many fields in which it might prove to be of very great use, and not only

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that, but it would foreshadow and lead to developments in the construction of motors and generators which would have very far-reaching effects.

Mr J. R. Jack (Member) said that he could not pretend to deal with this paper from the electrical side, but from the naval architects' point of view the proposal was extremely interesting; particularly so to himself, because he had long believed in some form of gearing between the turbine and the propeller, although he could never get a marine engineer to accept it. He had previously drawn attention to the similarity of conditions between the petrol motor and the turbine, with regard to the different respective speeds of generator and propeller at which they gave best results. With petrol motors he had tried chain transmission for reducing the gear for small craft with very good results, and he was glad to see that Mr Mavor had produced a practical method of gear reduction on a large scale. Mr Mavor had not made extravagant claims for his method, as was so often done with new proposals, but he stated the cases to which it was applicable, and clearly excluded those to which it was not. With regard to the effect of a head sea on the efficiency of the propeller, he thought that was a point which most people had overlooked. The propeller of a turbine steamer might be fairly efficient, but when that vessel was driven into a head sea, the efficiency sometimes broke down. The propeller might be big enough to transmit the power under trial trip conditions, but at the best it might easily be on the verge of cavitation. Whenever the resistance was increased by adverse weather conditions, cavitation began, and though the turbine might be showing a magnificent efficiency, a lot of horse power was lost, and the coal consumption remained at the same rate, while the speed fell off. With larger propellers and a corresponding larger disc area, there would be less intensity of pressure in the propeller race, under ordinary conditions, and the cavitation limit would go up enormously. The majority of turbine vessels had three shafts, and with regard to the centre one, while it was at present a necessary evil, it was none the less an evil from the shipbuilders' and owners' point of view. It was in an inconvenient position and it complicated the construction of the stern. This was the part of the vessel which the shipbuilder wished to proceed with at the earliest possible moment, as there was a great deal of work to be done there, but until the size of the propeller had been fixed, which took a lot of time and trouble, nothing could be done to proceed with the work. The position of the centre screw was close to the hull and rudder of the ship, which did not conduce to efficiency, and so long, at least, as marine engineers would persist in using the highly objectionable bronze alloys for propellers, the centre screw was a fruitful source of corrosion to important and costly parts of the hull. With Mr Mavor's arrangement it was quite easy to eliminate this centre propeller with all its manifold objections. In his supplementary remarks, Mr Mavor proposed to put the motors on a bulkhead, but against this proposal he felt it his duty to protest. If the vessel were pitching in a head sea the angular motion might be small in amplitude, but owing to the shortness of the pitching period, the rate of change of angular momentum would be considerable, and as the moment of momentum of the rotors would be fairly large there was bound to be a gyrostatic pressure produced. The tendency of a rotor driving a right-handed propeller would be for the starboard side to go forward and the port side to come aft when the stern rose, which tendency would be reversed when the stern fell. That would put a serious pressure on the shaft and bearings which would further complicate the friction and lubrication problem, but he had no doubt that this was a point Mr Mavor had already foreseen and provided for in the motor itself; but as the gyrostatic couple acted in a plane perpendicular to the plane of the bulkhead, it was in the direction in which the bulkhead was least able to resist it. Of course, in the case of the port propeller, which would

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be left handed, the motor would run in the opposite direction and the forces there would be reversed, so that if Mr Mavor intended to connect the two machines rigidly together, these couples would neutralise each other, but he hoped that Mr Mavor did not intend to transmit any of these forces through the bulkhead itself. In steering either to port or starboard there would be a tendency for one motor to tilt forward in the head and the other one to tilt aft, but as the movement would be extremely small compared with the pitching, he did not think that need be taken into consideration. One point that struck him as being of considerable value was, that the turbines were situated well up in the body of the ship and the condensers were a considerable distance below the turbines, which arrangement lent itself to very perfect drainage of the turbine casings. The method of electric transmission appeared to him to lend itself to the direct control of the propelling machinery from the flying bridge, and that was a matter of great importance to the officer in charge of the ship. If the machinery could be worked by an arrangement of the nature of a "tramway controller," then the officer on watch could do it himself. With the present system of telegraphing orders to the engine room, it might easily happen that the engineer on watch might not be standing at the starting gear, but going round the machinery seeing that all was right, or, possibly, attending to some slightly troublesome part, and it might be some little time before he got to the reversing gear to obey the order of the telegraph. During this time the ship would travel one or two lengths of herself, and that might mean all the difference between a collision and safety. If he was right in this supposition, and he saw nothing to prevent it from being done, it would be a matter that would appeal very much to those who had the responsibility of actually handling ships. In the Appendix, Mr Mavor had dealt with the propeller problem, which often came up and did not seem to get very much further forward when it did come. He

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did not think that the ingenuity which characterised the beautiful arrangements for the starting of the motor had been extended to the propeller problem, as the mathematical reasoning was not very easy to follow. He considered Mr Mavor's idea an excellent one, most ingeniously worked out, and he only hoped that he would get an early opportunity of carrying it into practice, when he had little doubt it would be a real success.

Prof. ANDREW JAMIESON (Member) observed that a great number of electrical engineers, himself included, had been thinking and planning arrangements with the same object in view, excepting, of course, Mr Mavor's invention of his novel motor. With regard to the turbine and generator, by simply following the latest and best land practice, one could have such a high mean speed of the different rows and sizes of turbine blades as to get a maximum efficiency from the steam. Mr Mavor estimated that he got a mechanical efficiency of 94 per cent., and he (Prof. Jamieson) thought it was quite possible to get a combined efficiency of turbine and generator of 70 per cent., as the transformation of from 70 to 80 per cent. of the energy of steam into useful work could be obtained from the Parsons' turbine. By using the simple rule that the efficiency $= \frac{\text{work got out}}{\text{work put in}}$ in the same time, or the ratio of the kilowatts got out from the generator, to the equivalent kilowatts of the B.Th.U. of the steam put into the turbine in the same time $=70$ per cent. But one did not get by this method the advantage of the steam thrust on the turbine blades to balance the opposite thrust of the screw propeller, which was at present obtained by a direct connected turbine and screw propeller through shafting. This disadvantage must be taken into account, and a suitable thrust block put in between the motor and the screw. In a large steamer an immense increase of space would result by clearing away the whole of the screw shafting and tunnels. This freed

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space could be used for cargo or other purposes. Moreover, there would be a minimum chance of broken shafts, since there would be nothing but the short, strong tail end propeller shaft. Mr Mavor had been exceedingly bold, and he complimented him on the ingenuity shown in his new method of motor design. However, as cautious people, they would like to see this plan tried, carefully tested, and reported upon. In a steamer of 3000 tons, with turbines of 3000 horse power, one could have two A. C. turbo generators and three A. C. electric motors at the stern. There seemed, however, to be no doubt that within a year the making of direct current motors of over 3000 horse power could be relied upon. All designers aimed at producing good direct current motors worked with suitable brushes, at currents of, say, 3000 amperes at 600 volts, or more. It would be best to begin with a steamer of, say, from 500 to 1000 horse power, with two or three very short shafts, with thrust bearings and direct current motors. In such cases the motors would be quite equal to almost instantaneous reversal at 50 per cent. overload, which could never be obtained by the present system of direct-connected shafting between the generators and the screw propellers. He quite agreed with Mr Mavor that 12·2 lbs. of steam per I.H.P. per hour was not by any means an over estimate. In fact, Mr. Rudd was quite within the mark when he spoke of 8½ to 9 lbs. of steam per I.H.P. per hour being possible, with highly superheated steam and a 29-inch vacuum. He would remind Mr Hall-Brown that with land central and sub-stations, the sub-station men might never see the central station men from one year's end to the other, so that his objection could be easily overcome. He complimented Mr Mavor upon the electrical part of his paper, and was sure that his ideas would be borne out with regard to efficiency. One required to study first of all Taylor's book on "Resistance of Ships and Screw Propulsion" before trying to follow what Mr Mavor was driving at in regard to the screw propeller diagrams at the end of his paper. So far as he could make out, it was this, that if he had a motor with its screw running at, say, 300 revolutions per minute and got, say, 60 per cent. efficiency, then Taylor's curves would enable him to determine the disc area, etc., of a new screw whereby he could get 70 per cent. But there were very few ships on the Clyde whose screw propellers gave even 50 per cent. net efficiency, and there was no difficulty in actually getting the 70 per cent. efficiency. As Mr Mavor's oldest electrical adviser in 1880, he (Prof. Jamieson) had the greatest pleasure in complimenting him upon his important paper.

Prof. J. H. Biles, LL.D. (Member), said he had listened with a great deal of pleasure to Professor Jamieson's remarks, the more so because he seemed to be the first electrical engineer who was on Mr Mavor's side. He could assure the members that all naval architects were on Mr Mavor's side. They all wanted to have something of the nature of Mr Mavor's proposal, and he thought the electrical engineers should all be on the same side as Mr Mavor, and if they did not approve of his proposals they should suggest something better. The question seemed to him to divide itself into two parts:—(1) Was it desirable to have electric transmission? (2) Was the method proposed by Mr Mavor a practicable one? The first point to consider was, Was it desirable to have any kind of alteration of speed between the generator and the propeller? At present they were directly connected. It was not necessary for electrical engineers to decide the question of whether some transmission system should be introduced, because there was no doubt that the loss of efficiency existed in direct connected arrangements where the propellers ran at a very high speed. Professor Jamieson had some difficulty in understanding this from reading Mr Taylor's book, but he would be very glad to give him another book in which the remarks on propellers would not present the same difficulty to him, and where it was clearly shown from Taylor's experi-

Prof. J. H. Biles, LL.D.

ments that high efficiency of propeller lay generally with large diameters and low revolutions, and low efficiency with high revolutions and small diameters. This tendency was accentuated at sea when the resistance of the ship was increased and the speed reduced. In this condition, the large diameter of propeller held up to its work still better than the small one. Hence from a naval architect's point of view, of obtaining high efficiency at sea, as well as on trial, it was desirable to have large slow running propellers. Hence electrical engineers might be quite sure that some system of transmission between a high speed generator and a low speed propeller was desirable. Electric transmission seemed to be a very convenient way of doing this, and Mr Mavor's proposals of introducing his motor enabled the propeller to be geared down, with the added advantage of giving variation of speed which they had not so far been able to get. For that reason he thought the subject was worthy of the most serious consideration by all who were interested in the propulsion of ships. The second point was the practicability of Mr Mavor's proposal. He was not prepared to say that this method was the only way or the best way, but Mr Mavor certainly deserved every encouragement from the naval architect for having brought this subject into public discussion, so that, not only he himself might work upon it, but that many others who were able might do so. One point of great importance that should not be overlooked was the facility for reversing which electric transmission gave. As great a speed could be obtained with the propellers going astern as with the propellers going ahead. The question whether the details of Mr Mavor's proposals could be carried out successfully must be largely an electrical one. The first objection that came to the minds of a great many people was the switching on and off of the load. He did not think that switching off was as serious as electrical engineers were disposed to think. They were in the habit of dealing with other kinds of loads than that which came upon the propeller. Water was a fairly soft thing for the propeller to rub against, and there was no vital necessity to switch off a load in $\frac{1}{100}$th part of a second. He did not think the difficulty was one that need be very troublesome. Mr Hall-Brown, he was sure, did not wish to convey any misapprehension as to the limit of reduction of power and speed which the electric transmission system permitted. There was a reduction possible from full speed to the stopping point. Any intermediate speed could be obtained, but the economy that took place varied from the top speed down to low speed. It might be better illustrated by a diagram than by talk.* There was no question that where such methods had to be applied to get economical results over a wide range of speed, these methods were more useful in vessels like warships than in ocean liners and cargo vessels, but there appeared to be an increase of economy even at the maximum speeds. Mr Speakman had said that he doubted the efficiency of the propellers being as high as 70 per cent., and he did not know of any records of experiments showing any such results, but Mr Taylor's book gave results as high as 80.

Mr SPEAKMAN—There was no sea-going data.

Professor BILES—There were records which would show higher than 70 per cent. at sea. Of course, it was a matter of opinion as to what was the real relation of the efficiency at sea, and the efficiency in model propellers.

Mr PHILIP D. IONIDES agreed with Mr Mavor to the extent that he believed there were possibilities in a system of electric transmission for driving ships as proposed, but his objections to the paper were on the grounds that, in his opinion, Mr Mavor had not made out the best case for electricity, and he did not approve of his method of obtaining speed variations. There were two kinds of electricity—direct current in connection with which commutators were required, and alter-

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* Prof. Biles sketched on the blackboard a diagram which it was arranged that Mr Mavor should embody in his reply to the discussion.

Mr Philip D. Ionides.

nating current which required no commutators. The question of speed variation could be easily solved by the use of direct current motors; but direct current was prohibited by the fact that it was impossible to commutate or collect currents on a direct current turbine-driven generator of high power. That being so, Mr Mavor had very naturally turned his attention to alternating currents, and for the purpose of this discussion the question could be confined to three-phase circuits. In alternating current circuits, the number of alternations depended upon the number of poles of the revolving field and the revolutions; that was to say, in a turbo generator at 1500 revolutions per minute—which was the speed Mr Mavor suggested—the use of two poles gave 3000 alternations per minute. Inversely, the speed of a motor depended upon the number of poles in the stator winding and the alternations of the circuit, so that, in a motor having four poles and supplied with current at 3000 alternations, the synchronous speed, or the speed at which the magnetic field revolved, would be 750 revolutions per minute. With six poles the speed would be 500 revolutions per minute, with twelve poles 250, with twenty-four poles 125, and so on. The method he suggested in preference to Mr Mavor's was a system whereby the windings of the motor could be grouped into different numbers of poles to give the required speed variations. This method was adopted in many industrial installations with marked success. A peculiarity of the induction motor, which had not been brought out in the discussion, was that, in order to attain a high efficiency, there must be a small air gap, and in motors of 1500 H.P. the air gap could not be more than $\frac{3}{32}$nds of an inch consistently with high efficiency and reasonable weight and price. The slightest increase in the air gap necessitated a very large increase in the weight of the motor, in order to obtain an equal efficiency; consequently, in order to obtain a high efficiency and low weight, it was absolutely necessary to have a small air gap. Mr Mavor's motor had two air gaps

Mr Philip D. Ionides.

with a spinner revolving outside the rotor. He maintained that it was almost an impossibility to construct such a machine of upwards of 1000 H.P., and ensure that the parts running at different speeds did not come into contact with each other. At different loads and different speeds, the temperatures of various parts of the motor changed, which, in the case of Mr Mavor's motor, doubled the liability of fouling. A further difficulty existed in the proposed construction of the bearings, which had been referred to by another speaker. On the other hand, the pole changing machine, such as proposed, consisted of a single stator with the rotor revolving inside, and the only objection would be the complication necessary to ensure the changing of the number of poles. This, however, was not a mechanical drawback and only necessitated a somewhat elaborate controller. Such an arrangement could readily be made for giving speeds of from 250 to 60 revolutions per minute, with a fairly high efficiency at each speed. Some remarks had been made regarding the question of remote control, and he thought that was a point very much in favour of Mr Mavor's proposal as it would be quite possible to bring the entire control of the propelling motors to a small desk or switchboard on the bridge of the vessel. He could speak of one system in London where the complete control of some thirty sub-stations, each supplying power to the London Underground Railways and all the principal Tube Railways, was centralised in a control desk no larger than that at which the President sat. Any failure of this system would practically paralyse the traffic of London, and the fact that it had operated successfully for a number of years proved that the remote control of such an equipment could be accomplished without serious difficulty.

Mr **James Hamilton** (Member) said that the association of a fast running machine with efficient slow running propellers appealed to him because he had two boats running very satisfactorily on that plan. In working with these boats he had

Mr James Hamilton.

found out two things that might be of use to Mr Mavor, or the electricians who were attempting to solve this problem. One was—and he would be glad if Mr Mavor would say in his reply whether it applied equally to his system—in the case of his boats, where there was chain belt transmission and different sized sprocket wheels, when he slowed down his propeller shaft, he got a very small pull on the chain, but multiplied the power on the shaft. He found that a very useful thing in connection with the turbine. It supplied a want that the turbine had in dealing with the power at starting. Another thing, by running a turbine at 30 revolutions to one of the propeller, one could afford to give the turbine an impulse by sending a rush of steam into it, with the result that one could approach a quay or landing place by impulses. There was no difficulty about the machine starting. It started at the moment it got steam, and one could get a substantial speed out of the turbine with a resulting small speed on the boat. That applied to a great many transmission gears, but he did not know whether it applied to Mr Mavor's. To all appearance Mr Mavor had the same size of rotor as generator, but the slowness of the speed of the shaft would indicate that there ought to be a multiplication for starting. With regard to Mr Sayers' gearing, he thought that Mr Sayers would find just what he himself had found with chain gearing, namely, that if it were fitted into an ordinary ship where the propellers could race, it was rather a bold thing to do.

Mr R. T. Napier (Member) remarked that it was clear from the paper that Mr Mavor did not look upon the system he proposed as suitable for either cargo steamers or for moderate sized high-speed steamers. It did not require much use of arithmetic to see that, in the case of such steamers, the weight would be prohibitive. It had to be remembered that the boiler room equipment, the piping and auxiliary gear, and the condenser and pumps, would represent no less weight in the case of the electric drive than at present; in fact, the condenser and

Mr R. T. Napier.

pumps would probably be heavier, as a high vacuum was essential to the economy of the steam turbine. He (Mr Napier) had to do with a high-speed twin-screw steamer, with engines indicating 3400 horse power. The weight of each engine up to the first coupling was 57 tons, and of this 17 tons was represented by the condenser and pumps, leaving 40 tons for the weight of the actual engine, or 80 tons for the two sets. An installation consisting of a steam turbine, a dynamo, and two motors, each of the latter giving at least 1500 brake horse power at 120 revolutions per minute, could not possibly be managed on 80 tons or anything like it. Gentlemen present had spoken of gearing as possible for marine work, but the last generation of engineers had too much experience of geared engines, and it was with the heartfelt approval of the sea-going staff when gearing was banished from the engine room. Mr Mavor spoke of the " efficiency " of a screw propeller as a calculable quantity. He (Mr Napier) had no fancy for the word in this connection. The most satisfactory propeller for any steamer was that which drove the vessel at the desired average speed, in all conditions of weather or loading, with the smallest number of revolutions, and each combination of ship and propeller had to be treated on its own merits. Every marine superintendent was alive to the fact that if, with the same revolutions, an alteration of the propeller would add a quarter of an knot to the speed, it would mean from two to three per cent. more turnover, and was well worth the outlay. He had his doubts as to any formula helping in the matter.

Mr LAURENCE MACBRAYNE (Member of Council) remarked that the question of cost (both capital and maintenance) had not been discussed at all, and it seemed to him that the problem covered a very wide area and had to meet widely differing conditions, that it covered both naval work and mercantile marine work, and the conditions in each case were very different. It was quite conceivable that for naval work it might be worth while to apply this system so that a ship might run

Mr Laurence MacBrayne.

for long periods at half speed, with one unit at full load, but commercial men generally designed their ships for a particular speed and for the greatest economy at that speed. Further, it struck him that there might be a field for Mr Mavor's scheme on different lines, namely, by increasing the power available for propulsion at full power by means of a combination of direct driving reciprocating engines and electric transmission turbines. He had heard that the reciprocating engine worked with greater economy than the turbine between the higher ranges of temperature, while in the lower ranges, corresponding to pressures below atmospheric pressure, the turbine was far the more economical. He had also heard of proposals to carry this exhaust marine turbine idea out by fitting a vessel with reciprocating engines on the wing shafts, and operating a central shaft by a turbine using the exhaust from the low pressure reciprocating cylinders, Fig. 8. In this proposal there was a bye-pass direct to the condenser, so that at low powers the turbine could be cut out and only the reciprocating engines used, the ratio of expansion being suitable for an early cut-off. In effect, at low power the engines were ordinary triple-expansion and at full power there were quadruple-expansion, the turbine acting in place of a fourth cylinder. In this scheme, as was usual, a compromise had to be effected, namely, the propeller had to be made too small for good efficiency, and the turbine had to be made of large diameter to reduce the revolutions; still, if there was anything in it, here was an opportunity for partial electric transmission. The inefficient propeller and the slow running exhaust turbine might be replaced by a fast-running exhaust turbine electric generator operating motors on the wing shafts, thus eliminating the losses of the inefficient central propeller and reducing the weight and cost of the turbine. The motors and reciprocating engines would act on the same shaft, and most of the power would be by direct drive. The electrical design was for electricians to evolve, but if it were possible for total electric

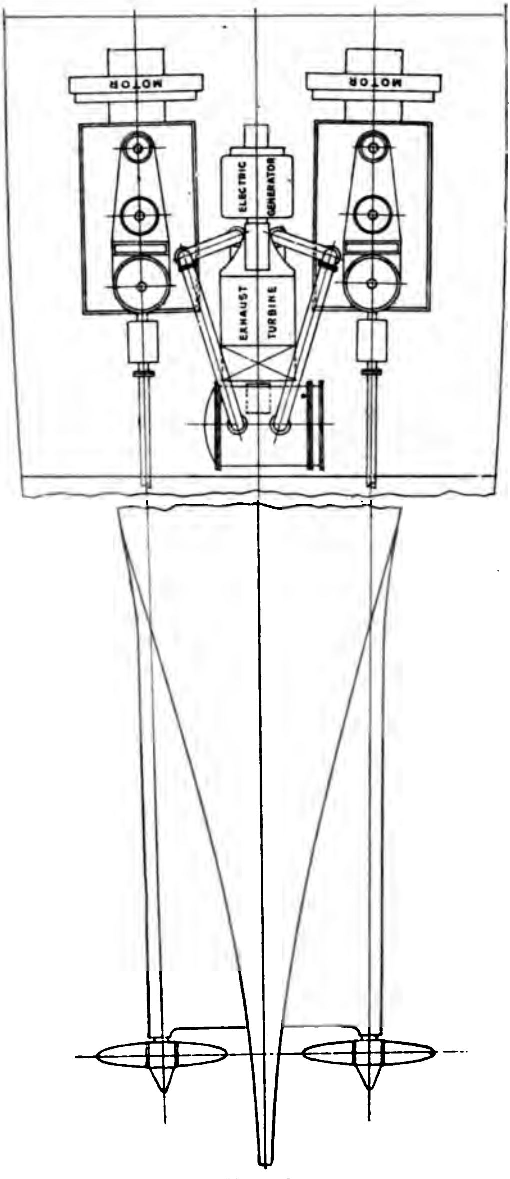


Fig. 8.

Mr Laurence MacBrayne.

transmission, it might be possible for partial electric transmission. The larger proportion of power would be communicated to the propeller by direct drive, so that electric transmission losses would only affect a small proportion of the power. Again, looking at the engine as a heat engine, and assuming that the work done at each stage of expansion ought to be proportional to the range of temperature in that expansion, there ought to be a gain on the last stage of expansion that would far more than counterbalance the electric transmission losses, and leave a substantial net gain to the power available for propulsion.

Mr W. B. Sayers said he would like to add a suggestion to his previous statement. It had been said that the balancing of the thrust by the turbine would be lost, but he would like to suggest that it would be possible—he would not say that it was a good thing—to balance the thrust magnetically, to have the rotor displaced lengthwise in the magnetic field, and so carry the thrust. It would be also possible to make the rotor slightly conical and to prevent it going too far into the magnets by a thrust block which would come into use in going astern. Referring to one of the speakers' remarks about the advantages of direct control from the flying bridge, it was also possible for the gear that he had shown to be controlled from the flying bridge, and, as a matter of fact, he had lodged a patent specification to cover that arrangement. The gear was changed by the application of brakes, and that could all be done by a controller on the bridge, without interfering, in any way, with the rotation of the turbine.

Mr Mavor in reply said that during thirty years' experience he had found that efficiency was the most difficult kind of problem, for two reasons, first, that electrical people thought they, and they only, knew anything at all about efficiency, and, second, they could not get anybody else to believe that. He knew the system was efficient, but he found it very diffi-

Mr Mavor.

cult to prove in figures the general or even any particular case. The demonstration by Mr Sayers of a speed-reducing gear, in the Author's opinion, was a demonstration of the impracticability of dealing mechanically with the problem in a scale of thousands of horse power. A toothed gear of any kind became enormously heavy, complicated, and inefficient, and had, therefore, never been considered applicable to powers and speeds such as those under consideration. Mr Sayers pointed out the fact that no engineer would suddenly use a stoppage and reversal of energy if he could help it, but there was one very curious and pretty thing in this proposal, which he had not noticed until he was reversing the motor itself. It then became evident that he could go direct from full speed ahead to slow speed astern by reversing the rotor only, leaving the spinner running in the full speed ahead direction. The spinner was floating in a magnetic field, and acted as an energy reservoir or buffer. The same applied in putting up the speed from slow speed astern to full speed ahead, but in this case he thought it was better to drop the current by shutting off steam, if it were only for a quarter of a second, and then turn it on again. This was not the same kind of problem that one was accustomed to on land. On a ship the motor made its own load by increasing the speed of the propeller; there was no dead load. The loss of efficiency at the low speed by the use of the spinner was comparatively trifling. Mr Sayers drew attention to the fact that the spinner returned energy to the circuit. The transformation applied only to a fraction of the power, and the efficiency of transformation was of the order of 95 per cent. when the spinner was working at its full load in the reverse direction. If Mr Hall-Brown's figure of 12 per cent. were accepted as the primary handicap against the proposal, it simply meant that if a case occurred where the handicap reached this figure, there must be other savings to counterbalance it, otherwise there was no inducement to adopt the new method. Figures were given in Dr.

Mr Mavor.

Robert Caird's contribution to the discussion, which pointed to the possibility of economy which seemed sufficient to counterbalance even such a heavy handicap. To allege that a cargo boat required practically constant speed and power, was to allege also that in this class of ship there was no problem to solve in dealing with economy at lower powers, but there remained the adjustment of engine speed to propeller speed. Mr Hall-Brown was not right when he said that the speed reduction only went down to 16 knots. It could go as low as was desired. The alternative use of the lower periodicity, where the generating plant was subdivided into units of differing periodicities, provided six changes, bringing the speed down from 18 to 16 knots, or less. The rest did not matter much, because the reduction of speed of the generating plant was less costly on small powers. The electric motor did not work with a uniform efficiency at all loads. There was a decided drop in efficiency in motors and generators at light loads, and it was for this reason that the proposals here made involved the use of two units, so as to minimise the loss of efficiency which applied much more to the present normal methods than to the new proposals. Mr Campbell MacMillan's and Mr Ionides' remarks might be taken together. Their proposals embodied pretty fully the suggestions which had preceded the proposals here made. These methods had been known for about fifteen years. and had had many practical applications for various purposes, but it was only necessary to scheme out a detailed application of them on board ship to find that they would be, as they had been, rejected alike by the naval architect and the marine engineer. Undoubtedly there were difficult problems to face in connection with the practical carrying out of the new proposals, but the difficulties of running clearances and bearings were of precisely the same character as those which had been successfully solved by the men who had made the marine steam turbine a success, and these same men were willing and able to deal with these parts of the problem. Mr Ionides was

Mr Mavor.

quite mistaken in supposing that increase of the air gap seriously affected the efficiency of the machine. One had to use a bigger current with a slightly greater loss in the conductors. On the other hand, the pole changing device for the present purpose was an absolute sacrifice of everything that was nice about the electric motor. The method adopted for ascertaining the comparative weights was simple. The motors had been drawn out and measured up. The turbo generators were in existence, and their weights were well known. The total weights were, as stated in the paper, approximately equal to the weights of marine steam turbine equipments for similar ships. Mr Speakman's difficulty as to weights was thus answered. The steam consumption given was on the authority of Messrs Parsons & Co., who were prepared to give commercial guarantees to support their figures. The propeller efficiencies assumed were supported by Professor Biles in his contribution to the discussion. Mr Speakman referred to 6000 and 7000 kilowatt alternators, running at 750 revolutions per minute. A propeller transmitting this power at maximum efficiency would run at less than 75 revolutions per minute. Small sizes of turbines were run at 3000 revolutions per minute, and this was not an abnormally slow speed for a propeller driven by a marine turbine. These cases justified the assertion that the speed ratio might be 10 to 1. Mr. Speakman was a recognised authority on the steam turbine, but it was necessary to give special study to the possibility of change of speed ratio to appreciate the entirely new field which this change opened up. The Author sympathised with the difficulty of seeing the bearings of the question, for less than a year ago his attitude was exactly the same as Mr Speakman's. Mr Rudd would be pleased to hear that the Author had received money from marine engineers previous to having the great pleasure of receiving their thanks, which were none the less welcome. If Mr. Rudd could produce a German engine which was better than British-built turbines, he would be pleased to consider

Mr Mavor.

the use of it in connection with his invention, but there was not yet a very large business in this class of plant for propelling British ships. Mr. Jack was to be complimented on his contribution to the discussion; it was valuable as giving evidence of a comprehensive grasp of the subject. His remarks on gyrostatic action should receive the attention they merited. The Author's view had been that this part of the question could be dealt with on well-established lines, because the revolving masses and velocities were throughout comparable to the elements of existing marine machinery. Professor Andrew Jamieson's observations on the use of direct current motors might be justified, but an alternating current motor, of the type described in the paper, offered the advantage of greater simplicity over the best conceivable direct current machine. The rate of rotation of efficient propellers was so slow that it was difficult to realise the expectation of reduction in the length of the tail shaft. A slow speed motor was necessarily of large diameter. Broadly speaking, the diameter of the motor was equal to, or greater than, the diameter of the propeller, so that the motor had to be carried forward so as to be at, or near, the full section of the ship. Professor Biles' authoritative statement of the case offered a complete answer to the criticisms on the assumption of propeller efficiencies attainable, and was altogether a most encouraging deliverance. His reference to the doubt as to switching off and on full load called attention to a most important consideration. It was not certain that the change in direction of rotation of either the spinner or the rotor could be suddenly accomplished at full voltage, without troublesome rushes of current which might be injurious to the plant or conducting circuits. This was a matter for experiment. A very important point also was the possibility of economy at decreased loads. There was always, of course, a loss of efficiency associated with decrease of load, but this loss in the case of the steam turbine was greatly modified by keeping the turbine at, or near, its full speed. Messrs. Parsons put

Mr Mavor.

the limit of economical speed change at about 20 per cent. downwards from full speed. The use of generating units of different size, all being in use at full speed, was a distinctive feature of the present proposals. Fig. 9 illustrated the principle without profession of quantitative accuracy. It referred to the ship discussed in the text. At full speed and power A, the economy, was at its best. The two generating plants were in operation at full load, and the rotors and spinners of the motors were running in the same direction. Between A and B, the turbines, dynamos, and motors were slowed down with a consequent loss of efficiency. At B the spinners and one generator were stopped, the rotors ran at their synchronous speed, the remaining generator being restored to its economical speed. From B to C the system was again slowed down with a repetition of the conditions of lower economy. At C the spinners were again set in motion, but in a direction contrary to that of the rotors, and the turbine was restored to full speed, but as the load was now small, the economy was less than formerly. It would be seen that within limits the power available from the engines was independent of the speed of the ship. This was an important advantage when steaming at reduced speed against wind and sea. From C to D the generator was again lowered in speed, and at E the generator of lower periodicity was put in operation, restoring in some measure the economy. At E the spinning motors were running in the same direction as the main rotors at the lower periodicity, and the cycle E to G was similar to the cycle A to D, but at a lower periodicity, lower speed, lower power, and decreasing economy. Mr. James Hamilton was right in assuming that with electric transmission there was associated the principle of change of speed and power ratio, just as in the case of a chain gearing. In electric transmission the speed of revolutions was inversely proportional to the number of magnetic poles in the generator and motor respectively. The motor had the greater number of poles and therefore the slower speed. The Author

Mr Mavor.

could not accept Mr R. T. Napier's interpretation of the limits of application of his system. Mr Napier had stated the case of a ship of 3400 horse power. It was not possible to make a

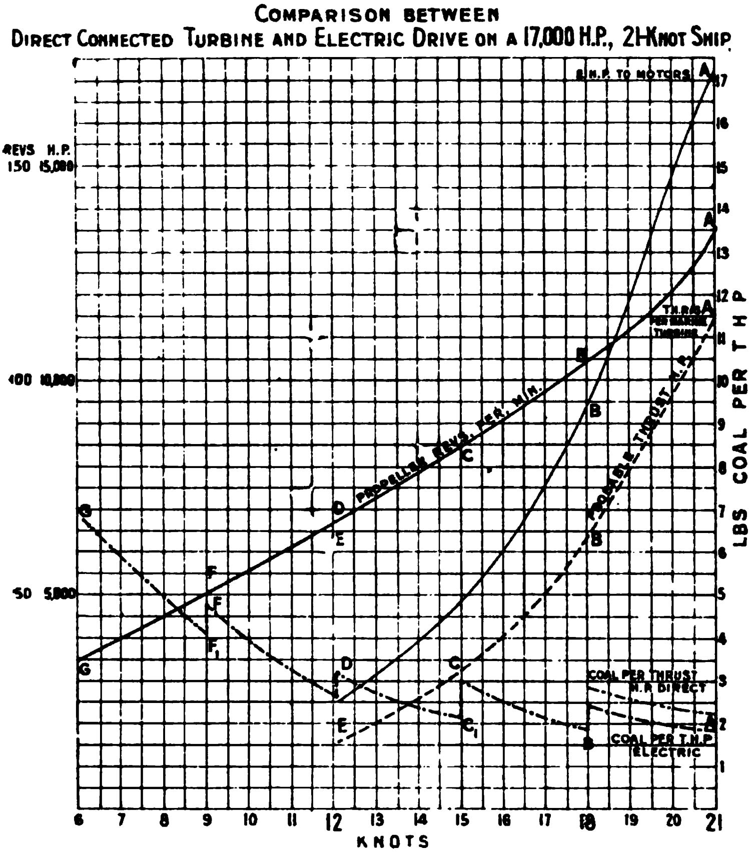


Fig. 9.

comparison with the data which he gave. It was probably true that the weight of the turbo generators and motors for 3000 B.H.P., at 120 revolutions per minute, would exceed 80

Mr Mavor.

tons, but that was not the full statement of the case. The justification for the use of electric equipment must be sought for in improved economy by the use of the turbine, or in a possible reduction of the B.H.P. for the required thrust horse power. This last was only to be attained by a change in the propellers. If the particular ship in question, taking the power alleged, were run at a speed of upwards of 14 knots, the Author would, in respect of the propeller, consider it an unfavourable case for the application of his system, because the speed of the engines and the speed at which the propeller gave its best efficiency were in agreement, and there was no call for any intermediate mechanism. If, on the other hand, the speed of the ship were of the order of 11 knots, the efficiency of the mechanism could be so improved by the use of larger propellers, at lower revolutions, as to reduce the total power. The steam per H.P. would be reduced by the use of the turbine, and there would be a saving in boiler weight, and weight of water and coal, which might well compensate for a considerable increase in the weight of the machinery actually applied to propulsion. Since this discussion took place the Author had had an opportunity of going into several propositions to apply his system to cargo ships, and the result was satisfactory in the matter of weight, for the reasons above indicated. The Author agreed with Mr Napier that formulæ would not drive the ship, but they were useful for recording and comparing the results of practical experience. Mr MacBrayne appreciated the fact that the use of electric transmission was susceptible of an infinite variety of applications, and there was no doubt that the marine engineer would avail himself of this means in one form or another. He was pleased that the paper had excited so much interest, but felt sorry that some of his friends, who had intended to take part in the discussion, were unavoidably absent. Their absence had rather handicapped the discussion, especially with regard to the question of weight, on which some of them could have spoken with authority.

Mr Mavor.
That was an extremely difficult question, but in comparing the weight of four or five ships of different types, he found that there was nothing to discourage him as far as his proposals were concerned. Shipbuilders had been most generous, and had told him the weights of their ships, and he could assure his audience that he could put in the equivalent for the same order of magnitude on the 17,000 horse power ship discussed in the paper. Ships of smaller size had also been examined with similar result.

The **President** (Mr John Ward) said that there had been a most interesting discussion on what he believed was an epoch-making paper. One of the speakers had contrasted the work of engineers interested in reciprocating engines with what the electrical men had been able to do, with apparent disparagement to the former. It was exactly one hundred years ago last August, since Fulton's steamer, the "Clermont," with Watt's improvements on the steam engine, commenced running on the Hudson as the pioneer passenger steamer of marine navigation, and remembering as they did, the men who had unceasingly and patiently, from then till now, gone on perfecting Watt's machine and in doing so achieved victories that had been splendid indeed, and none the less real because they were bloodless—he thought the speaker should have treated the facts more generously than he had done. However, the delightful thing was, that it was on the Clyde, and through James Watt, the marine engine first commenced as a real power to revolutionise the spread of commerce, and engineers had gone on through the century until the completion of a hundred years of progress had culminated with the grand triumph of their friend and colleague, the Hon. Charles Algernon Parsons, in his wonderful turbine marine engine. In this the first year of the second century they had, from a member of their own Institution, a paper which gave good promise to open up a new era. In Mr Mavor's paper there was evidence of what he thought would, ere many years, be looked upon as an equally wonderful and helpful

Mr Robert Caird, LL.D.

invention. He had great pleasure in hearing the discussion, and he need only ask them to accord Mr Mavor a hearty vote of thanks for his paper, and for the valuable addition it was to the proceedings of the Institution.

The vote of thanks was carried by acclamation.

Correspondence.

Mr Robert Caird, LL.D. (Past-President), observed that there were two points of view from which Mr Mavor's proposals might be regarded:—

1. The efficiency of ordinary merchant steamers at maximum speed, and how this might be modified by Mr Mavor's system, *firstly*, in the engine itself, and, *secondly*, in the propeller.
2. The falling off of efficiency at reduced speeds, and how Mr Mavor's system might affect it.

It had been thought that an arrangement such as Mr Mavor suggested, however effective in Admiralty practice, or in exceptional cases, was scarcely applicable to ordinary mercantile work. In making an analysis it was necessary to safeguard oneself by stating clearly the assumptions made, more particularly seeing that the apparatus was still only in the experimental stage. If, therefore, on any practicable scale, turbines could be run on board ship as economically as in the Carville tests; if electrical power could be applied in the form of thrust as economically as Mr Mavor claimed, at such reduced revolutions as were required to obtain maximum propeller efficiency; then the following comparative results might be accepted as feasible. Taking four actual cases, working out one, and taking the others proportionately, it would be found that—

Case 1. 20 knots, triple expansion, twin screw, thrust H.P. = 3630.

Brake H.P. at maximum propeller efficiency = 5215.

or, at 95 per cent. motor efficiency = 4096 kilowatts.

Mr Robert Caird, LL.D.

The report of tests at the Carville Power Station showed that with Steam pressure = 200 lbs.,

Vacuum = 29 inches, and

Superheat = 108 degrees F.

a 4096 kilowatt turbo generator, running at 1200 revolutions per minute, consumed 13·8 lbs. of steam per killowatt hour, Allowing 6½ per cent. for steam consumed by auxiliaries on board, Mr Mavor's steam consumption for this case, under these conditions, would be

$$4096 \times 13{\cdot}8 \times 1{\cdot}065 \text{ lbs. per hour.}$$

The actual steam consumption of this steamer must be about 15 lbs. per I.H.P. per hour, and her I.H.P. at 20 knots being 5950, then

$$\frac{\text{Steam consumption of turbo generator}}{\text{Steam consumption of piston engines}}$$

$$= \frac{4096 \times 13{\cdot}8 \times 1{\cdot}065}{5950 \times 15}$$

$$= 0{\cdot}674$$

or 32·6 per cent. saving in favour of Mr Mavor's combination.

N.B.—The efficiency of this case might be improved to the extent of perhaps 7½ per cent. by quadrupling, and 2½ per cent. in the propeller design. Even assuming this, there was still a balance in Mr Mavor's favour of over 20 per cent.

On the same basis,

Case 2. Torpedo boat destroyer "Daring."

I.H.P. = 4900 at 30 knots.

Kilowatts = 3650.

Showing 27 per cent. saving.

Case 3. Triple expansion, single screw.

I.H.P. = 8850.

Kilowatts = 5500.

Saving 39 per cent.

Case 4. Triple expansion, twin screws.

I.H.P. = 8000.

Kilowatts = 5420.

Saving 33·5 per cent.

So that, on the original assumptions, a saving of from 20 to 40 per cent. over current good practice in the mercantile marine might be claimed for Mr Mavor's system. This, of course, at top speeds. Turning to the second condition, the most careful tests of piston engines, those, for instance, of Weighton in Newcastle, and Melville in America, which closely agreed, showed an increase in steam consumption per I.H.P., at one-fifth of full power, of about 26 per cent., and a decrease in mechanical efficiency of about 15 per cent.; together, about 47 per cent. increase in the steam consumption per B.H.P. According to Stevens & Hobart, in their book on "Steam Turbine Engineering," the increase in steam consumption per kilowatt hour for a 4000 kilowatt turbo generator, at one-fifth of full power, was about 63 per cent., and allowing 5 per cent. drop in motor efficiency, this became about 70 per cent. increase in steam consumption per B.H.P. in the turbo generators and motors combined, as in Mr Mavor's scheme. But Mr Mavor claimed that, by splitting up his units, a great part of this loss might be avoided. In ordinary practice it was found that, even at considerable ranges of speed, propeller efficiency remained constant, so that there did not appear to be any room here for improvement by this system.

Mr H. M. **Napier** (Member) observed that he had read Mr Mavor's paper on "Electric Propulsion of Ships" with great interest, and having a large installation of three-phase induction motors driving machines, could see how suitable and free from trouble such would be on board ship. The method, too, of varying the revolutions by the use of concentric rotors got over the drawbacks of constant speed induction motors such as were at present in use. Some years ago he read of a motor car being driven by a petrol motor, working direct on to a dynamo, with

Mr H. M. Napier.

an electric motor on the back or driving axle, and thought that such a system would be of still more use on board ship, where the naval architect was ever faced with the problem of how to obtain a maximum power on a minimum weight of propelling machinery. An opportunity of putting this into practice arose when, in 1904, the London County Council issued specifications for their fleet of river steamers. As an alternative to paddle engines, he proposed twin-screw vessels with a petrol motor driving a direct-current dynamo, and a series-wound motor on each shaft. The variation in revolutions for full speed, half speed, and slow speed, was seemingly ample, reversing by switch easily arranged, and the weight of propelling machinery reduced by about 50 per cent. The whole arrangement looked quite satisfactory, but the London County Council preferred paddle engines, so the matter dropped. The steam turbine ran at a very much higher velocity than the petrol motor, allowing of a smaller and lighter dynamo being used, and, as Mr Mavor showed, his motor could be wound for any required speed of propeller, and have three variations in speed, so that for special vessels this turbo-electric system offered great advantages. As to propellers, the theory of efficiency as propounded might be correct, but in practice the proportion of pitch to diameter was fairly constant, and as a slow running engine, though heavier, was more economical in fuel, the diameter of propeller was usually regulated by draught of water, and made as large as draught would permit, always provided there was sufficient horse power to get the required revolutions. In the turbo-electric system *weight* would be the controlling influence in regulating the size of propeller. The difficulty of getting a large motor, suitable for low revolutions, into the after part of the vessel, would lead to a smaller diameter of propeller and higher revolutions. He thought that a theory which took everything into account would point to present practice as being correct. There were many possible applications of Mr Mavor's variable speed induction motor, and he wished him every success.

Mr William P. Durtnall.

Mr William P. Durtnall (London) observed that for the last few years he had given considerable attention and study to this subject from technical and commercial aspects. He should like to congratulate the Institution on having an opportunity to discuss this subject, and the Author for bringing such an important matter to the notice of its members. He was certain that it would be an advantage financially, as well as practically, if there were a thorough independent investigation of this scheme of electric transmission of power from the steam turbine, as applied to marine propulsion. It was a subject that covered a vast amount of ground and had several governing factors, such as the best speed of the turbines in relation to power developed; the most economical steam pressure to work at, taking into consideration the high vacuum that could generally be obtained at sea, under service conditions; the extent that economy could be effected by proper application of superheated steam; and, in consultation with expert designers of vessels, the best, taking things all round, position of the turbo-electric generators. The generating plant could be distributed, if necessary, and not particularly set in one turbine room, especially if it were found desirable for buoyancy and distribution of weight, and other practical considerations, such as strength of hull, etc. With respect to the electric motors, these would, of course, have to be placed at the extreme end of the vessel, and should be of such design, as regards diameter, as would permit them to be placed within the narrow limits at the stern of the ship. It appeared to him that the design of motor shown was of rather large diameter in relation to the power it would be able to efficiently give, especially when calculated for long continuous runs. What did the Author consider the weight per B.H.P. of the motor shown would be? Weight had to be propelled and fuel consumed to do so, and it was a very difficult thing to design motors that would run cool and, at the same time, do their work efficiently with the very lowest weight per horse power

Mr William P. Durtnall.

developed. He thought that some supplementary system of, say, water cooling would have to be adopted in such large capacity machines as would be necessary to use in connection with the generation and transmission of the power proposed, or even some system of forced air cooling might be employed. He might say that, having experimented with polyphase alternating current machinery in connection with heavy load vehicles, one of the most difficult features he had to contend with was to get sufficient starting torque with the squirrel cage rotor of a polyphase induction motor. The Author stated that "the multiphase induction motor has all the properties to be desired in marine motors, but requires artificial means to enable it to develop its full turning moment," at starting, he presumed the Author meant. In that particular matter he differed from the Author, as on a motor omnibus, tested under his supervision, an induction motor was mounted which started the vehicle loaded with pig iron, having a total weight of 17,740 lbs., along a wet Macadamised road, on a 1 in 10 upgrade, with no trouble whatever; and the conditions of marine propulsion were diametrically opposite in character to that of the vehicle in question, for which the motor was designed to produce the maximum starting torque, with short-circuited squirrel cage rotor, etc. In the marine application, the starting torque was relatively small, and no difficulty would be encountered in starting, especially at the lower of the three speeds provided in the system that he had developed for marine propulsion, in connection with high-speed steam turbines, for which Letters Patent had been granted in 1905, in not less than 19 countries. The control could be arranged from the bridge, and was by means of the exciting current, which was small, and there was no reason for the operator to handle the heavy current-carrying parts, or conductors, etc., either in arranging for dead slow, ¼, ½, ¾, or full speed. Full power and speed could be immediately obtained on reversing together with the above slow speeds, etc., without touching the electrically and mechanically governed turbine generators, which could be governed to about from 2 to 5 per cent. of the loaded speed. In the event, however, of a sudden reverse, a momentary overloaded full power reverse could be very easily and safely provided by admitting live steam to the latter part of the turbines. The temporary overload capacity of the steam turbine, polyphase generator, and induction squirrel cage motors was noted for its long-suffering character, and was, no doubt, well known. Further, the flexibility of such a system could not but appeal to highly-trained engineers, as the auxiliary plant could be partly driven from the main generators, and so arranged that in the event of the main motors being suddenly stopped, that portion of the auxiliary plant, such as fans, pumps, etc., would automatically slow or stop. This would, to a certain extent, tend to economy, and could easily be arranged for, if required. As the Author pointed out, the economy in steam was really, commercially speaking, an important matter, and the very highest economy in coal or fuel consumption should be sought. For comparison, it was necessary to note the effect of a direct-coupled turbine for, say, ¼ speed. The steam consumption was reduced, but not per horse power developed, to the extent that in a ship with, say, three turbo generators, two of them could be readily closed down, while the other might run considerably under-loaded, but at high speed, and comparatively at the highest economy. Another advantage which would appeal to sea-going engineers was the fact that, in a vessel going at full power, in rough weather, owing to severe pitching, the propellers might leave the water, but no racing of the plant could possibly take place under these circumstances. Taking the power as being a maximum when the propellers were at the lowest depth, then, as the propellers rose nearer the surface, the power, at the constant speed provided, would automatically adjust itself in relation to the generating plant, so that it would fall until the propellers left the water, and

Mr William P. Durtnall.

when in that condition the power would be equal to that required to turn the propellers only, without racing. He was doubtful if such an ideal condition of affairs could be got in any other way than electrically. In reference to the number of propellers it was advisable to use, and taking into consideration that reduction of dead weight was the most desirable thing consistent with safety, all other things being equal, he would like to ask the Author if the number of propellers might not be increased to, say, 5 or 6? He was aware that such a proceeding would help the design of motors, by increasing the speed for a given power. Would an increase in the number of propellers not tend to reduce vibration? He thought that in fast boats the long run at the stern would possibly allow this to be done, and, at the same time, give clearance for the disposal of the displaced water and not to unduly interfere with the stream lines. He sincerely hoped that the subject, so ably dealt with by Mr Mavor, would receive the serious consideration of shipbuilders and engineers, and that ere long they would give the electrical engineer a chance to assist them in securing economical high speeds at sea.

Mr Mavor said Dr. Caird's contribution to the discussion was of special interest and value. He had found much difference of opinion among marine engineers as to the possibility of using superheated steam and augmented vacuum on shipboard, and while Dr. Caird made the assumption of these possibilities with all due reservation, it might be taken that he was of the view that the assumption might be made the basis of a useful comparison. In doing this he went further than the Author dared to go. The steam consumption given in the paper, although based on the Carville tests, eliminated the effect of superheat and other conditions not normally applicable to marine practice at the present date, and the Author took only the figures which could be guaranteed without departure from normal practice in the use of steam at sea. It was of the

Mr Mavor.

highest interest and importance to cast off this reserve and examine, as Dr. Caird had done, the possibilities of economy at sea, in the light of the most advanced land practice. Mr H. M. Napier's interesting contribution to the discussion stated very clearly the difficulties which had to be met by the new system, but he overlooked the possibility of increasing the number of propellers, which was much more easily done with electric motors than with steam engines. It was found, as Mr Napier said, that the motors in most cases could not be got into the narrow after-part of the vessel, but the alternative which had the appearance of most suitability was to bring the motor forward of the generating plant, keeping the diameter large and the revolutions low. In answer to Mr W. P. Durtnall, he might say that the electrical equipment imposed no limit on the number of propellers.

MALLEABLE CAST IRON: ITS EVOLUTION AND PRESENT POSITION IN THE METALLURGICAL WORLD.

By Mr WILLIAM HERBERT HATFIELD.

Read 17th March, 1908.

SHEFFIELD, the Author's native place, has just lost a very distinguished citizen in Dr. Sorby. His work in the scientific world is well known to everyone, but one of his chief claims to the gratitude of his fellow-townsmen is the fact that, it was he who introduced the microscope to the science of metallurgy. The paper to-night illustrates the improvements which have been made in malleable cast iron by the study of its micro-structure, and the Author will be happy indeed if he can show one direction at least in which the Doctor's favourite science has been of practical utility.

A short time ago the Council of the Iron and Steel Institute issued their "Nomenclature of Iron and Steel," which contained the following definition of "Malleable Cast Iron":—

> "Malleable cast iron, iron which when first made is cast in the condition of cast iron, and is made malleable by subsequent treatment without fusion. Although the English name of this variety suggests that it is cast iron, it is not truly a variety of cast iron, because it lacks the essential property of cast iron, viz., its extreme brittleness."

To say that this material lacks the extreme brittleness of cast iron hardly does it justice, and going further into the above definition the Author ventures to suggest that malleable cast iron is truly a variety of cast iron, having all the advantages of such a casting with none of its disadvantages.

Fig. 1 shows the cold bending and twisting tests performed upon standard test bars, while Fig. 2 illustrates the malleability of castings of this material.

The object of this paper is to endeavour to raise malleable cast iron to that position to which it is now justly entitled both by its physical properties and its very general usefulness. The Author has for some years been working upon the scientific production of this material, and some of the results obtained will be referred to later.

The better to make clear the subsequent points, it is proposed as a preliminary to study the evolution of the malleable casting, which owes its existence in the first place to the art of moulding, and in the second place to the science of metallurgy.

The art of moulding is considerably older than the science of casting iron. Samples of fine bronze castings are in existence made many centuries previous to the use of cast iron itself. As to the excellence in the art of founding attained by the ancients the bronze replicas of their sculptures testify. A casting in iron could until very recently only be made when the iron approached in composition to that of the various pig irons of to-day. The melting point is the determining factor, and the following table gives the comparative melting points of various metals:—

	Cent.
Platinum, - - - - -	1750°
Pure carbonless iron, - -	1600° (about)
Steel (1·45% carbon), - -	1425° (about)
Pig iron (3·80% carbon), - -	1150° (about)
Copper, - - - - -	1084°
Gold, - - - - -	1064°
Silver, - - - - -	962°

The iron produced in early times was relatively pure, and owing to the extreme heat required to reach its melting point, our ancestors did not successfully accomplish the casting, and hence the art of the blacksmith of forging wrought iron was so superbly developed. It will therefore be seen that until the more easily fusible irons were produced, the work of founding in iron could not flourish.

It is proposed now to trace the evolution of the modern blast furnace, in which the pig iron from which both cast iron and malleable cast iron are produced, from the methods employed by the early races of mankind, which ancient methods are still prevalent in some of those countries into which modern civilisation has not sufficiently penetrated.

The method employed by the Celts on the Cheviot Hills, previous to the Roman invasion, was practically identical with that at present employed by the native African tribes on the banks of the Zambesi. Man very early learned that a lump of iron ore in contact with the fuel of a fire became so reduced to the metallic condition that he could forge it to a useful purpose.

A similar rudimentary method of extracting iron in its malleable condition seems to have been at work amongst most primitive peoples. In order that they might take advantage of the prevailing winds, small hearths were placed at the top of windswept gulleys, and with this natural draught and charcoal fuel the crude smelting was done. By such means a piece of iron was prepared direct from the ore and could be forged into the various forms either for domestic or warlike purposes. This rudimentary direct reduction of the ore, developed in different countries and in a remarkably similar manner. The first development was, of course, the substitution of a form of bellows (usually made of the skin of an animal) for the winds, and subsequently such ingenious devices as the foot bellows of India and the box bellows of China were evolved. A method displaying considerable ingenuity in the application of the blast has been in use, from very early times, at Orissa in Lower Bengal. The crucible and tray used consists of ferruginous sandy soil, moistened and kneaded on to a skeleton of flexible wood. This furnace produces small "blooms" of wrought iron, and a distinctive feature is the ingenious way in which the blast is applied. The metal is taken out at the tuyere hole, and from another hole at the side the slag is run off. The tuyeres, strange to say, are of bamboo.

Amongst the earlier European developments was the Catalan forge, Figs. 3 and 4, in which malleable iron was produced. This furnace held its own in western Europe down to a very late period. It consists, as will be seen, of a four-sided cavity or hearth into which the charcoal and iron ore are fed. The drawing shows how the blast is introduced through one tuyere. The main feature again is the method by which the blast is produced. In this case, by an apparatus, a Trompe, invented in early times by an Italian. It consists of inducing the air by means of falling water.

The next development is the Osmund furnace, Figs. 5 and 6, which is really a large Catalan forge. The drawings from which Figs. 5 and 6 are produced, and the unique description of Fig. 5 which follows, were supplied to Dr. Percy by Mr. Andreas Gills half a century ago.

a. Heap of bog ore not calcined.
b. Calcining heap on wood.
c. Heap of calcined bog ore.
d. Earth borer to search for ores.
e. Charcoal rake.
f. Iron shovel.
g. Tongs for drawing the Osmund bloom out of the furnace.
h. Cinder hook used also in taking out the bloom.
k. Bar for cleaning the cinder hole and twyer hole.

l. Large sledge used to hammer the bloom when first taken out.
mm. Lump of iron " Blastra " or Osmund, partly cleft.
n. The hatchet.
o. The treadles to work the bellows.
p. Bridge of wooden planks.
q. Tap hole for the cinder.
r. Twyer.
s. Wooden shovel, for charging ore into the furnace.

The Stuckofen, Fig. 7, is the last furnace in which a malleable iron is produced directly from the ore, and it would be well to compare carefully the section of this furnace with the section of the Osmund. It will be seen that it is the Osmund furnace with the addition of a truncated cone of masonry. This increased height, by increasing the time in which the iron is in contact with the fuel, produced occasionally, and one might almost say accidentally, the first cast iron. The modern blast furnace, Fig. 8, owes its origin to this simple Stuckofen, and the ingenuity of engineers in providing the gradually increasing motive power required for producing the necessarily increased blast. In a paper read before the Institution of Mechanical Engineers last year, Mr D. E. Roberts very carefully and thoroughly traced this evolution in blowing engines.

Having obtained pig iron, it can be conveniently cast into all sizes and configurations for industrial purposes, and as all malleable cast iron processes are commenced by making cast iron, it will be seen that a period is now being reached when this material came into existence.

As early as the fourteenth century there is evidence of cast iron being used in this country, but it was in the sixteenth century that the industry of iron founding began to flourish, and guns and such large castings were made.

The first description of the method of making cast iron malleable is due to Reaumur. He published in 1722 " the fact that the heating of cast iron castings embedded in red oxide of iron softens the metal perfectly and much more rapidly than all the other matters which he had tried." Practically the identical method described by Reaumur is at the present time in operation, and is producing a large quantity of the malleable cast iron consumed in this country. It is strange that Samuel Lucas should have been allowed to patent, in 1804, a process which obviously was so well known practically a hundred years previously, but such is the case.

Diagram Illustrating the Position of Malleable Cast Iron in the Metallurgical World.

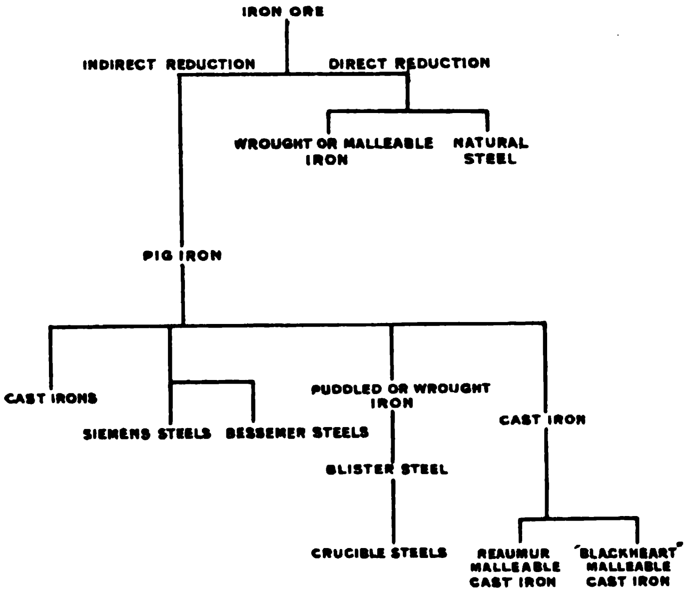


Fig. 9.

Of later date there has been developed another process for making malleable cast iron which is called in America the "black heart" process. Before going into the difference in the two varieties produced, it might be well to describe what malleable cast iron really is.

It consists of castings made by melting suitable pig iron and casting it into the required forms, which castings are, of course, annealed in order to produce the requisite malleability. The finished article, if successfully manufactured, possesses all the advantages of cast iron in that the low melting point of the pig iron allows the most intricate and difficult castings to be made, and these castings have the same beautiful skin and finish for which cast iron is so well known. As a further fact, it may be said that this material is practically free from blow holes, the composition of it ensuring the perfect occlusion of the gases which in a steel casting very often cause so much trouble. As regards the physical properties, it is malleable and ductile, and is easy to work in the machine shop.

All malleable cast iron when cast is identical in analysis with some variety of pig iron, it having present in its composition from 3 to 4 per cent. of combined carbon, which gives to it that intense hardness which is found in the unannealed casting. The malleableising of the material is done either by the oxidation and elimination of the carbon or by precipitating it into such a condition that it does not militate against the production of the qualities desired.

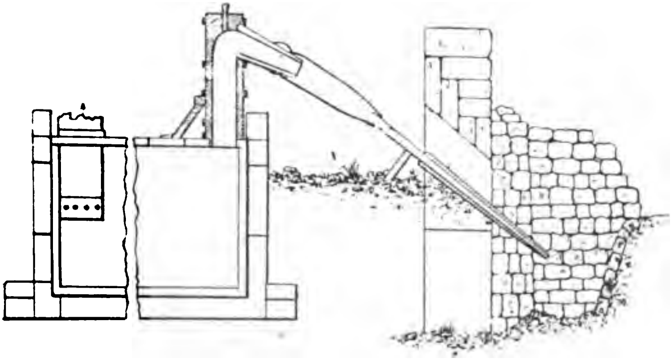
Certain specific conditions are, of course, necessary for the production of this material when the carbon is merely changed in form, and as the irons from which the malleable castings in this country and Europe are made are generally extremely high in sulphur, not being able to change the form, manufacturers in the past have had to eliminate the carbon. Consequently the method employed is that of Reaumur, namely, packing the castings with iron ore which oxidises and eliminates the carbon to such an extent that the casting has attained that degree of malleability which is desired, the fracture of such casting being very similar to that of steel.

The malleable castings produced in America are of the black heart variety, and generally speaking the American process consists of precipitating the carbon and not eliminating it.

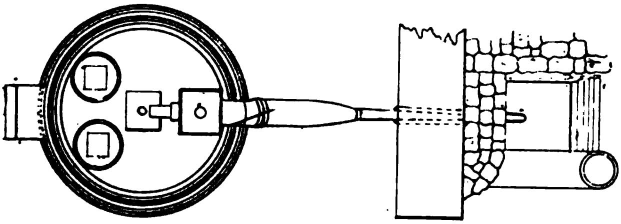
Fig. 1.

Fig. 2.

Fig. 3.



Trompe and Furnace Longitudinal vertical section



Tine and Furnace Plan

Fig. 4.

Fig. 5.

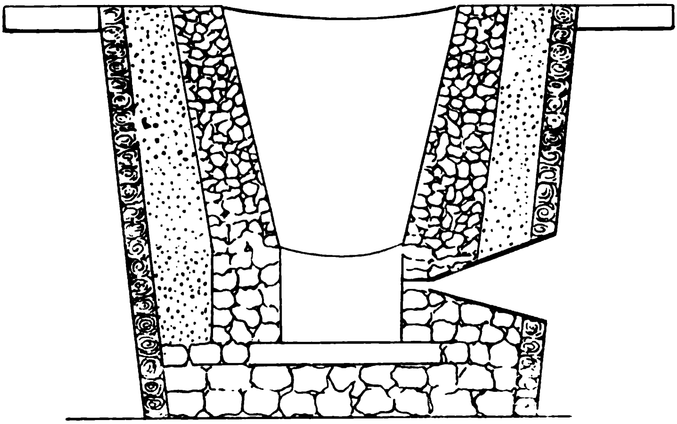


Fig. 6.

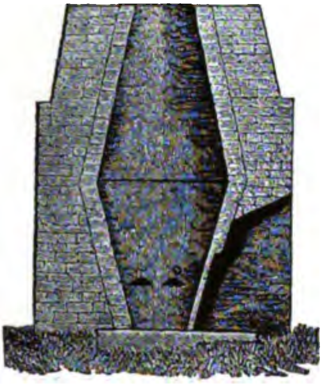


Fig. 7.

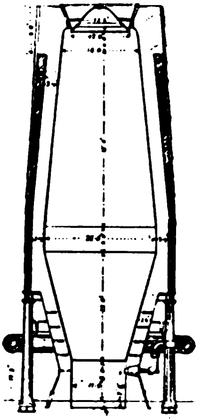


Fig. 8.

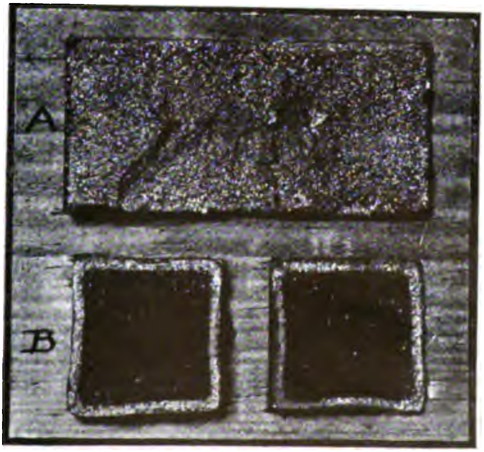


Fig. 10.

A. Reaumur.
B. Known in America as black heart.

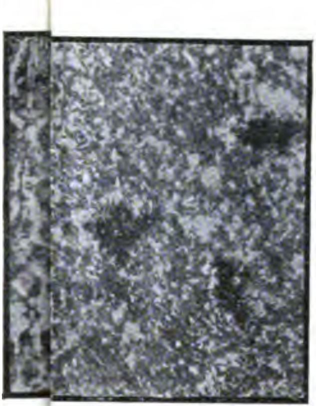


Fig. 15.

Fig. 16.
Microsection of the white iron after being converted into malleable cast iron, showing the structure of the free carbon.

W
the
two

Fig. 20.
ructure of special
e cast iron (known
ica as black heart).

fication 90 dias.

Fig. 21.
Microstructure of grey cast iron, showing plates of graphite.

Magnification 45 dias.

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Fig. 22.

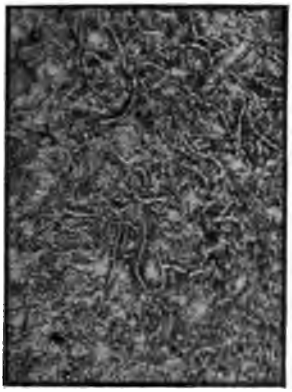

Fig. 23.
Grey Cast Iron as Cast.
M.S. tons per square inch, 12·0.

Fig. 24.
Grey Cast Iron (annealed).
M.S. tons per square inch, 3·0.

Fig. 25.

White Cast Iron as Cast.
M.S. tons per square inch, 22·8.

Fig. 26.

White Cast Iron as Cast.
M.S. tons per square inch, 14·5.

There are castings which, in the finished state, have the same composition as pig iron, and which bend double and fulfil the most stringent malleable cast iron specifications. Owing to the natural resources of America producing a pure iron with very little sulphur, the secrets of the manufacture of black heart castings were quickly learned, and it is interesting to trace the rapid growth of this industry which to-day produces from 700,000 to 1,000,000 tons of malleable castings per year. In the early days of the last century, Seth Boyden, in Newark, New Jersey, U.S.A., laid the foundations of this enormous trade.

In a little street half hidden behind a tumbled down factory is an old foundry in which his first experiments were made. Here Seth Boyden toiled for the few years during which he worked out his system of producing malleable cast iron. It is not claimed that he invented the process of production, for his notes show that he was in possession of data from England. His information was, however, very scanty, and, on that account, great credit is due to his having worked out the details necessitated by his own particular circumstances and environment. In this first malleable iron foundry of America, he made buckles, harness fittings, and other such small castings.

Starting to melt the iron in crucibles in his forging fire, as trade increased crucibles were no longer satisfactory, and he built a " large " air furnace that could melt 1000 lbs. at a time. The furnace was not tapped through a tap hole, but his men would go with clay washed ladles and dip them in the bath, taking the weight of iron that they required. With regard to annealing, it is wonderful how accurate were many of his observations; the temperature used he ascribed as that of the melting point of silver. Pyrometers as now used were not then in vogue.

In the first place, the iron in both the American malleable processes and the European was melted in the crucible; the next stage was to melt this iron in cupolas as bigger quantities were required, and as purity became more essential the reverberatory and the open hearth furnaces came into play. The methods of annealing, of course, have been considerably improved, but it is not my intention to go into details of the manufacture of this material, but to illustrate by means of photomicrographs the capability and constitution of these two varieties of malleable cast iron.

During the last twenty or thirty years, the system of producing malleable similar to that produced by the American black heart has been developed. The Author is at present actively engaged in producing both varieties, each having different qualities and, therefore, applicable to its own sphere of utility. A fracture of each variety is shown in Fig. 10, that with the steely fracture is the original malleable cast iron as produced in Europe. The lower fractures are of what is known in America as the black heart casting. These two fractures are the result of the method of manufacture. The upper one, the "Reaumur," having the steely fracture, is obtained by the oxidation of the carbon contained in the original casting by hematite iron ore. The lower one, called "special" malleable, has been produced merely by changing the form of the carbon.

All malleable, as previously stated, consists of cast iron of suitable composition annealed in various ways with the usual result of a malleable product. In the Reaumur process as at present conducted, the castings are of such a composition that to render them malleable it is required to eliminate to a great extent the carbon originally present. Most of the malleable castings in Europe are of this type. The castings are packed in cast iron boxes in haematite ore and taken to a heat at which the ore commences reaction with the carbon in the castings.

This action is the converse of the production of steel by cementation, in which process the carbon enters from the outside and gradually permeates the whole bar. In the elimination of the carbon exactly the contrary takes place, and the carbon is gradually eliminated from the outside first, so it follows that the interior of one of these castings has generally considerably more carbon than the outside. If successfully manufactured, however, the carbon in the centre is in such a condition as not to militate against its working capabilities.

As to the actual chemical reaction which takes place between the iron ore and the carbon in the iron, it is not as yet sufficiently understood. However, it is known that gases easily diffuse through metals of the iron group in considerable quantities, and it is most likely that the action is somewhat dependent on the equation $CO_2 + C = 2CO$. In other words, the oxygen of the ore oxidises the first carbon to CO_2, and this carbon dioxide possibly combines with more carbon forming CO, which in itself receives further oxygen from the iron ore, and so what might be called catalytic action takes place in which the CO is the carrier of the oxygen from the ore to the carbon contained in the interior of the castings. Such explanation seems as likely as any other at present put forward.

From the casting lying on the table with the fracture displayed, it will be evident that this variety is very much like some grades of steel. The photomicrograph, Fig. 17, shows the constitution of this metal as seen by the high power of the microscope. It consists chiefly of well laminated pearlite distributed through a ferritic matrix.

A few weeks ago the following abstract from a paper read before the Scandinavian Technical Society, regarding the strength of malleable castings as made in the Scandinavian Peninsular, was published in one of the technical papers:—

> "The paper gives the tensile strength as between 40 to 50,000 lbs. per square inch. It has an elongation varying with different samples from 1 to 6 per cent.,

> with a reduction of area at the breaking point of from ¾ to 3 per cent. It is thus seen that the ordinary grade of cast iron having a tensile strength of 20 to 30,000 lbs. per square inch is but half as strong as malleable castings, though its compressive strength is much higher," etc.

Obviously the malleable castings are of similar type to the Reaumur, and the above appears to be a fair statement of the mechanical tests which this type of malleable will give. The similarity between this material and steel is very much in evidence on comparing the microstructure, and it seems remarkable that, whilst the elongation and reduction of area of this type of casting are so low, it can not only be hammered and bent to a very considerable degree, but it will both harden, temper, and forge if properly made.

However, it must be confessed that whilst this material has great malleability, and great working powers, and is extremely useful for parts where wear and tear take place, it does not produce anything like the tests which the Author has obtained by the development of the black heart type. Attention was first seriously drawn to the development of this special malleable by the requirements of the British Admiralty. Their specification, by the way, is 18 tons to the square inch, a minimum elongation of 4½ per cent. in three inches, and a bending angle of at least 90 degrees over a 1-inch radius, the bar being 1-inch × ⅜-inch in section. The variety of malleable casting known as American black heart has for its essential distinction the fact that the castings when cast are of such a composition that the carbon, which previously exists as combined carbon, is by annealing completely changed to that condition of carbon known as annealing carbon, to which Ledebur, the German metallurgist, gave the name of Temper Carbon.

The Author, in May, 1907, went thoroughly into this question of the change of the carbon, in a paper read before the *Iron and Steel Institute, under the heading "Decomposition of Carbides," and he thinks this change can be best explained by reference to some of the photomicrographs given in that paper. These are six in number, Figs. 11 to 16, the first being the hard initial casting, whilst the last is the completely softened finished one. Fig. 11 gives the typical structure of cast iron. All the carbon is in the combined state, the carbon of "supersaturation" being present as carbide Fe_3C, whilst the carbon of "saturation" is present as a compound roughly equivalent to $Fe_{24}C$. The castings are heated up during the annealing process to the temperature required (this, of course, differs with different makers), maintained for a varying period at this temperature, and are then cooled. The result is a casting in which the carbides are completely broken down into pure carbon and iron. Fig. 16 clearly illustrates this. Figs. 12, 13, 14 and 15 show the intermediate appearances of castings whilst the change is taking place.

This series of micrographs illustrates that chemical change and rearrangement of microstructure which takes place during the heat treatment of white iron. The heat treatment, in such a case, has broken down the carbides and balled up the resulting free carbon. Whereas the maximum stress as cast would be 13 tons, after heat treatment it is increased to 23 tons per square inch. It is interesting to compare the effect of heat treatment on a grey cast iron casting. The microstructure of such a casting is shown in Fig. 23, and showing the worm-like sections of the plates of graphite which are the cause of the comparatively low tensile strength of such material. The other constituent is "sub-carbide" of iron. On heat treatment of this iron all the carbon is, as in the case of white iron, disassociated into free carbon and iron, and if reference is made to Fig. 24, it will be noticed that the weak-

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* "Cast Iron as Cast and Heat Treated."

ness caused by the graphite is merely accentuated during the annealing, whilst the strengthening influence of the combined carbon present in Fig. 23 has disappeared. In such a case the tensile strength of the grey iron by annealing has been reduced from about 12 tons maximum stress to 3 tons.

It is interesting to note that, the microscope often throws considerable light on the variation in the strengths of iron of like composition cast under the same conditions, and in a paper read by the Author before the Iron and Steel Institute,* in 1906, the two micrographs which appear in Figs. 25 and 26 were published. They consist of white iron of like composition cast under identical conditions. Fig. 25 gave a remarkably high test of 22·8 tons per square inch maximum stress, and shows a beautiful, well-mixed structure. The other section, Fig. 26, is similar material which gave only 14·5 tons per square inch. It will be obvious, on examination of these micrographs, that the cause of the low tensile strength was undoubtedly due to that peculiar flow of the micro-crystalline structure which is so noticeable.

Reference will now be briefly made to wrought iron, which is prepared by eliminating in the plastic condition, by means of oxides, the carbon and other impurities from pig iron. The result is pure iron, with traces of sulphur, phosphorus, manganese, and a little carbon with a varying proportion of slag, the slag being mechanically contained in the iron. Wrought iron of the best make is as pure as iron can commercially be made, and everyone is familiar wth its great ductility and malleability. Apart from iron, the only content of this material worth considering is the involved slag which, during the rolling out of the iron, is drawn into threads running the length of the bar, and gives to wrought iron that peculiar fibrous nature of the fracture. Of course there is no such thing really as fibre in iron products, as they are all crystalline.

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* "Influence of the Condition of Several Varieties of Carbon upon the Strength of Cast Iron."

Fig. 19 represents a section of wrought iron cut across the bar. Very little else is visible but the crystals of ferrite, except a few dots of slag, which, of course, consist of the cross sections of the threads of slag before described. A longitudinal section of the bar which merely shows the crystalline structure of the pure iron along with a longitudinal section of the slag threads is shown in Fig. 18. It is obvious that this slag is practically of no detriment to the high properties of wrought iron. Wrought iron forgings, were it not for their high cost, are unquestionably excellent, and in working upon the subject of malleable cast iron, wrought iron forging has been taken as a basis, and the endeavour has been made to produce in a malleable casting a structure as similar as possible.

The maximum stress in wrought iron is approximately 20 to 21 tons per square inch, and its elongation will vary from 20 to 30 per cent.; now, if against this the test previously given for malleable cast iron is placed, namely, about 20 tons tensile strength with 1 to 6 per cent. elongation, it will be noticed that there remains considerable scope for improvement in the last-mentioned product.

Working on these lines, bars have been produced giving a tensile strength of 23 tons along with 19 per cent. elongation, 20·6 reduction of area, along with 180 degrees bending angle. Fig. 22 is a facsimile of a test sheet containing the tests obtained from this material. Material such as the one of which the tests have just been given, and which is, of course, a casting and not a forging, is, one might almost say, a new product; the old tests for malleable cast iron have been left far behind, and a material has been produced which has before it a much greater field than the original malleable cast irons.

These special castings are very similar in structure to wrought iron. Microscopically they consist of ferrite, which is pure iron, with free carbon in such a form as will be obvious by the results obtained to be little more detrimental than the slag which is found in wrought iron; in fact, samples of wrought iron have been met which have not given much better results than the tests submitted in this paper. It will be well to conclude by asking whether malleable cast iron with the properties and tests as stated is not entitled to a much higher position in the metallurgical world than it is given, and the Author would venture to suggest that the "Nomenclature" Committee gave malleable cast iron undeservedly short shrift when they stated that it merely lacked "the *extreme* brittleness of cast iron."

The demand for malleable in this country as compared with that of the United States gives food for thought. The Americans are said to be producing over 90 per cent. of the world's production, Europe only producing the remaining 10 per cent. Here in this country, a material giving tests considerably superior to those obtained in the States is produced, and yet this self-same material is excluded from many purposes for which in the States it would be allowed to be used.

The following table gives the comparative results which are now being obtained:—

MATERIAL.	M. S. Tons Sq. inch.	Elongation. Per cent.	R. of A. Per cent.	Bending Angle.
Cast Iron, ...	12·0	Nil.	Nil.	Nil.
Old Process Malleable (Reaumur),	21·0	3·0	4·0	45°
American Black Heart, ...	19·0	5·0	6·0	90°
Special Malleable (Meadow Hall Ironworks), ...	23·0	14·0	17·0	180°
Admiralty Specification, ...	18·0	4·5	—	90°

It will be noticed that in the special malleable maximum, stress is very high, whilst the ductility much surpasses that of any other malleable cast iron. One obvious feature will be the ease with which this material passes Admiralty requirements.

Before concluding, the Author desires to acknowledge the share which Mr J. F. Crowley, of Sheffield, has had in the working of this system. Without his unfailing energy and unquenchable optimism, the Author would not have been able in this paper to include these unique results.

Discussion.

Mr J. **Foster King** (Member) was struck by the position which malleable cast iron had achieved in the metallurgical world, and Mr Hatfield's paper should certainly awaken the interest of users of iron and steel. He did not presume, for a moment, to enter into the metallurgy of the subject, or to make more than a passing reference to the interest to non-experts such as himself, of the epitome of its evolution which the paper contained; but he would like to ask Mr Hatfield where in his experience he found wrought iron in practical use which justified the standard of comparison adopted, and which placed its tensile strength at from 20 to 21 tons per square inch, and the elongation at from 20 to 30 per cent. His own experience had been very much in the direction of finding that wrought iron of such high quality was not ordinarily available. Mr Hatfield, in stating that malleable cast iron could be made to show a tensile strength of 23 tons per square inch, and an elongation of 14 per cent., along with a bending angle of 180 degrees, gave results much better than one was accustomed to obtain from wrought iron, and they were certainly worthy of the consideration of shipbuilders and engineers. He would like to draw Mr Hatfield's attention to the fact that the percentages of elongation as stated in the paper might mean many things, and as it was now a matter of common knowledge that the proportion of the area of the test piece to its length meant everything, he thought that all experiments should now be made on the standard test pieces

Mr J. Foster King.

of the Engineering Standards Committee. In any case, the proportions of the test pieces should always be given in papers such as this. The metallurgical position of malleable cast iron might not interest many, but if Mr Hatfield could tell the members of the Institution what the commercial position of the material was, he would greatly interest them all. Was it possible to produce malleable iron castings at such a price as to compete with cast steel for anything but the very smallest castings? Was its use capable of being extended to take the place of the innumerable small forgings required for ships and engines, which were of practically standard patterns? Above all, he would like to know if the tests given did not mean that the material was so soft as to be practically useless for such purposes, because it was possible that the high breaking stress and large extension obtained might be, in association with plasticity, so great as to render the castings incapable of retaining their form under ordinary rough usage.

Mr R. A. McLaren (Member) said that the results given in the paper were exceedingly good, and justified Mr Hatfield's claim that he had practically got a new material, but the main reason why malleable castings would not take the place of forgings was the risk of hidden flaws. He would like to ask Mr Hatfield whether, by his process, he could produce castings which would be free from the flaws which were found in ordinary malleable castings. Of course, in a lawn mower or a domestic mangle it did not matter much if a malleable casting broke, but in engineering works of importance that was a very serious consideration. In all the malleable castings he had seen, and he had seen some very good ones, there was always a certain proportion of them in which a flaw would be found. Regarding the question of elongation which Mr Foster King had mentioned, the Author did not give the length on which the elongation was measured, and without that information the percentage of elongation was valueless.

Mr Hatfield, in reply, said, regarding the point that tests

Mr Hatfield

given for wrought iron were higher than Mr King found in practice, he (Mr Hatfield) wished to do justice to wrought iron, and therefore preferred to give the tests obtained in his own experience from good brands. Mr King had mentioned the size of the bar and its influence on the percentage of elongation. The elongation in each case stated in the paper was in three inches, and the section of the bar was the Admiralty section 1-inch × $\frac{3}{8}$-inch. The elastic limit of this malleable cast iron was considerably more than half its maximum stress. It might therefore be said that the elastic limit of this material was equal to the maximum stress of the best cast irons. With regard to the question of malleable cast iron replacing steel, comparison was simply made from the malleable casting point of view. With steel castings, it meant anything up to 50 or 100 tons in weight, but with respect to small castings, he had pointed out in his paper that the composition of the iron rendered freedom from blow holes a certainty, whereas members did not need to be told that this was not so in steel. Castings too difficult and light to be run in steel could easily be produced in this material with an excellent surface. Mr Foster King's query as to the material being found too soft in practice was answered by the fact that the material had actually been successfully adopted in a number of works, to the inevitable displacement of some of the "innumerable small forgings." As to Mr McLaren's question about flaws, in all castings there were likely to be flaws. A casting was not a forging, and the freedom from flaws was dependent upon the skill of the moulder. Bearing upon the respective virtues of malleable castings and steel, he thought the opinions of the American expert, Mr Moldenke, embodied in the following quotation, might be of interest:—"For the repeated stresses of severe service, the malleable casting ranks ahead of steel, and only where a high tensile strength is essential must it be replaced by that material. This is best illustrated in the passing of the car coupler made of malleable cast iron. Not only have a

Mr Hatfield.

large number of drop tests shown the high value of the malleable coupler compared with one of cast steel, but the scrap heap tells an interesting story. In making comparisons of broken malleable couplers with steel, a large number of each were selected in which the heads were badly battered by the succession of blows occurring in railroad service. Coupons were cut from the barrels of these couplers. These, when pulled apart in the testing machine, with but few exceptions, gave the palm to the malleable casting."

The **President** (Mr John Ward) asked if Mr Hatfield had made much headway in this country with his material, and if it had been adopted by the Admiralty and private firms in connection with the steel castings required for turbine and other work in private yards and engine works, such as shipbuilders and engineers were constantly occupied with.

Mr **Hatfield**: Yes, it had been largely adopted.

The **President** said Mr Hatfield had given them a most instructive paper, and he thought that the more they looked at the diagrams they would appreciate the value of Mr Hatfield's research work. Those members of the Institution who had visited Sheffield eleven years ago, would remember the kindness and hospitality of their Sheffield friends, and also the openhandedness with which the employers had thrown open their great works for the inspection and appreciation of the members of the Institution. They would like to say to Mr Hatfield, as a representative from Sheffield, and speaking as he had done of one of the latest triumphs of the district of Sheffield, that the subject was one more specially interesting to them. They did not need the gospel of steel preached to them in the Glasgow district, because they lived by the production of it. He would suggest that, instead of confining himself to this paper and these figures, Mr Hatfield would show them the actual facts during business hours, because,

"Facts are chiels that winna ding,
And downa be disputed."

The President.

The discussion on the paper had been short, but most interesting. It was certain that there was a large field for the material in this country, and that if it came up to the expectations claimed by Mr Hatfield, and he thought deservedly claimed, he had no doubt that it would ere long make the headway it deserved. Not only had Mr Hatfield given a most interesting paper, but he had shown tested specimens of the material twisted into all manner of forms, illustrating thereby its uniform ductility and goodness. On the occasion of the reading of his paper, Mr Hatfield received a very warm and hearty vote of thanks from the Members, and to-night, at the end of the discussion, they again tendered him their appreciation and thanks.

Correspondence.

Prof. A. McWilliam (Sheffield) desired to draw attention to Mr Hatfield's achievements in the manufacture of special malleable cast iron, particularly to the high percentages of elongation and reduction in area combined with the very considerable maximum stress, and also to the fact, not mentioned in the paper, that by altering the treatment he could obtain a maximum stress of 30 tons with the 6 per cent. elongation given by ordinary black heart. A feature of interest to all connected with metallurgical education was, that Mr Hatfield represented a combination of the training given in the metallurgical department of the Sheffield University, namely, the study of the science of metallurgy, developed on practical lines, combined with works experience under a commercial management which showed its appreciation of the highest scientific and technical training, by giving to the possessor of these an opportunity to apply them in ordinary commercial works' practice. He had himself tested many samples of Mr Hatfield's special malleable cast, but in case any member of the Institution should think that these results of his were merely produced under experimental conditions, he would like him in his reply to say what test he was prepared to accept

Prof. A. McWilliam.
as a commercial specification. He was pleased to see Mr Hatfield's reference to Dr. Sorby, as with all the Doctor's characteristic modesty, nothing seemed to delight him more than hearing of the useful application of his work by others. He would like to point out that the nomenclature of iron and steel, mentioned by Mr Hatfield, was an American production put before the Iron and Steel Institute for the purposes of criticism, and not officially sanctioned by that Institute. With regard to the temperature scale, given on page 399, there was still some little doubt about the actual melting point of pure carbonless iron, but the figure given by Mr Hatfield was now generally regarded as too high, and it would seem, from the most recent results, that it lay somewhere between 1500 degrees C. and 1550 degrees C. The carbon of saturation could only be said to be present as a simple substance corresponding to the formula $Fe_{24}C$ in quenched samples, or when the temperature was above the A1 point (in the neighbourhood of 700 degrees C.); in ordinary white cast iron at atmospheric temperatures it was present as pearlite, consisting of carbide of iron Fe_3C, alternating with pure iron in the proportion of Fe_3C to Fe_{21}, or about 13 per cent. of carbide to 87 per cent. of iron.

Mr BENNETT H. BROUGH (Secretary of the Iron and Steel Institute) wished to be permitted to correct a slight inaccuracy in Mr Hatfield's interesting paper on Malleable Cast Iron. The Author referred to a definition of malleable cast iron contained in a report on the nomenclature of iron and steel issued by the Council of the Iron and Steel Institute. As a matter of fact, that body was not responsible for the definition quoted. The report was drawn up by a Committee of the International Association for Testing Materials, of which Prof. H. M. Howe, New York, was chairman, and Prof. A. Sauveur, Harvard, was secretary. The report was submitted to the Iron and Steel Institute for consideration, and the comments received from members were published in the Journal of that Society (1907, Mr Bennet H. Brough.

No. II., p. 216). The Council had, however, not expressed an opinion upon the statements made in the report or on the criticisms submitted. The matter was not one of great importance. To users of malleable cast iron, it was immaterial how it should be classed. Mr. Hatfield modestly insisted that it should be regarded merely as a cast iron. On the other hand, the Nomenclature Committee, having regard to the admirable qualities of the material, considered that as it did not present the drawback of extreme brittleness, the characteristic property of cast iron, it was entitled to a higher rank and should be classed among wrought irons.

Mr **Hatfield**, in reply, wished to thank Prof. McWilliam for his remarks, and particularly for his corroboration of the mechanical tests given in the paper. With regard to his request that a commercial specification be given for this material, he would say that as the tests given in the paper represented actual works practice it was hardly necessary to enlarge upon them. The temperature for the melting point of carbonless iron was taken from the work of Sir William Roberts-Austen, but he was pleased to accept Prof. McWilliam's correction. His views also were quite in accord with those of the Professor as to the sub-carbide being present below 700 degrees C. as pearlite, $Fe_3C\ Fe_{21}$. Regarding Mr Brough's courteous contribution, he admitted that he was mistaken with respect to the authority behind the definition quoted from the Journals of the Iron and Steel Institute. Exception was taken to this definition, on the ground that it hardly did justice when it used an expression which was again reiterated by Mr Brough, viz., "lacked extreme brittleness." As this material was not brittle in any degree whatever, but was a beautifully soft, ductile, and malleable material, it would no doubt be clearly appreciated why exception was taken to the phrase mentioned. Whilst he was of opinion that malleable cast iron should strictly belong to the cast irons owing to its chemical composition, as it frequently contained from three per cent. to four per cent. of

Mr Hatfield.

carbon, he was nevertheless pleased to see that the Nomenclature Committee of the Iron and Steel Institute considered malleable cast iron to be of such a nature that in its opinion it should be classed along with wrought irons.

THE ELECTRICAL EQUIPMENT OF THE CUNARD EXPRESS STEAMER "MAURETANIA."

By Mr W. C. MARTIN (Member).

SEE PLATES XI., XII., XIII., XIV., XV., AND XVI.

Read 31st March, 1908.

IN the equipment of a modern steamship great improvements have been made in recent years for the economical working of the vessel and for the comfort of the passengers. Of all the changes that have been made, none have been more welcome and so thoroughly appreciated as the introduction of electric light.

The first vessel to be fitted was the American steamer "Columbia," the lighting of which was carried out under the direction of Mr. Edison in 1880. There were 115 lamps of 10 C.P. and two dynamos driven by belts from a counter-shaft.

In December, 1881, Professor Andrew Jamieson delivered a lecture to this Institution, in which he stated that electric lighting was fast replacing oil lamps on steamships, and gave a description of the installation fitted on the Cunard steamer "Servia" at a cost of £1000. When I mention that the total cost of the electrical installation on each of the latest Cunarders has been about £65,000, some idea will be formed of the great progress electrical engineering has made within the last 26 years.

Since the introduction of electricity on board ship, it has proved itself to be the "acme" of perfection for lighting, and has not only added greatly to the comfort of passengers, but has enabled shipowners to utilise lower deck spaces to better advantage for passenger accommodation; and not only passenger vessels have benefited by the adaptability, safety, and economy of electricity, but the ordinary cargo steamer of the present day is taking full advantage of it for the safe and rapid handling of cargo. No first-class cargo steamer is now complete without electric light, and shipowners are finding a great many charters cannot be secured unless their vessels are lighted electrically.

While it would be interesting to follow the development of the various systems of electrical installations on shipboard since the introduction of the first 6 kilowatt machines on the little steamer "Columbia," to the 1650 kilowatts in four machines on the "Mauretania," I can only make a brief reference to some of the more important points.

In the earlier designs of dynamo construction, the generators were run at a very high speed, and in many vessels the power of the engine was transmitted by belts or ropes and counter-shafts to the dynamos. Belts on board ship are most objectionable, not only on account of the great space required, but because of their unsteadiness. Many attempts were made in the early days to produce some means of connecting the slow-speed engine and high-speed dynamo without belts, but even the most successful arrangement devised, namely, friction wheels, was found unsuitable for all but the smallest powers. Nothing really reliable for ship work was in use, until the advent of the high-speed steam engine made it possible to couple engine and dynamo directly together. In fact, it was this very demand for a suitable engine that led to the development and perfection of the high-speed engine and steam turbine.

The choice of an engine for electric power on board ship is about equally divided between the slow speed type at from 200 to 300 revolutions, and the high speed of from 500 to 700 revolutions per minute, while an occasional engineer prefers a turbine. Engineers in charge of these plants claim to have the most satisfactory results regarding efficiency and economy; but undoubtedly, the steam turbine is the ideal for ship work.

It has all the advantages of light weight, less space, steadier driving, higher efficiency under certain conditions, freedom from vibration, and, having no reciprocating parts, there is less wear. It has been proved that, in smaller sizes, the turbines are not so economical in steam consumption, but it is almost certain that this will be overcome, and in the near future the turbo-driven dynamo will become universal.

Since the first installations many new fittings and devices have been invented for safe, reliable working on board ship, and the most important of these is the system of wiring, and the protection of the same. The first insulated wires used for ship lighting were covered with cotton cloth and white lead, and a further protection of rubber tubing when passing through specially damp places.

One of the greatest difficulties in ship lighting has been to find wires and fittings that would not be affected by sea air and water, and it still remains a fact that, no matter how good the quality of the insulating material and armoured protection may be, if the wires have not been well laid by experienced men, deterioration sets in quickly with most disastrous results. Any electric installation fitted to-day with the best material and workmanship should last as long as the hull of the ship. Shipbuilders dare not ignore certain standard rules in the building of a ship, but in some instances they are not so particular with regard to the lighting of the same, and it would be to the interest of all concerned if insurance registries and the Board of Trade took a more intelligent interest in this kind of work.

In preparing an installation to be fitted on board ship, particular attention should be paid to the placing of the wires, so that they might always be accessible and above all things they should be proof against fire and water.

In the Cunard steamer "Servia" there were 117 Swan lamps and 2 arc lamps equal to about 10 kilowatts of 13·4 H.P. In the "Mauretania" the total output of the 4 electric generators is about 2200 E.H.P., while the actual power required for all the lights and motors running at one time is 2773 H.P. It is found in general practice that, the power being very intermittent, 2 generators are capable of doing the work, thus leaving a large margin in hand for emergencies.

To find space for such powerful plant and to fit the installation on the safest and most reliable system, presented some interesting problems. The first of these was to determine the most suitable type of steam generator. After due consideration, the Cunard Company and the builders of the vessel decided to adopt the steam turbine, by the use of which the space required was reduced to a minimum, with less weight and more freedom from noise or vibration as compared with ordinary high-speed engines.

There are 4 sets of Parsons' turbo continuous-current generators, Fig. 1, each dynamo is shunt wound and is capable of giving an output of 3750 amperes at 110 volts and 1200 revolutions per minute. These generators are placed on an elevated platform abaft the engine room, in two separate compartments divided by a water-tight bulkhead and arranged so that, in the event of either dynamo room being flooded with water, the ship could still be lighted from the unflooded side.

A better arrangement for the generators would have been to place them nearer the centre of the ship, but being a vulnerable part, the Admiralty required them to be placed below the water line, hence the reason for placing them so far aft.

MAIN SWITCHBOARD.

To control this great power with safety and efficiency in a confined space exposed to a high temperature and possible trouble from vibration, required controlling switch gear of a substantial design, yet sensitive in action. The main switchboard, Fig. 2, is divided into two parts, one section being erected in the port generating room and the other in the starboard generating room.

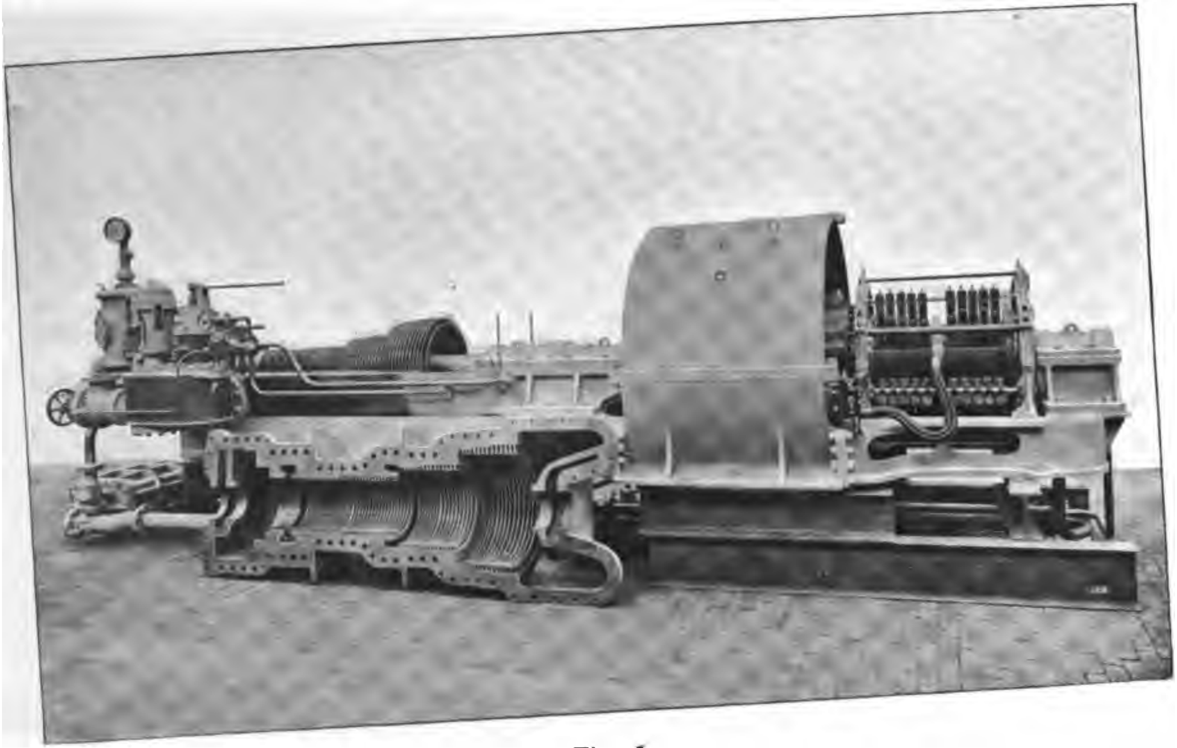

Fig. 1.

Each board has two generator panels, twelve feeder panels, and one disconnecting panel. Normally the two switchboards are connected together as one board through the disconnecting switches, but may be separated in a moment from *either* room, and each side of the ship operated as a separate installation.

The use of fuses for the control of the large currents dealt with, would have been inconvenient and unsafe, and instead automatic circuit breakers (performing the function of both switch and fuse) were fitted.

These circuit breakers are of massive construction, the contact surfaces being pressed firmly together by levers. The make and break contacts are massive carbon blocks, at the extremity of the switch arms, and the main circuit breakers are so arranged that the flash at breaking takes place in fireproof compartments well clear of the attendant. To accomplish this object and to make the operation of the switches easy, the handles are placed below and connected to the switches by insulating links behind the board. These switches are held in the closed position by engaging with a trigger which may be released either by hand or by a trip coil.

In order to prevent the opening of the circuit breakers during a momentary overload, a relay is introduced which closes the trip coil circuit when an overload occurs, after a period adjustable up to 15 seconds. Should, however, a reversal of current through the generator take place, the relay promptly closes the trip coil circuit, and thus cuts the machine out of circuit. The opening of the circuit breaker in turn breaks the trip coil circuit, and prevents damage to the coil or waste of energy.

The feeder switches are operated in a similar way, but without the reverse current arrangement. They have, however, in addition, a trip coil in series with the main current, adjusted to open the circuit with a greater current than the relay is set to operate at, but instantaneous in action. Thus, should a short circuit or heavy overload occur and the relay fail to operate, damage to the cables and machinery is effectively prevented.

The relay is simple and reliable in operation. It consists of a small motor, similar to that used in meters, through which part of the current is shunted. This motor tends to wind a strong silk cord on to a drum against the pull of a weight fastened to the other end of the cord. The cord passes round a drum to which the contact arms are fitted. When the current exceeds the overload limit, the torque of the motor is sufficient to wind up the cord, and thus close the trip coil circuits. The adjustments are affected by altering the weights and varying the distance between the contacts.

All the ammeters and voltmeters are of the moving coil type, the former being operated from shunts in the main circuits. By this means it is possible to have the reading instruments in any convenient place, and in the " Mauretania " two instruments are fitted for each machine, one being in the port and one in the starboard room. On each board, one additional ammeter is fitted, connected to bars behind the feeder panels, and so arranged that it may be connected by a plug to any one circuit at a time. By this means the current in any feeder may be ascertained without the expense of separate instruments for each circuit. Two station voltmeters and two paralleling voltmeters are provided, and the shunt regulators, which are placed behind the boards, are operated by a hand wheel on the front.

MAIN CABLES.

The Cunard Company, with their usual precautions for the comfort and safety of their passengers, decided that a high voltage would not be advisable, which accounts for the current being generated at only 110 volts. This necessitated cables of a great carrying capacity, and also very heavy switch gear.

The Admiralty further required all main cables to be run under the water line, and to accomplish this it was necessary to utilise the only available spaces in the coal bunkers or through the boiler rooms. Those who have had experience in the lighting of ships will know that these spaces generally are most objectionable for electric wires, especially the coal bunkers. The high temperature of the boiler room and the very large cables necessitated special precautions being taken to prevent the heat softening the insulation and allowing the cable to sink through the rubber, causing a short circuit. With ordinary armoured and lead-sheathed cables, the heat would readily affect the insulating materials. It was, therefore, necessary to adopt fire-resisting covering as well as the usual vulcanised rubber, so that in addition there is a heat-resisting compound and an outer covering of two coats of asbestos braid fitted on the cables. Fig. 3 shows the method of fixing and protection of cables.

The double wire system is used throughout, and there are 48 main cables of about 2 inches external diameter running from the generating station to the various sections of the ship, Figs. 4 and 5. The power is divided into 24 sub-stations of approximately 100 H.P. each, 12 of these being on the port side of the ship and 12 on the starboard side. Eight of these stations provide power for forced draught fans, 2 to supply the engine room machinery, and 2 for engine room lighting, the remaining 12 being connected to auxiliary switchboards at convenient distributing centres throughout the ship.

AUXILIARY SWITCHBOARDS.

These 12 auxiliary switchboards are placed directly opposite each other, port and starboard, and cross connecting cables are fitted so that, in the event of one section failing, the supply can be maintained from the other side. It should be mentioned here that, as the motors are only used intermittently, there is always sufficient surplus carrying capacity in the cables to provide for emergencies of this nature, thus guarding against any total extinction of the light.

The auxiliary switchboards are fitted in fireproof chambers, principally on the main deck. The switches are single pole, and the fuses double pole—Mr Lackie's patent zinc fuse—which breaks circuit with a minimum flash. Each board is provided with a spare panel containing spare fuses ready at a moment's notice.

BRANCH CABLES AND WIRES.

From these auxiliary switchboards, vulcanised rubber cables are carried in wood casings to section fuse boxes, which again provide distributing boxes at convenient positions for supplying the lights, the wires being run without joints. It will be noticed from Figs. 4 and 5 that these cables running from the main deck to the different sections above are like the trunk of a tree, with branches spreading out to the different decks. Special precautions were taken to keep all positive and negative wires in separate grooves.

In the corridors the casings are arranged as shown in Fig. 6, so that all wires are accessible at all times. In all the rooms of the ship the frieze forms a covering to the electric casings. A special feature of this is to be seen in the lounge, library, and smoking room, and all over the ship the wires are accessible, Figs. 7 and 8. No fuse boxes have been fitted, but all fuse panels are built in specially arranged recesses in the panelling, the panel itself forming the door; a door is also fitted behind for access to the wires. Inside the door, a tablet or card is fitted, giving information of what each branch supplies, with size of fuse.

In the wiring of engine and boiler spaces and other parts of the ship exposed to rough work, the protection of the branch wires calls for special treatment. Some engineers think screwed iron conduit or galvanised iron tubes are most suitable, but experience has proved that tubes sweat and retain condensed moisture which very soon destroys the best insulation. The best results are obtained with parallel twin conductors, each conductor being separately insulated with pure rubber and vulcanised rubber, braided and bound together, then sheathed with an outer armour of galvanised iron wire.

This system of armoured twin conductors has special advantages for engine rooms and other exposed parts. It is compact, requires less space, and has as strong a mechanical protection as an iron tube, but does not harbour moisture about the insulation as in the case of tubes. When well coated with paint the armouring is further protected from corrosion. It is water-tight and fireproof, has no soldered joints, and is always accessible.

In addition to the lighting and power circuits, there are single core and multiple core cables for electric bells, telephones, fire alarms, electric clocks, and the Stone Lloyd system of indicating the position of water-tight doors. These cables are too numerous to give in detail. There are over 200 miles of wire fitted, the copper in which weighs over 100 tons.

ELECTRIC LIGHTING.

There are over 6300 lamps distributed over the ship, fitted to pendants, electroliers, and brackets of various designs to suit the furnishings of the respective rooms. In the public rooms and state rooms the fittings are of a most handsome design, and the arrangement of concealed lamps for lighting the dining saloon dome gives a beautiful sunlight effect, while other compartments are brilliantly illuminated with beautiful crystal fittings. A special feature throughout has been to design the fittings so as to obtain reflected lighting from the ceilings as well as from the lamp itself.

ELECTRIC POWER.

Electrical transmission of power was evidently not thought of when the Cunard Company built the " Servia," and it will be interesting to follow the latest development in this branch. In every department of engineering the electrical transmission of power has become almost universal, but on shipboard it has made but little progress. In the latest Cunard steamers, however, there has been a decided advancement. In no other steamship, including the most recent German vessels, can be found anything to compare with the electrical installation on the "Mauretania."

The Cunard Company and their engineers realised that if steam were used for auxiliary work, the loss through condensation in the enormous lengths of steam pipes would be very great, and also that the annoyance to passengers would be unbearable. They therefore took full advantage of the simple and more economical method of distributing the power electrically throughout the ship.

In this installation there are:—

16 motors aggregating 800 H.P. for forced draught.
28 ,, ,, 276 H.P. for ventilation of machinery space.
18 ,, ,, 400 H.P. for auxiliary machinery in engine room.
16 ,, ,, 52 H.P. for ventilating the ship.
53 ,, ,, 156 H.P. for the thermotanks supplying heated air.
4 ,, ,, 64 H.P. for refrigerating machinery.
2 ,, ,, 16 H.P. for 2 passenger elevators.
4 ,, ,, 108 H.P. for lifeboat winches.
8 ,, ,, 48 H.P. for electric jib cranes.
6 ,, ,, 78 H.P. for mails and baggage hoists.
6 ,, ,, 20 H.P. for hoists and stores.
2 ,, ,, 10 H.P. for printing machinery.
1 ,, ,, 5 H.P. for wireless telegraphy.
20 H.P. for pantry and kitchen service machinery and hot plates.
80 H.P. for 106 electric radiators for special state rooms, bath rooms and hospitals.

A total of 2133 H.P. independent of the power for lighting.

The forced draught for the main boilers is supplied by 32 fans arranged in pairs and driven by 16 electric motors of 50 H.P. each; the motors are of the enclosed type, developing the power at 450 revolutions per minute, with the current at 110 volts. The fan impellers are of the single inlet type, being 66 inches in diameter and each capable of delivering 33,000 cubic feet of air per minute, against a water pressure of 3¼ inches on the discharge side when running at 450 revolutions per minute.

Owing to the high temperature in which these motors have to work, a very ingenious arrangement is provided whereby they may be cooled. Situated between the motor at the commutator end and one of the 66-inch fans, is an auxiliary fan with separate casing, the disc being 48 inches in diameter and made of sheet brass. The discharge is connected to the under side of the motor and plate, the air being circulated round the commutator and armature, and leaving at the opposite end. Each fan is provided with a water-gauge and tachometer. Fig. 9 illustrates a forced draught motor and fan. Each motor is also fitted with a controller or switch capable of regulating the speed in equal increments by field variation from 225 to 450 revolutions per minute. Low voltage and overload automatic releases are fitted to these controllers, giving complete protection to the motors under all conditions.

When running at the lowest speed the approximate output of air from each fan is 17,000 cubic feet per minute, against a water pressure of 1 inch. Each fan room is also ventilated by 8 single inlet fans 21 inches in diameter, each being driven by a motor of the totally enclosed type capable of delivering 1000 cubic feet of air per minute against a water pressure of 1 inch, when running at a speed of 900 revolutions per minute.

The motors are of the four-pole series wound type, and are each capable of developing normally an output of 5 H.P. when supplied with current at a pressure of 110 volts and running at a speed of 900 revolutions per minute. Each motor is supplied with a controlling panel consisting of a one double-pole quick break switch, tubular fuses, and starting and regulating resistances, the whole being self contained and mounted upon a panel suitable for erection on the bulkhead.

In the engine room the electric motor performs a most important part in the manipulation of the main turbines and other gear. For dismantling the turbines there are 6 sets of lifting gear, each consisting of a 30 H.P. motor, driving a horizontal shaft above the turbine, coupled to two 7-inch diameter vertical lifting screws and worm gear, by which means the turbine casing or rotor can be lifted in turn, Fig. 10. The weight of the L.P. rotor is about 125 tons and the H.P. rotor 72 tons, and these can be lifted in 30 minutes.

One of the best illustrations of the adaptability and usefulness of electric motors on board ship is to be found in the case of the electrically-controlled sluice valves. There are two 75-inch and two 60-inch sluice valves in connection with the high pressure turbine exhaust steam, and in each of these is fitted a 12 H.P. motor operating a worm gear, as shown in Fig. 11. Each is controlled from switches, Fig. 12, on the starting platform, where an index shows the action of the valve. The fact that the valves can be closed in a minute or two by the electric motor, and that it would take 4 men 2½ hours to close it by hand, shows a remarkable saving in time and labour in favour of the electric motor. Other useful applications of the electric motor in the engine room is the 30 H.P. motors installed for the turning gear, and 25 H.P. motors which drive centrifugal pumps drawing off surplus water from the condensers.

For ventilating the engine room there are 10 Sirocco fans of 25 inches diameter, each driven by a 5 H.P. motor; 6 fans of 30 inches diameter, each driven by a 30 H.P. motor; and 4 fans of 15 inches diameter coupled to 1½ H.P. motors.

The general heating and ventilating of the ship is maintained by 53 thermotanks, each fitted with a motor-driven fan, the motors varying from 2½ to 4 H.P., making a total of 156 H.P., Fig. 13. Each motor fan supplies a section of the ship with warm or cold air, or by arrangement of valves on the tanks, the fans can be made to extract the air from various compartments.

DECK WINCHES AND OTHER APPLIANCES.

Electric power driving is also extensively used for deck winches, passenger hoists, and other appliances to the extent of 270 H.P.

For the passenger lift, two motors of 8 H.P. supply the power to the winding gear, Fig. 14, while other two motors of 15 H.P. supply the power for two 40-cwt. baggage hoists, and two 5 H.P. motors operate two 10-cwt. store hoists, while two more of 1½ H.P. control the two 2-cwt. pantry hoists for conveying food from the kitchen. There are also two mail hoists fitted with 12 H.P. motors.

In addition to these there are 4 electric jib cranes, each made to lift 12 cwts., Fig. 15. The lifting motions are operated by a 12 H.P. motor through worm gear, and the slewing motion through worm and spur gearing by a 2½ H.P. motor, the motors being series wound of the enclosed type. These cranes do their work absolutely without noise of any kind and are conveniently placed on the boat deck for lifting stores, or luggage and mails from tenders that come alongside.

Another important part performed by electric power is the hoisting and lowering of the lifeboats. This work is done by four electric winches placed alongside the lifeboats, Fig. 16. The motors attached to these winches are each of 27 H.P. connected to worm gear running in an oil bath. The rapidity with which the lifeboats can be manipulated, as compared by hand, must be apparent to all.

An interesting application of electric driving is in connection with the refrigerating machinery, Fig. 17.

The two gas compressors are each coupled direct to a 12-pole shunt wound motor of 35 H.P., giving a constant torque between 40 and 110 revolutions per minute. The armature is provided with two windings which are in series at starting, and by turning the hand-wheel on the switch-gear, the starting resistance is cut out and a variable resistance inserted in the shunt circuit to regulate the speed between 35 and 75 revolutions per minute. By transposing the armature windings from series to parallel connections without resistance, and by inserting the shunt resistance again, the speed can be increased to 110 revolutions per minute. The two brine pumps are operated by shunt wound motors of 3½ H.P. each.

In addition to the large number of motors already enumerated, there are still a great number of other applications, but time will only permit me to refer to them briefly.

Among these are the motors for driving the printing machine and the Marconi apparatus of 5 and 3 H.P. respectively, and provision is made by having connections on deck for driving winches of 112 H.P. on the quay or in barges. In the galleys and cooking department an electric motor drives a machine capable of making bread for 3000 people; and in the cooking ovens there are 4 vertical spits, driven electrically, capable of dealing with a ½ ton of meat at a time; other motors are fitted to knife-cleaning machines, dish-washing machines, circular knives for cutting bacon, potato peelers, whisking machine, freezing machines for making ice cream, and numerous electric hot plates for keeping food warm during service.

TELEPHONE AND ELECTRIC BELL SYSTEM.

Telephone instruments are fitted throughout the first-class state rooms. Having an exchange on board, passengers can converse with one another without leaving their rooms. On arrival in port the exchange is connected to the Liverpool or New York exchange, so that passengers may be in communication with their homes or offices up till the hour of sailing or immediately on arrival.

Another telephone system connects the captain and officers on watch on the bridge with the engine rooms, and crow's nest on the foremast. These consist of Graham's navy pattern loud speaking telephones, and are used for docking and steering as well, connections being fitted on the forecastle, in the wheel house aft, and in the steering-gear room at the stern of the ship. For the officers' use there is an intercommunication telephone service fitted, consisting of the Parsons Sloper secret instruments, each officer being able to call up another from his own room.

In addition to the telephone system there is a large installation of electric bells with Gents' patent indicators. In every first-class state room there is a combination fitting of electric bell push, electric light switch, connection for portable reading lamp or curling tongs heater, and electric fans, while a number of special rooms are fitted with electric radiators.

A complete installation of electric clocks is fitted on the magnetic system. In the public rooms, and principal entrances, and corridors there are fitted, in all, 48 clocks, controlled from the master clock, situated in the chart room adjoining the bridge.

There is also a complete electric fire-alarm system. A brass plate and red lamp indicate the position of the alarm push in the corridors, these being connected to indicators in the engine room and the navigating house on the bridge deck. There is also a subsidiary fire alarm apparatus fitted near the bridge, consisting of a small cabinet into which a number of tubes are led from the various holds, a small electrically-driven fan continually exhausts the air from the tubes, and in the event of a fire it would be easily detected from which hold the smoke issued. A mercury-contact type fire alarm indicator is also fitted in the case, which, with the rising temperature, rings an alarm bell.

In addition to the ordinary life buoys, there are two special buoys fitted on the bridge deck operated by Martin's electric release gear, which can be operated from the bridge and other positions, on the alarm being raised.

In connection with the Stone Lloyd system of water-tight doors, an electric indicator is fitted in the navigating house which shows the position of every water-tight door in the ship, Fig. 18. The doors are closed or opened by hydraulic power simultaneously, by the officer in charge moving a handle which operates the control valve. The function of the electric indicator is to show the officer exactly what doors are open or closed. The indicator has a small lamp for each door with wires led to a contact switch at the door which, when the door is closed, completes the lamp circuit and lights the lamp.

Another important fitting on the bridge is Martin's automatic indicator for the navigating lamps, which is shown open and closed in Fig. 19. The indicator controls five lights as shown, each light consisting of a duplicate filament lamp, one filament being lighted normally. In the event of this filament failing, the armature of a small electro-magnet which is in circuit is released, and falls against an auxiliary contact, which completes a circuit through the remaining lamp filament and through the indicator lamp corresponding to the light affected. Attention is also drawn to the occurrence by an electric horn attached to the indicator. On the officer in charge pulling a handle the horn ceases to sound, and the electro-magnet is inserted in circuit with the second filament; should this latter fail the horn again sounds, and cannot be stopped until the lamp is replaced or switched off. The several lamp circuits are controlled by the slipper switches seen under the indicator, and the latter—as, indeed, all the important apparatus on the ship—is connected through a change-over switch from either the port or starboard feeder systems, thus guarding against a failure in the navigating lights.

In conclusion, I commend to marine engineers and naval architects a closer study of the advantages of electrical power driving for all auxiliary machinery. The question of propelling the ship by electric motors awaits development, but the electrical equipment of the "Mauretania" shows many advantages over the present wasteful system of steam engines.

Discussion.

Mr W. B. SAYERS (Member) observed that it was just about twenty-five years ago that he (Mr Sayers) first went in charge on a trial trip on a ship fitted with electric light; that ship was the Orient liner "Cotopaxi." She was fitted with a Bürgin dynamo similar to the one exhibited in the entrance to Port Dundas Electricity Supply Station. The "Cotopaxi" was fitted with one hundred lights or less in the saloon, writing-room, smoke-room, and captain's room, but electrical engineers had gone a long way in advance since then. He had not very much to say on the numerous applications of electricity in the "Mauretania," except to remark that they certainly were greater than even one would have expected. At the time of his trip on the "Cotopaxi," electric light was in its infancy, but it had grown to be quite a big boy. Mr Martin said that the turbine was often preferred, and on page 423, remarked that—"It has been proved that, in smaller sizes, the turbines are not so economical in steam consumption, but it is almost certain that this will be overcome, and in the near future the turbo-driven dynamo will become universal." Mr Martin had not stated such to be the case, but he (Mr Sayers) understood that the turbines on the "Mauretania" were non-condensing, the reason being that the exhaust steam was utilised for heating purposes, etc. What he was going to say could be taken as a general reply to the criticism that was often offered against steam turbines. It was this, that steam turbines as constructed by Messrs. Parsons and others were entirely unsuitable for the high pressure end. Mr Parsons acknowledged that when he advocated, as he seemed to do, the reciprocating engine at the high pressure end. Looking at Fig. 1, it would be seen that the buckets or blades at the

Mr W. B. Sayers.

end nearest the inlet were almost indistinguishable. The inlet required for, say, 50 horse power at 100 lbs. steam pressure, assuming the velocity of the steam to be 600 feet per second, was less than half a square inch of cross sectional area. An annular space such as was required to receive Parsons' blades having this area, after making allowance for the space taken up by the blades and for the obliquity of the flow, and taking only 3 inches diameter of drum, might be, say, ¼ of an inch wide radially, that was, the blades must be about ¼ of an inch in length, less the clearance allowed; and remembering that the clearance path was straight and uninterrupted by blades, it became clear that a very large proportion of the total steam could leak past the blades at the inlet of a turbine on these lines. The conditions improved, of course, as the size of the turbine increased, but not very materially, especially when it was desired to keep speed as low as possible. At the high pressure end the leakage space must be nearly as big as the working space, and it was quite impossible to get a satisfactory design on these lines. The form of turbine that would certainly solve this difficulty was one in which the steam was not divided into a multitude of small streams, and did not use Mr Parsons' idea of a parallel flow, but was kept more or less in a single stream flowing round the periphery of the turbine. He felt quite justified in saying that, on these lines, a turbine could be made that would run at as low a speed as anyone desired, and which would be highly efficient even at the high pressure end; and, also, one which would be capable of working with what was being called "red hot" steam, that was steam with initially a very high superheat.

Mr Campbell MacMillan, B.Sc. (Member), thought it would have been interesting had Mr Martin separated the progress in electric lighting and the adoption of motive power on board vessels. If one deduced from his information these separate elements, it would be found that the increase in lighting was not so great as at first sight appeared. Perhaps during the time that the Cunard Line had been running steamers their size had increased some thirty times or so, and in that period, during which electric light had been in use, the Company had increased the cost devoted to electric lighting about twenty or thirty times, and the kilowatt capacity about forty or fifty times, so that there was not such a great discrepancy beween the increased transport service given and the amount of electric plant devoted to that service in kilowatt capacity and money value. Regarding the utilisation of power, in passing from the time when power was not used at all, till now, a relatively greater increase would be found. In the present instance there were three or four times as much electric plant directed to the distribution of power only, as was devoted to the distribution of light. He did not assume that Mr Martin held himself in any way responsible for those who had planned the use of electric power on board the "Mauretania," but he had complimented those responsible and so identified himself, to some extent, with them. It was interesting to critically examined the list which appeared on page 430, of the purposes to which electricity had been devoted, in order that one might look for further outlets for its use, and, perhaps, criticise some of the ways in which it had been already utilised. As steering gear had not been mentioned, he assumed that electricity had not been applied to it, where one would have naturally thought the application of electricity would have been of great value. On the other hand, a considerable amount of power had been installed in the engine room, where some of the advantages of electric driving were not so obvious. About 300 horse power were spread over the decks in winches and other appliances, and the remainder of the 2000 horse power was pretty well concentrated in the engine room. It would be very interesting if Mr Martin could show the other advantages of electric driving, which made it preferable even in the engine room of a steamer. For instance, the first item ran to about 50 horse power for each motor, and a steam engine

Mr Campbell MacMillan, B.Sc.

of 50 horse power would, he ventured to say, give a good account of itself in efficiency, however much it might fail in convenience, and any information regarding the relative merits of the rival units would be interesting. In the matter of other advantages which might be obtained from the use of electric motors as compared with small steam engines, of as great efficiency, he did not know that these had been referred to in any part of the paper, but they might play a large part in decisions favourable to electric motors. Reference was made to the controlling of large sluice valves by electric motors, and attention had been called to that as one of the best instances of the adaptable nature of electric driving. He did not know why similar methods were not carried a little further, so that they might be directly controlled from the bridge. He knew one or two vessels in which there was such direct control, but they were relatively small vessels. Such boats had been used for the Chicago Fire Service, where twin propellers had been driven with a 250 horse power motor on each of the shafts. These were supplied from a generator on the shaft of a turbine used for the primary purpose of pumping water for the fire service. The twin screws could be operated by the captain from the bridge, and did not require the intervention of the engineer. Seeing that the electric motor had been used, he thought that the feature of direct control from the bridge could easily be added. Another question which might arise in that connection was, Why it should not be of great advantage to utilise the power in the vessel for further objects, such as handling coal at the quay? He thought that such devices might be introduced where so much power was available. The main lesson that marine engineers and shipbuilders ought to take from the paper was, that if these appliances were permissible and advisable in such a ship as the "Mauretania," they must be to a large extent equally so in other vessels; and he felt that there ought to be a discussion in which the representatives of modern shipbuilding and engineering practice would either severely criticise so great an adoption of electrical working, or show some good reasons why it should not be adopted to a much greater extent than at present.

Mr R. T. Napier (Member) said it was well known that steam-driven auxiliaries afloat were kept running with a heavy loss of steam through leakage and condensation. He asked the Author to state what the probable percentage of loss would be of electrical horse power, taking this collectively, over that of the auxiliaries which were in daily use at sea.

Mr Gilbert Austin said he would like to call attention to the position of the dynamos, which were placed about 100 feet from the stern of the ship. In a ship approximating 800 feet in length, this meant the transmission of steam from the boilers right through the engine room to the dynamos, the conversion of that steam into electric energy, and the retransmission of that energy to the centre or forward part of the ship. The "Mauretania" and the "Lusitania" were built to Admiralty requirements, and the dynamos had to be placed below the water line. Regarding the main cables, it had recently been pointed out that armoured cables were quite as good as asbestos cables, but in this ship it was considered desirable to have something better than had ever been installed before, to avoid the possibility of a breakdown. In the "Mauretania" the main cables were carried on porcelain insulators, and if the insulating covering broke down the electric supply could still be maintained. The installation was on the duplicate system throughout, and yet the duplication did not cost, anything to speak of, more than that of the ordinary single installation. The port side of the ship was treated as an entirely separate installation from the starboard side, and at the auxiliary switchboards there were cross-connecting cables, so that in the event of a breakdown on the port side, the ship would get its supply from the starboard side. One side of the ship was quite able to take care of any load which might occur in ordinary circumstances for lighting and other purposes on the other side

Mr Gilbert Austin.

of the ship. Quite a large proportion of the electric energy in the ship was used for motors, winches, hoists, elevators, and apparatus of that description, which were only working a certain fraction of their time. Passing to the wiring of the ship, he thought the point of great interest to shipbuilders was the arrangement of distributing fuse boxes and switchboards in recesses which could be readily opened, to give access to the wires behind the distributing boxes, and there was no cable fitted into the "Mauretania" that could not be got at in two minutes. In the lighting of the ship ordinary lamps had been used throughout. Metallic filament lamps might have been used, but the question was, Would they last? In one ship with which he was acquainted, there were 700 metallic filament lamps installed, and the breakages in one voyage amounted to about 250, nearly one-third of the whole. Evidently the time was not ripe for metallic filament lamps. The electric motors in the engine room were mostly used for driving the ventilating fans, and were, he thought, more suitable than steam engines for this work. They ran at a much higher speed, were practically silent, and required little or no attention, owing to the system of lubrication employed. Electric motors had been adopted for other purposes for the reason that standby losses were not experienced by their use.

Mr Martin, in reply to Mr Sayers, said the question of obtaining the most economical results in steam turbines would open up a wide field for discussion, which did not appear to be within the limits of his subject. In smaller vessels, as far as his experience went, the turbine had not proved itself so economical as an ordinary single cylinder engine for the electric lighting of ships. The turbines on the "Mauretania" were designed to run both on the auxiliary condenser and the feed heater, the object being to save all the fresh water by running them in connection with the auxiliary condenser while in port, and by connecting them to the heater at sea for heating purposes. Mr MacMillan thought it would have been interesting

Mr Martin.

if he (Mr Martin) had separated the progress in electric lighting and the adoption of motive power on board vessels. In that connection, he wished to point out that the present conditions were very different to what obtained when the Cunard Company lighted their first ship in 1881. The increased efficiency and greater production of the present day entirely changed the money value of what was done in 1881, so that electric installations fitted on the latest ships showed equally as great an advancement as the increase in size of the ships. Regarding the adaptability of electric power for auxiliary machinery on board ship, he considered it more economical in every way than the ordinary steam engine. Wherever engines worked intermittently, engineers had proved beyond doubt in land work that the electric motor costs less for upkeep in repairs and consumption of fuel. In marine work there were several reasons why it had not become more general. There was a considerable amount of prejudice amongst those who had not had experience in electric power driving, and there was the fact that makers of auxiliary machinery were naturally slow to set aside the manufacture of steam plant for the modern electric motor. There was also the question of first cost of electric power which, in many instances, was considerably greater. Electric steering gear had been fitted in some ships, and the control of their movements had been conducted by the captain from the bridge by electric power, without the intervention of the engineer. These developments were interesting in a way, but the experience gained did not justify a general adoption for such great ships as the "Mauretania." The chief advantages of electric motors over the ordinary steam motor in the engine room was economy in space and saving of power, and this was especially so where there was intermittent work to be done; besides there was less gear and more silent working. He saw no reason at all why the electric motor should not become as general for auxiliary machine driving on board ship as it was now on land.

Mr Martin.

A great number of the largest engineering and shipbuilding establishments in this country must have proved the relative merits of the rival units to be all in favour of electricity, and if so, Why should the use of electricity on board ship not become more general? It was only a question of time for development; there was no real difficulty in the way, and a modern ship electrically equipped would reduce much of the present waste in fuel, and the work would be done with less wear and tear and more comfort to passengers. Respecting Mr Napier's remarks, there was absolutely no loss from electric cables that could be compared to the loss from condensation in steam pipes. When a number of motors used intermittently were grouped together on the same supply cables, the loss in the cables would probably be only from 1 to 2 per cent., and this only while some of the motors were actually in use. The efficiency of the motors themselves might vary between 80 and 90 per cent. according to size.

The PRESIDENT (Mr John Ward) said in connection with this paper two things were borne in upon the shipbuilding members, namely, that every ship was a compromise and that the bigger the ship the less room was there for all the owner's requirements. The paper read by Mr Martin was specially interesting, not only on its own account, but also as a detailed supplement to that of Mr Luke, given before the Institution of Naval Architects last year in connection with the scantlings and general details of the "Lusitania," and to that of Mr Bell, read this year before the same Institution, giving the sea performances of the "Lusitania." The outcome of these three papers was to give a large amount of most helpful and valuable information regarding the two pioneer steamers of the largest size that had yet carried the British flag across the Atlantic. It was interesting to remember the reason which brought the building of these ships into being a national question, and how—despite, in a general way, the absence of sentiment from public life—

The President

when the national pulse was stirred, as it was when the Shipping Combine of America tried to take the lead in the Atlantic trade, our own Government, with the approval of the nation, advanced the money for building these vessels, and so proved to all concerned that on the ocean's highway Britain meant to still "carry the flag," and carry it in the van. The "Lusitania" and "Mauretania" had each been a great success, and as time went on would considerably improve on what they had done. He believed that if the same owners were building to-day further improvements would be achieved by them. That would be due to the experience which every year brought, and which, as professional men, in every department, they were finding out. He moved that Mr Martin be accorded a hearty vote of thanks for his paper.

The vote of thanks was carried by acclamation.

STUDENTS' SECTION.

(SELECTED PAPERS).

THE LAYING OUT AND USE OF CALCULATING CHARTS.

By Mr T. B. Morley, B.Sc.

SEE PLATES XVII., XVIII., XIX., AND XX.

Read 4th February, 1908.

The engineer, or the naval architect, in the course of his business, has frequently to arrive at the value to be assigned to a particular quantity or dimension, by the application of a mathematical formula involving the data supplied to him or quantities determined by his judgment and experience. Even apart from the use of a formula as a general custom, there are numerous cases in which he is allowed no choice, and is compelled, in order to satisfy the regulations of a survey society like Lloyd's, or a Government department like the Board of Trade, to settle certain dimensions by the application of a rule in the shape of a formula. There is thus, in an engineering establishment, a large amount of arithmetical calculation required. The object of this paper is to indicate how much of the labour and time spent in purely routine calculations can be saved by the use of a graphical method, which, once the preliminary labour of preparing a chart has been accomplished, enables the result of a particular calculation to be found in a few seconds.

The very simplest form of calculation is, of course, addition or subtraction. Fig. 1 shows how this can be performed graphically. Along the horizontal base line is laid off a scale of values of A, along the vertical a scale of values of C, and, if these scales are equal, lines marked with values of B are drawn at 45 degrees as shown. Then, by erecting a perpendicular from the point representing any given value of A, to meet the inclined line for the given value of B, and drawing a horizontal to the vertical axis, the value of $C = A + B$ is determined.

The values of C so found can be connected with a second series of lines for values of D in a similar manner, and hence the sum of $A + B + D$ found as shown on the chart; and by repeating the process any continued summation may be effected. The same chart serves, of course, for subtraction, since it simply shows the relation between the quantities (A, B, and C, for example), so that if any two whatsoever are given, the third may be found. Hence, if C and A are given, the chart serves to find B, their difference. The spacing of the inclined lines is regular, and intermediate values may be readily interpolated.

Obviously, if the scales of A and C are different, the lines for values of B will be inclined at an angle not equal to 45 degrees, but 45 degrees is the most convenient angle to use. This type of chart finds its *practical* application, however, in cases where the values of A and B, *i.e.*, the quantities to be added, are not given directly, but represent the given quantities multiplied or divided by a constant.

As an example of this, Fig. 2 shows a chart for the valuation of $K = {\cdot}038\,H + {\cdot}009\,M + {\cdot}002\,L + {\cdot}0165\,S$, this being part of the formula given by Lloyd's for the calculation of the diameter of shafting for triple-expansion marine engines. H, M, and L denote the diameters in inches of the high, intermediate, and low-pressure cylinders respectively, and S denotes the length of stroke in inches. K is found from the above formula, and then the shaft diameter in inches is given by $D = K\sqrt[3]{P}$, where $P =$ boiler pressure in lbs. per square inch above atmosphere.

In the chart, Fig. 2, the actual distances set off to scale do *not* represent H, M, L, and S, although they are marked simply with values of those quantities, but they represent H, M, L, and S each multiplied by its proper co-efficient. Thus, using the notation of the first example, A corresponds to ·038 H, B to ·009 M, and so on. In each case, however, 1 inch on the diagram, measured horizontally or vertically, represents the same value of A or B or C, etc., so that all the inclined lines are at 45 degrees.

To construct this chart for the range of values shown, the procedure is briefly as follows:—Values of H are required, ranging from 20 to 30, so that $A = \cdot 038\ H$ varies from ·76 to 1·14. A scale of values of A from ·76 to 1·14 is laid off horizontally at the bottom of the diagram. The smallest value of M required is 30, and the corresponding value of B is ·27; hence the smallest value of $A+B$ is 1·03. Similarly, the maximum value of $A+B$ is found to be 1·59. Values of $A+B$ from 1·03 to 1·59 are set off vertically to the same scale as the values of A. A point on the line for $M=30$, *i.e.*, $B=\cdot 27$, can now be found, since it corresponds to $A=\cdot 76$, and $A+B=1\cdot 03$; similarly, a point on the line for $M=50$ is found. Through these points lines are drawn at 45 degrees, and since the scales of A and of $A+B$ increase from left to right, and from bottom to top, these lines must slope upwards to the right. The lines for intermediate values of M divide the distance between these two extreme lines regularly and are readily drawn.

The addition of $(A+B)+C$ is now arranged for in the same way, and finally that of $A+B+C+D=K$. A, B, C, etc., are marked in brackets on the chart to illustrate the construction, but are not required for practical use. As an example of the use of the chart, suppose $H=23$, $M=38$, $L=61$, $S=42$, then the dotted line shows the course followed, viz., vertically from $H=23$ to the line for $M=38$, then horizontally to the line for $L=61$, then vertically to the line for $S=42$, and then horizontally to the scale of K. K is thus seen to be 2·03; arithmetical calculation agrees with this, giving 2·031. The upper portion of the chart is for the calculation of $D = K\sqrt[3]{P}$, and involves the operation of graphical multiplication, which now falls to be described.

In Fig. 3 a horizontal scale of values of A is set off. From the zero point, lines are drawn having slopes proportional to

1, 2, 3, 4, etc., and these are marked $B = 1, 2, 3, 4$, etc., respectively. Then, any vertical, such as P M, is obviously proportional to the product of the values of A and B, shown at M and P, hence the vertical scale of C represents products of A and B. Of course, the scale of C can be altered if required, by altering the slopes of all the B lines to correspond. For example, to double the value on the C scale, it is only necessary to double all the numbers on the B lines. Note that radiating lines must converge to the zero of A and of C. The scale of C may be placed at either side of the diagram, and by means of a set of lines D, the product of C and D may be obtained and shown on scale E, *i.e.*, E shows the product of A, B, and D. Similarly, by a repetition of this, any continued product may be obtained, although it will be shown later that for multiplication or division only, there is a much better method.

The same chart also serves for division. $C = A \times B$, therefore $B = C \div A$, and if C and A are given, inspection of the chart determines B. Division may also be performed as follows:—On the D lines are marked values of $D^1 = \frac{1}{D}$. Now, $E = A \times B \times D$, therefore $E = A \times B \div D^1$. Hence the dividing by D^1 can be graphically performed, the line bearing the required value of D^1, instead of D, being used. For example, Fig. 2 shows the multiplication of 2×3, giving 6, also $2 \times 3 \times 2$ giving $E = 12$, or $2 \times 3 \div \frac{1}{2}$ giving $E = 12$.

Returning now to Fig. 2, the upper part of the chart gives a means of calculating $D = K\sqrt[3]{P}$. D and K are laid off on scales at right angles, and the inclined lines correspond to values of $\sqrt[3]{P}$, although simply marked with values of P. The inclined lines would meet at the zero of the K and D scales, but as this is inconveniently situated, they have been plotted by finding two points on each P line by calculation. For example, suppose $P = 160$, $\sqrt[3]{P} = 5{\cdot}43$, therefore, when $K = 2{\cdot}7$, $D = 2{\cdot}7 \times 5{\cdot}43 = 14{\cdot}66$. Hence the intersection of the vertical from $K = 2{\cdot}7$, and the horizontal from $D = 14{\cdot}66$, gives one point on the line for P = 160. Similarly, the other points required can be very easily and rapidly fixed, and the lines drawn. To use the chart, suppose from the previous formula K is found to be 2·03, and P is given as 160; from K = 2·03 follow the vertical to the line P = 160, and from the intersection follow the horizontal to the scale of D, as shown by the dotted line. D is thus found to be 11·07 inches. Arithmetical calculation gives the value 11·03 inches. The error is thus only 4 in 1,100, or ·36 per cent., and is on the safe side. This particular calculation has been taken quite at haphazard from the chart used, in which the scale of D is full size.

In the chart illustrated the two scales of K might have been made to coincide, and the last dotted line for the first calculation (that of K) could have been carried right to the line for P, thus omitting altogether the intermediate step of finding K, *i.e.*, D would be found at once from the given values of H, M, L, and S.

This kind of chart, using only natural scales, is specially useful where calculations involving addition as well as multiplication are involved. Also the quantities plotted to scale need not be the given numbers, but functions of the numbers. Thus, Fig. 4 shows a chart for finding mean effective pressures in steam engine cylinders from the formula

$$p_m = f\left(p_o \frac{1 + \log_e r}{r} - p_b\right).$$

where r is the ratio of expansion, p_o the stop valve pressure, p_b the back pressure, and f the diagram factor.

The lower part of the chart is for the calculation of

$$p_o \frac{1 + \log_e r}{r};$$

the vertical scale marked with values of r measures *really* values of

$$\frac{1 + \log_e r}{r},$$

and by means of the radiating lines for various values of p_0, the product

$$p_0 \frac{1 \times \log_e r}{r}$$

is obtained. Thus, if $r = 7{\cdot}5$, $p_0 = 167$ lbs. per square inch,

$$p_0 \frac{1 + \log_e r}{r}$$

is given by L M. For a non-condensing engine, the back pressure is taken as 18 lbs. per square inch, and is represented by $O_1 N_1$, therefore $N_1 P_1$ represents

$$\left(p_0 \frac{1 + \log_e r}{r} - p_b\right).$$

$N_1 P_1$ is multiplied by the diagram factor in the usual way, the lines radiating from N_1 corresponding to various values of the diagram factor. For diagram factor $= {\cdot}65$, the product is shown by $P_1 Q_1$ or $Q_1 R_1$ and from the scale is read as 32 lbs. per square inch. The topmost portion of the chart is the same in principle, but arranged for condensing engines, $O_2 N_2$ representing a back pressure of 4 lbs. per square inch. In this case the mean effective pressure is shown by $O_2 R_2$ and is read as 41 lbs. per square inch. The results of arithmetical calculation in these cases are 31·9 and 41 lbs per square inch respectively.

Of a similar character to the foregoing is the chart shown in Fig. 5 for determining the B.H.P. of motor vehicles on various roads. The first calculation is that of the tractive effort T in lbs.

$$T = W\left(R + \frac{2240}{m}\right),$$

where m is the gradient (expressed as 1 in m), R the road resistance in lbs. per ton, and W the load in tons. The lower scale is one of reciprocals, measuring really not m but $\frac{2240}{m}$. A B represents R, and O A D (where O is the zero point lying to the left of

A) represents $\frac{2240}{m}$. Now DE = DC = AB, therefore OAE represents

$$\left(R+\frac{2240}{m}\right).$$

O A E is multiplied by W in the usual way by means of the sloping lines of W, so that E F represents

$$W \times \left(R+\frac{2240}{m}\right),$$

i.e., E F represents T the tractive effort. The remaining calculation is

$$\text{B.H.P.} = \frac{T \times V}{n \times 375},$$

where V is the speed in miles per hour, and n the efficiency of the gearing; and the chart for this is on the lines of the ordinary multiplying chart. A complete calculation is shown by the course of the heavy lines marked with arrow heads.

Logarithmic Charts.

For most purposes, and especially for calculations involving multiplication or division, and no additions, charts using logarithmic scales are by far the most convenient.

The use of a logarithmic scale practically converts a multiplication or division into an addition or subtraction, which may then be dealt with by the method first described (see Fig. 1). Thus, if $A \times B = C$, then $\log. A + \log. B = \log. C$, hence for any value of B say, log. A and log. C are connected by a straight line graph, the line being at 45 degrees if the scales are equal.

The logarithmic chart has also the advantage of being readily applied to powers and roots of numbers, no matter how complex the power or root may be, this case corresponding to that of Fig. 2, viz., the addition of numbers multiplied by fixed coefficients.

Let $A^m \times B^n = C$, then $m \log. A + n \log. B = \log. C$, and here again parallel straight line graphs for values of B are obtained.

As in the former example, Fig. 2, of addition, the scales may be so adjusted as to make the sets of parallels lie at 45 degrees, and this is usually an advantage. In this event, the scales of A, B, and C are proportional to *m*, *n*, and 1, *i.e.*, to the respective indices of A, B, and C in the formula. Any constant in the equation has only the effect of shifting the scales bodily. The construction of such a chart will be best seen by considering an example such as that dealing with the horse power formula for a steam engine.

$$\text{H.P.} = \frac{2\ P\ L\ A\ N}{12 \times 33{,}000},$$

where, A = area of cylinder, double-acting, in square inches,
L = stroke in inches,
N = number of revolutions per minute,
P = mean effective pressure in lbs. per square inch.

A = ·7854 D^2, where D = cylinder diameter in inches, so that the formula becomes

$$\text{H.P.} = \frac{2 \times \cdot 7854}{12 \times 33{,}000}\ P\,L\,D^2\,N.$$

A scale of piston speed $S = \frac{L\,N}{6}$, may also with advantage be marked on the chart, which is shown in Fig. 6. To construct it, set off a logarithmic scale of values of N say from 40 to 300 at the left, S from 400 to 1000 at the top. From the point corresponding to N = 40 and S = 400, draw a line at 45 degrees sloping downwards to the right (since N and S increase downwards and to the right). Now, when N = 40 and S = 400 feet per minute, then L = 60 inches, so that this line corresponds to L = 60. The spacing of the L lines will be logarithmic and to the same scale, measured horizontally and vertically, as that of N and S, and the remaining lines for L can thus be set down. It will be found to be more accurate, however, to fix a few more points by independent calculation. Thus S = 1000 and

$N=200$ gives $L=30$, and so a point on the line $L=30$ is found. This also saves trouble in determining in which direction the values of L increase and in which they diminish. Now, a set of lines with opposite slopes to those for L may be drawn, representing values of D. These lines must be spaced twice as openly as the others, since D appears in the formula to the power 2. On a vertical line just to the right of this section of the chart, values of the product

$$K = \frac{\cdot 7854}{33{,}000} S D^2$$

may be marked lightly in pencil, as they are not permanently required. Thus, when $S=1000$ and $D=80$, then $K=152$. When $S=400$ and $D=20$, then $K=3{\cdot}8$. A few other intermediate values of K should also be found, and the scale of K tested against a true logarithmic scale to correct any inaccuracies which may have arisen in plotting the D lines.

Now, lay off the bottom horizontal scale of H.P., also logarithmic, and to the same scale as that of L, N, and S. $P = \frac{\text{H.P.}}{K}$, and points for various values can be found by calculation, and the lines for values of P drawn. It is advisable to sketch out a chart roughly at first, showing only extreme values of the various quantities, and from it determine how the final chart can be most conveniently arranged so as to cover the range of values required. The dotted line shows the course followed in calculating the H.P. from the chart, starting either from the revolutions per minute and the stroke, or directly from the piston speed. Such a chart is simply the graphical equivalent of a special compound slide-rule, although, of course, it is not so convenient. A compound slide-rule for horse power is on the market. The chart shown has been chosen simply to illustrate the method of laying out. A compound slide-rule made to order for a special purpose is, however, expensive, and this is where a useful field for the logarithmic chart is found. It is cheap, and does not take long to construct. Like the slide-rule, the chart shows very conveniently the effect of altering the values of any of the quantities to be dealt with, and, of course, it may be used as readily to calculate any one of the quantities as any other, provided the remaining ones are known. Thus, for a given piston speed and H.P., the pressures required for various sizes of cylinders can readily be seen, or *vice versa*. This convenience, it may be mentioned, is a feature of all these charts, whether logarithmic or not.

Objections to logarithmic charts lie in the necessity for dividing or plotting logarithmic scales, and also the increased difficulty of interpolating between the lines, owing to the non-uniformity of the divisions. Owing to this difficulty in interpolating, more lines must be drawn within a given range, and this leads to another defect, viz., the liability for the eye to become confused in following the course of a line, and end up upon the wrong line. The use of variously coloured inks obviates this defect to a certain extent.

The scales may be set off from a slide-rule, or preferably from a strip cut from a sheet of logarithmically ruled paper, which can now be readily bought, but the choice of scales to be had thus is limited, the paper being manufactured in only a few sizes; and for odd scales the plan followed by the Author is as follows:—Two different logarithmic scales are carefully marked off on two parallel lines at a suitable distance apart, the standard being either the common slide-rule, which gives two scales, one double the other, or the logarithmic paper which may also be had in two rulings. Corresponding points are then joined by a series of converging lines properly numbered, and finally the diagram so obtained cut into strips with edges parallel to the original scales. A complete set of scales is thus provided. Another method of setting off lines logarithmically spaced is as follows:—Find independently two extreme lines of the set required. Suppose these lines are for values 15 and 120 say, then lay a logarithmically ruled strip across the lines, and adjust it until the 15 and 120 on the scale lie on the corresponding lines. The other lines of the set can now be drawn as parallels through the various points on the scale. This method, however, is inaccurate if the inclination of the scale is much removed from being perpendicular to the lines.

The advantages of the logarithmic chart for multiplication, compared with that using natural scales as in Fig. 3, are:—

(1) The crowding of the lines at the corners is avoided.
(2) The lines, being parallel, are more readily drawn.
(3) The chart is more compact.
(4) In using the natural scale chart, points have to be determined by the intersection of lines which at some parts of the chart meet at a sharp angle, and hence inaccuracies arise. This is not the case in logarithmic charts, since the meeting lines all cut at 45 degrees or 90 degrees.

As well as these advantages, there is the very important advantage of dealing with powers and roots, which has been already mentioned.

Fig. 7 shows a chart of the same type as the preceding one for calculating the thickness of boiler shells from the Board of Trade rule. It is arranged so that the quantities which are not likely to be frequently varied, *i.e.*, S, the tensile strength of the plate; F, the factor of safety; and R, the percentage strength of joint, are all together at one side of the chart. Lines A B, B C, C D, may thus be permanently marked on the chart for the usual values of S, F, and R, and in most calculations the line C D serves to connect these quantities with the values of the pressure and diameter required.

Charts may often be considerably simplified by attention to such points as this in arrangement.

Fig. 8 shows another logarithmic chart for calculating the diameter of marine engine shafting from the Board of Trade rule

$$D = \sqrt[3]{\frac{\frac{1}{2} S P L^2}{3f}}.$$

In this case, since the power 2, and a cube root are involved in the calculation, the scale of D is three times, and that of L twice as open as the scales of the other quantities.

In all these charts the arrow-headed lines show the course followed in making a calculation. The foregoing charts have all been drawn upon squared paper giving two series of parallels at right angles which facilitate the use of the chart. Logarithmically-ruled paper is not, unfortunately, of much use for plotting charts (except for furnishing scales as already mentioned), because, as a rule, the various scales on the chart, when arranged to give the greatest convenience and compactness, do not have a common starting point, whereas, with the sheets of logarithmic paper this is the case.

Logarithmic paper may, however, be used with very satisfactory results for calculations dealing with two quantities connected by a law which involves fractional powers. For example, the law of expansion of gases is $PV^n = \text{constant}$. Here there are only two variables, viz., V and P, but the law $PV^n = \text{constant}$, is not adapted to simple arithmetical treatment since n is fractional, usually lying between 1·3 and 1·41.

Fig. 9 shows a diagram—it scarcely can be called a chart—by which such calculations can be very quickly performed. The vertical logarithmic scale is for values of P, increasing upwards, and the horizontal for values of V, increasing to the left. Let $P V^{1 \cdot 4} = \text{constant}$, then the line A B has a slope of 1·4 vertically to 1 horizontally, and passes through the point A corresponding to $P = 100$ and $V = 1$ (in any units). To use the chart, suppose P_1 is given $= 54$, and $V_1 = 2 \cdot 6$, $P_2 = 21$, and it is required to find V_2. The point C corresponds to $P = 54$ and $V = 2 \cdot 6$; the line C D drawn from C parallel to A B to meet the horizontal at $P = 21$ fixes the point D, and from the chart the volume at D is read as 5·1. The line C D need not be actually drawn. A strip of paper is laid with its edge along the horizontal at C, and the points C and E marked on it. This strip is then transferred to the lower line for $P=21$. The point E being adjusted to the line A B at E, the other one gives the point D. This operation can be performed very easily and rapidly. The numbers can be multiplied or divided by 10, or 100 for convenience if required, just as in using a slide-rule, although, if the range of values of P or V goes from hundreds to tens, or tens to units, care must be exercised if the chart covers only the range 1 to 10, or 10 to 100. The chart shown is drawn on paper having a range from 1 to 100, which will cover most actual cases. The same chart may have different lines drawn upon it, preferably in different colours, for different values of the index n. The device of marking points on the edge of a strip of paper in the manner just described, instead of drawing lines upon the chart, may be used also on the charts previously illustrated, and enables them to have fewer lines, which avoid the defects previously mentioned. But in charts dealing with several variables, this introduces other disadvantages.

It will be noticed that all the foregoing charts have only straight lines drawn upon them, which can therefore be very quickly plotted. There are cases in which charts having curved lines may be used with advantage, as, for example, that shown in Fig. 10, but the principle of graphical working must not be carried too far. Charts have been evolved bearing a multiplicity of intricate curving lines, but it is evident that if the preparation of the chart itself requires the working out of an excessive number of numerical calculations, no nett gain in time or labour will be realised.

In conclusion, the Author would emphatically state that he does not in any way wish to overestimate the usefulness of calculating charts, and that he is fully alive to their limitations; also, he makes no claim to have reached finality in the methods of constructing and using them, for, from the time he first gave them attention, and even during the writing of this paper, improvements have kept on suggesting themselves.

The examples shown have not been chosen with regard to any particular line of work, but simply to illustrate the method of designing and using the charts, the object of the paper being to put one in a position to design and lay out charts for his own particular purposes, and to draw attention to a matter which, while simple in principle and application, yet appears to be not so widely known and practised as it deserves to be.

SOME NOTES ON ELECTRIC DRIVING.

By Mr Theodore Parsons.

Read 3rd March, 1908.

In the course of my business, which is to generate and sell electric power, I have come across many people who are unaware of the immense advantages which electric driving has over other methods and who have an exaggerated idea of its cost. In what follows I purpose treating of some of the chief advantages of electric driving, illustrating them with examples from my own experience, and whilst most or all of the points will be well known to those who are accustomed to the installation and running of electric machinery, there will probably be much which is more or less new to those who are brought into daily contact with electric driving.

PART I.

The advantages of electric driving may be summarised under the following heads:—

(1) Maximum production with minimum labour charges.
(2) Wide range of speed without the use of gearing.
(3) Small floor space required.
(4) Reduction of shafting, etc., to a minimum.
(5) Low cost of installation, extension, and running.
(6) High efficiency.

Maximum Production with Minimum Labour Charges.

To the uninitiated this may sound a far-fetched claim, and at first sight it is certainly somewhat difficult to see why the output of a given tool or machine when electrically driven should be greater than when it is driven by any other means. The reason is, that owing to the steadiness of the drive a higher average speed can be maintained. This has been very clearly shown in the case of spinning machinery, and recently the output of certain mills was increased by 5 per cent., with fewer breakages and better products, with motor-driven spinning frames than was possible when the plant was driven by steam. A short time ago it was stated in "Electrics" that the average speed had been increased 15 per cent. by the introduction of an electric drive. An interesting pair of curves was given in the same article, showing the speed variation on an engine and on a counter-shaft driven from it, fourteen looms being driven from the counter-shaft. The speed variation of the engine was 3 per cent., and that of the counter-shaft 20 per cent., due to slipping of belts, etc., which, with an electric drive, would be done away with.

Mr. Williamson, in a paper read before the Institution of Electrical Engineers in 1903, stated that at the Barrow Works of Messrs Vickers, Sons, & Maxim, it was found that when the conversion to electric driving was made the production was increased by 50 per cent. with the same labour charges.

This increase in production is especially noticeable in shipyards and similar works. A few years ago I was called upon to alter some steam-driven punches, which ran at 26 strokes per minute without load, and fell to half that number when doing work. When the electric motor was fitted, the full 26 strokes per minute were maintained with a proportional increase in the output.

Some electrically-operated jennys designed by Messrs Jessop & Appleby were installed at Leicester for transporting goods to wagons, and the proprietors found that, while formerly this cost 8d. per ton, the electric jennys performed the same work at a cost of ¼d. per ton, with a further saving of 2d. per ton due to accelerated despatch of wagons, or a total saving of 9¾d. per ton.

It is a fact that the power charges per finished article are, as a rule, a small proportion only of the total cost of manufacture, the labour charges in most cases being a very much larger amount, so that it will obviously pay to increase the power charges a little if, by doing so, the labour charges can be reduced. The following rather extreme case is an instance of this. Certain work was done entirely by hand by a smith and helper at a cost of 1s. 3d. per article of labour. A special electrically-driven pneumatic hammer was installed, and the power charges were increased from nothing to ¼d. per article while the labour charges were reduced to 3d., a saving of 11¾d. per article. A steam hammer would not have done in this case as the work was far too intermittent. In my opinion, in 99 cases out of 100, an electrically-driven pneumatic hammer is far cheaper to operate than a steam hammer, up to 10 cwts. The cost of working pneumatic hammers is very small, as will be seen from the following figures obtained under actual working conditions:—

> A 5-cwt. hammer serving three fires took 35 units in 7½ hours. Three hammers of 5, 7, and 10 cwts. respectively, serving 15 fires between them, took an average of 30 units per hammer per day of 10 hours, the test lasting for ten days.
>
> A 3-cwt. hammer serving three fires took 1·37 units per hour.

Wide Range of Speed.

A wide speed variation is required in many operations, and although this can be obtained by use of gearing, by far the simplest way is by means of a variable speed motor.

With an interpole shunt wound motor a speed variation of even as high as 12 : 1 can be obtained with a shunt regulator, the motor working at high efficiency at all speeds. The number of different speeds will depend on the number of contacts on the shunt regulator, which can, of course, be made as numerous as required to meet any special case, so that instead of having a few speeds only, obtained by means of coned pulleys, a gradual change of at least 50 different speeds can be made by simply turning the handle of the rheostat. In the case of facing up a piece of work of large diameter in a lathe, the top cutting speed can be maintained from start to finish, which with an ordinary lathe would be impossible. I am aware that there are one or two mechanical change gears which enable the cutting speed to be altered without stopping the work, but they have not the same wide range and gradual increments of speed as the electric drive.

Wide ranges of speed are required in some special classes of work, such as newspaper, calico, and wall-paper printing. The machines at first require to be run dead slow for setting the type and pitching the colours, and with the old belt drive this was done by making the belt slip on the fast or loose pulleys, causing a loss of a great deal of time and breakages of paper due to the jerky motion obtained in this way. With the steady drive from a variable speed motor, coupled with series regulation, all this loss of time and material is done away with, and a higher running speed is maintained, with a consequent increase in the output. In one case which came under my notice about six years ago, the output of a paper printing works was increased by 50 per cent. with the same labour charges, due to the change from steam to electric driving, the average speed with the electric drive being higher and the stoppages due to broken paper fewer.

Small Floor Space Required.

Floor space, especially in towns of any size, is valuable, and for a given power there is no other method of driving which takes up so little space. A motor can generally be put into a corner, or it can be fixed to the wall, ceiling, or on the machine to be driven.

The floor space required for motors varies from 1·3 square feet per H.P. for very small powers, to 18 square feet per H.P.

for larger motors, including sliding bedplates in both cases. The space occupied by steam or gas engines is very much more than this, and, in addition, steam engines require boilers, and gas engines, unless run by town gas, require producer plant, which also takes up a considerable amount of room.

REDUCTION OF SHAFTING, &c., TO A MINIMUM.

The losses in driving shafting and belts is very great, and if it were possible to sum up these losses all over the kingdom, it would probably be found that at least half the power generated was wasted in shafting and belts. In a series of tests carried out in this country and abroad, it was found that the average loss in shafting and belts, in 163 different works, amounted to 54 per cent. of the power generated.

The following instances are taken from tests carried out by myself during the last few years:—

The power taken to drive all the machinery in one engineer's shop was 60 H.P. The power taken to drive the shafting and belting alone, with all the machines on the loose pulleys, was 30 H.P.

In another shop 140 feet of 2½-inch shafting, running at 135 revolutions per minute, took from 11·9 to 13·1 H.P.

In another, 150 feet of shafting, ranging from 3¼ inches to 2 inches in diameter, running at 160 revolutions per minute, took 7·15 H.P., and with the machines working from 13·1 to 16 H.P.

Some tests on rope drives gave the following results:—

a. A cross drive of 40 feet with the rope running light took 4·9 H.P.

b. Crane rope for a shop 150 feet long took 10 H.P.

c. Crane rope for a shop 150 feet long took from 5·9 to 7·7 H.P.

In a small factory the power taken to drive the shafting was from 2·37 to 2·97 H.P., and the power actually used to drive the machines was from 1·19 to 2·39 H.P.

These losses can be almost entirely done away with if electric driving is employed and in some cases, as with cranes, for instance, can be got rid of altogether.

The powers absorbed by the shafting in the above tests appear to me to be fairly representative of what is commonly found when tests are made, as sufficient attention is not, as a rule, given to either the erection or maintenance of shafting. With a steam or gas drive these losses go on every day unsuspected, but with a motor drive they can be detected at once. It is only necessary to put an ammeter in the motor circuit and take the readings when the machines are working and again when they are running light.

In one shop which was fitted with motors, I found a length of 2½-inch shafting in which the bearings were in a very bad state, in fact, at several the diameter of the shafting had been reduced to 2⅛ inches. If shafting is allowed to get into such a state, it is easy to account for a good deal of loss. In this particular case, however, in spite of the fact that all the shafting and bearings were about as bad as they could be, it was found cheaper to run with motors than with a steam engine.

Shafting, if properly installed and looked after, need not, of course, take so much power, as the following records of better tests will show:—

d. 150 feet of 3-inch shafting, running at 150 revolutions per minute, took 3·5 H.P., which compares very favourably with the same length running at 160 revolutions per minute, which took 10·7 H.P.

e. 123 feet of 2-inch shafting, running at 130 revolutions per minute took 2·8 H.P.

f. 130 feet of from 3-inch to 2-inch shafting running at 180 revolutions per minute took 3·6 H.P.

Low Cost.

If current is taken from an outside supply, which, in the majority of cases, is the cheapest thing to do, the first cost of installation is considerably cheaper for electric driving than for steam or gas. The cost per H.P. of motors varies with the speed and output, but the cost per H.P. for high-class motors, rails, and starting gear, can be taken as varying from £5 to £1·8 per H.P. for high-speed motors between 2 and 100 H.P., and from £7 to £2·06 per H.P. for slow-speed motors.

Practically no foundations are required in ordinary cases except for large H.P. motors, no special buildings are required, and the cost of erection is very much less than with steam or gas engines, while the cost of a great deal of shafting and gearing can generally be dispensed with. Extensions to existing works can obviously be carried out at a lower first cost, as the motor can be taken to the exact place where the power is required.

More economical arrangements can often be made with electric driving than is possible by other methods. Not long ago I was consulted regarding the fitting of a motor to a blower to supply the blast to five fires. Instead of the blower, which took 12 H.P. to drive it, I recommended instead small fans driven with direct connected motors for each fire. This was carried out, and it was found that the current amounted to 7 units per week per fan, with the smiths working full time, whereas, had the old arrangement been kept, it would have taken about 500 units per week, or 71 per fire, which, at 1d. per unit, would amount to 5s. 10d. per week per fire, in place of 7d.

The following Table giving the cost of running individual machines, and of workshops in various trades, may be of interest, the price in all cases being taken at 1d. per unit:—

TABLE I.

Cost of Working Hoists and Cranes.

Number Installed.	Works Installed at.	Capacity.	H.P. of Motors.	Units in One Year.	£	s.	d.	Remarks.
2	Bakers	25 cwts. & 3 cwts.	11·5 & 5	2,016	8	8	0	Hoists.
1	Iron warehouse	10 ,,	5	244	1	0	4	,, lift at 90 feet per min.
1	Shaft	...	25	2,544	10	12	0	Contractor's hoist.
3	Boiler shop	...	...	560	2	6	8	Jib cranes in smithy.
1	Foundry	5 tons	18·75	2,790	11	12	6	Travelling crane, 3 motors.
2	Engineers	20 and 30 tons	...	4,720	19	13	4	,, ,, ,,
3	Boilermakers	...	101	19,142	79	15	2	Travellers, very long shop.
1	Engineers	15 tons	26	3,164	13	3	8	Travelling crane, 3 motors.
2	,,	30 ,,	27	7,508	31	5	8	,, ,, ,,
2	,,	10 and 15 tons	10 & 4·5	322	1	6	10	Jib and yard traveller.
1	Smithy	6 tons	...	137	0	11	5	... ...

TABLE II.

Cost of Working Sundry Individual Machines.

Machine.	H.P.	Period.	Units.	£	s.	d.	Remarks.
Punch and shear	17	1 week	80	0	6	8	27 strokes per min., punches 1½ in. × 1½ in., shears 1½ × 5 in.
Shipyard winch	7	1 „	83	0	8	11	
Side planer	35	92 hours	578	2	8	2	Speed 30 ft. per minute.
Hydraulic pumps	120	1 week	1354	5	12	10	Auto starting and stopping. In 66 working hours pump actually ran 37. Pump 3 rams 3 in. × 12 in. stroke, 65 R.P.M., 1500 lbs. per square inch.
Hydraulic pumps	35	1 „	656	2	14	8	Auto starter, 3 rams 3 in. × 6 in., 56 R.P.M., 1900 lbs. per square inch. In 10 working hours ran 4 hours, operated 83 times, and took 118 B.Th.U.
Radial drills	10	66 hours	178	0	14	10	2 drills driven by bevel and spur gear, drilling ½ in. to 6 in. holes.
Boiler shell drills	30	56 hours	246	1	0	6	4 heads drilling ½ in. to 2 in. holes.
Screwing machine	7·5	56 „	58	0	4	10	Screws up to 3½ in., actually running 41 hours.
Grindstone	2	56 „	22	0	1	10	6 in. diameter 70 R.P.M., actually running 47 hours.
Crane	...	56 „	67	0	5	7	Builder's crane.
Fans	...	8 days	21	0	1	9	3 forge fans.
Saw	8	12 months	800	8	0	0	Portable circular saw.
Grate	1	12 „	1497	6	4	9	Grate annealing furnace.
Pug mill	8·75	12 „	4750	19	15	10	£2·27 per H.P. per annum.
Mortar mill	10	12 „	5928	44	14	0	£2·46 „ „
Ventilating fan	15	12 „	5616	23	8	0	£1·56 „ „

A motor-driven mortar mill is rather a good illustration of the increased output to be obtained by electric driving. With a steam-driven mill the man in attendance has to be continually altering the steam supply, or the machine either crawls or races, and the average speed is very much lower than that of a motor-driven one. In one mill that was altered, when steam driven one man attended to it and one cart took the mortar away; but after the motor was fitted, the proprietor put a boy on to help to keep the pan full and two carts to take away the finished material.

A short time ago I was told that electrically operated capstans for hauling railway wagons at a siding would cost double what hydraulic or gas-engine driven capstans would do. For such intermittent work the statement seemed to me absurd, and I took a careful note of the power used in handling coal at the electricity works, Govan. The average length of pull is 300 feet, with a gradient of 1 in 100, and a sharp curve of 90-feet radius. The coal is brought in, tipped, conveyed to the bunkers, and the empty wagons returned by electric power. The height the conveyer has to lift is 45 feet, and it carries the coal a distance of 66 feet. In a week, 164·2 tons of coal, in wagons weighing 117·1 tons, were brought in.

The units used for hauling and tipping were 12·4
,, ,, by conveyer ,, 22·2

a total of 34·6 units, which is equal to ·211 units per ton of coal.

The men's time during the week amounted to:—

9¼ hours	@ 6½d.	-	60·125d.
12½ ,,	@ 5d.	-	62·5d.
Total,		- - -	122·625d.,

or ·747d. per ton of coal handled, so that taking the price per unit at 1d., the total cost of handling the coal amounted to ·96d. per ton, of which the power cost was only ·211d. The amount for hauling, tipping, and returning the wagons only

TABLE III.
Running Costs taken of One Year's Work from Various Trades.

Trade.	Units.	Cost.	H.P. connected.	Cost per H.P. per annum.	Remarks.
Engineers ...	54,103	£225·5	42	£5 35	
,, ...	39,018	162·5	65	2·5	
,, ...	81,109	337	72	4·7	
,, ...	9,182	38·3	18	2·12	
,, ...	11,400	47·5	10	4·75	
,, ...	22,000	92	25	3 66	
,, ...	40,854	170	116·5	1·46	
,, ...	14,627	61	32	1·9	
,, ...	56 206	234	120	1·95	
,, ...	33,944	141	103	1·37	
,, ...	37,196	155	137	1·13	Constructional iron work.
Shipbuilders...	26,817	111·8	88	1·33	
,,	11,130	46·5	101	·217	Repairs only.
,,	19,102	80	115	·7	,, ,,
Boilermakers	204,035	850	1018	·79	
,,	19,753	82	101	·81	
Chainmakers	42,252	176	47	3 73	
Brassfinishers	54,300	226	53	4·26	
Foundry ...	25,540	106	63	1·68	Jib crane and welding machine.
Ropemakers	223,965	972	245	3·95	
Patternmakers	6,786	28·1	7	4·	
,,	3,200	13·3	14·5	·92	
Joiner ...	374	1·56	4	·39	
Cooper ...	1,092	4·56	5	3·91	
Timber sawyer	38,000	158	80	1·98	
,, ,,	2,348	9 8	5·5	1·78	
,, ,,	1,916	8	7·5	1·06	
,, ,,	2,280	9·5	5 5	1·73	
,, ,,	1,786	7·45	5·5	1·35	
Bakers ...	12,160	50·6	22·5	2·25	
,, ...	13,556	56·5	16	3·5	
,, ...	13,462	56·1	20	2.8	
Wire weaving	32,842	137	19·5	7·04	Driving 16 looms.
,, drawing	43,966	183	41	4·46	
Printers ...	14,964	62·5	30·5	2·04	
,, ...	17,358	72·5	27	2·68	

was ·0755 units per ton, giving, at 1d. per unit, ·0755d. per ton, which appears to be a reasonably low figure. The total cost per ton would have been much less if larger wagons had been employed.

High Efficiency.

The very high efficiency of electric motors is a great point in their favour. The full load efficiency varies from 80 per cent. for small motors to 95 per cent. for large ones, and taking a moderate-sized motor with a full load efficiency of 90 per cent., the half-load efficiency would be about 86·5 per cent. and quarter-load efficiency about 74 per cent., from which it will be seen that the drop in efficiency at light loads is small; and it must be remembered that in electric driving practically all the loss is in the motor, while in the case of steam engines the losses are both larger and more numerous.

Where energy is taken from a public supply authority, the consumer has a ready means of checking the efficiency of his works in his accounts for current, and if these go up without due cause in the shape of extra work, he should look around his shop first of all to see where current is being wasted. He may take it that in 99 cases out of 100, the meter is reading accurately, and the fault lies in his own machinery.

Some tests which I carried out recently, on the efficiency of steam and electric feed pumps, may be of interest. The tests with the steam pump could not be made over very long periods, owing to the difficulty in measuring the condensed water. The pump was one of Weir's usual pattern, and the exhaust was taken to a coil of 2-inch piping immersed in the feed tank, from which the outlet discharged into a barrel and the water was afterwards weighed. The water pumped into the boiler was measured with a Schmid water meter. Two tests were made with the steam pump each lasting about 1½ hours, and the results showed that in the first test 1·6 per cent. of the steam evaporated was used on the pump, and in the second 1·3 per cent. Tests were then made with two electric pumps, one of which was too large and had to be run on a series resistance, while the other ran at full load to keep up the water level. In the first case the motor took 1·13 per cent. of the units generated and in the second ·642 per cent.

A Weir pump is about as economical a steam pump as it is possible to get, but even this does not come up to the first test of the electric pump run under very favourable conditions, and it ought really to be compared with the second test which was the ordinary working conditions of the electric pump. As many steam pumps take about three times the amount of steam that a Weir pump does, it is obvious that electric pumping is more efficient than steam.

The following interesting figures of the efficiency of a motor-driven turbine pump are from tests made by Messrs. Harland, Bowden & Co. In this case the pump was guaranteed to throw 400 gallons per minute against a 653-feet head, through 500 yards of pipes, a total calculated head, including friction, of 665 feet:—

TABLE IV.

R.P.M.	Gals. per Minute.	Total Head.	B.H.P.	Efficiency. Motor.	Efficiency. Pump.	Combined
1035	390	661	110	88·5	71·2	63
1050	400	653	127	88·5	62·6	55·25
1045	380	663	127	88·5	68·9	60·5
1040	410	638·9	123	88·5	64·6	51·1
1040	423	643·9	117·3	88·5	70·5	62·5
1065	410	670·9	126	88·5	66·5	58·5
1045	385	663·9	112·5	88·5	68·5	60·9

There is a very great drop in efficiency if there are any air leaks on the suction side. On one occasion with this pump there was a small air leakage, and the delivery dropped to 210 gallons per minute, the H.P. falling only to 99. The maximum efficiency usually obtained with this type of pump is about 72 per cent., about the same as a three-throw ram pump driven through cut gear.

PART II.

Success in motor driving generally depends on the type of motor employed. For work where a constant speed is required, and where there are no sudden heavy demands for power, a shunt wound motor should be used, where sudden heavy demands are made a compound motor, and for intermittent heavy work, such as that done by cranes, rolls, etc., a series motor.

Some still advocate the use of shunt motors on such tools as punches and shears, but the right motor is undoubtedly a compound one. Such machines are always provided with heavy fly-wheels. A shunt wound motor runs at a constant speed, and if applied to a machine of this order it endeavours to do all the work and to keep the fly-wheel up to speed, thus preventing it from doing what it was specially intended to do; the result is that unless the motor is very much too large for the job, there is trouble with sparking at the commutator and rapid deterioration of the motor. With a compound motor, when the heavy load comes on, the motor tends to slow down to the extent of the compounding, and allows the fly-wheel to do its work, and at the end of each stroke speeds the fly-wheel up again, restoring the energy expended in the previous stroke. The same thing applies to circular saws, planers and wood-working machinery generally, which should all be driven by compound motors.

Plate rolls, except in the case of very light ones, should be driven by series motors with reversible tramway type controllers, and as the operator always holds the handle of the controller whilst the machine is at work, there should be no fear of the motor getting too high a speed whilst running light. It must be remembered that a series motor, when full working voltage is applied with no load put on, will speed up until the armature bursts. To guard against such a possibility, and also to facilitate the working of the rolls, the motor should be provided with a magnetic brake.

Travelling cranes, if in constant use, are best driven by series motors, one for each motion, and each having a tramway type controller; but if the crane is only used occasionally, a much cheaper and a quite satisfactory job can be made with one compound motor, the various motions being worked by friction clutches.

Jib cranes should be driven with compound motors provided with magnetic brakes.

Hydraulic pumps should be driven with heavily compounded motors with automatic starting gear. To use a belt shifting device so that the motor is always running is not a satisfactory job, and is wasteful of power. As an example, take the case of one of the hydraulic pumps mentioned in Table II. If this pump had been worked with a belt shifting device, it would always have been consuming power when running light, taking quite four units an hour. Accepting the proportion of actual pumping hours to the shop's working hours as 2 to 5, which from observation made was the case on two busy days, and taking 2700 as being the working hours per annum, then for 1620 hours the motor is running the gearing only, and at 4 units per hour this is equal to 6480 units, or £27 per annum at 1d. per unit.

There are several automatic starting and stopping gears on the market, all of which are primarily actuated by a float switch worked from tappets on the accumulator which switches on and off the supply of current to the starter proper. Most of the starters are worked by dashpot controlled solenoids for cutting out the resistance gradually. An exception to this type is the capstan starter, made by Messrs Brook, Hirst & Co., which is moved by a cord from a small pulley on an extension of the armature shaft of the motor. In action the float switch closes the circuit of the solenoid D.P. switch and causes the main current to be switched on, and as the first step of the starter is alive the motor at once starts up, and as it revolves it slowly winds the starter by means of a worm and sector until all the resistance is cut out. When the starter is full on, the sector, being no longer able to move, forces the worm out of gear and causes the armature at the end of the driving spindle to fall away from the retaining magnet. As a lamp resistance is automatically cut into circuit with this magnet after it has first pulled up its armature, it has not now sufficient power to lift the armature again, and the worm spindle being provided with a universal joint, it simply revolves clear of the sector. This starter works well, but it has this objection, that the time taken to cut out the resistance depends on the load on the motor. If this is heavy it may take too long to bring the motor up to speed and so will heat up the resistance unduly.

Another interesting example of automatic starting gear is the ratchet type made by Messrs Bertram, Thomas & Co., Manchester. In this type the current is switched on to the starter proper in the same way as already described. The starter itself consists of a series of resistance contacts, arranged in a vertical line, which are cut out of circuit by a solenoid plunger. The plunger works a ratchet and the process is carried out by a series of lifts. To effect the alternating motion required for this, the lift of the plunger itself breaks the circuit of the solenoid, so that, as soon as a complete lift is made, the solenoid is de-energised and the plunger falls ready for the lift to the next contact, the re-closing of the solenoid circuit being retarded by a small dashpot to prevent it working too quickly. In addition to the lifting pawl on the plunger, there is a retaining pawl which holds the contact plate in the position to which each successive lift brings it, and when the last lift has been made, the contact plate is held there stationary, because a small insulated rod is lifted on the last point and intercepting the switch of the electromagnet prevents it from closing again.

The no-volt release is another small solenoid, and where the current is switched off, the plunger in this solenoid falls, striking out the retaining pawl and allowing the toothed plate and contact rubber to fall to the bottom ready for the next start. This starter is applied very successfully both to hydraulic pumps and air compressors.

REVERSING GEAR FOR PLANERS, &c.

An interesting gear for this purpose has been put on the market by the Lancashire Dynamo & Motor Co., and one of the first was fitted to a planer in the Govan district. The motor drives direct through gearing without using any belts, and the reversal is made by reversing the direction of rotation of the armature. Within predetermined limits any desired speed can be obtained on either cutting or return stroke. The starting and reversing gear consists of a D.P. switch, solenoid starter and resistance, shunt resistance, reversing gear, reversing switch, reversing rod, magnetic brake and brake resistance. The reversing rod which actuates the reversing gear is moved by the planer table in the usual way by stops on the table. If the rod is moved so as to throw the reversing switch into the forward position, the solenoid starter draws up its core which first cuts out the resistance in the armature circuit, then the series coils, and then throws in the resistance in the shunt circuit and speeds up the motor. At the end of the stroke the reversing switch is moved into the "off" position, where it remains for a fraction of a second whilst the magnetic brake tends to draw up the motor, and at the same time the armature is short-circuited through a resistance to help to bring the machine sharply to rest. The momentum of the table carries the reversing switch over and the motor starts up in the reverse direction.

Any speed between maximum and minimum, for which the motor is designed, can be obtained either on the cutting or return stroke entirely independently of each other. The usual speed limits are 3:1 variation, so that, taking a minimum cutting speed of 40 feet per minute, it is possible to have a speed of from 40 to 120 feet per minute, and a return of the same speed. The planer can be started, stopped, or reversed by simply pulling the reversing rod, so that the workman has nothing to do with the electrical equipment of the machine.

In conclusion, there is one point I would like to impress upon everyone, and that is, do not buy cheap motors and, above all, do not buy cheap starting gear. My experience of electric driving has been that the greatest trouble is caused by cheap and flimsy starting gear. Acquire only the best and it will be by far the cheapest in the long run.

THE "JAMES WATT" ANNIVERSARY DINNER.

THE "James Watt" Anniversary Dinner was held on Friday evening, 17th January, 1908, in the Grosvenor Restaurant, Gordon Street, Glasgow. There was a large and representative gathering, the company numbering upwards of 400 gentlemen. Mr John Ward, President of the Institution, was in the chair, and the croupiers were Mr William Brown, Mr Alexander Cleghorn, Mr Andrew Laing, and Mr William Melville. At the Chairman's table were—The Most Hon. The Marquis of Ailsa; The Right Hon. Lord Inverclyde; Col. Sir John E. Bingham, Bart., V.D.; Sir John Ure Primrose, Bart., LL.D.; Sir William Arrol, LL.D., D.L.; Sir George T. Beatson, K.C.B., B.A., M.D., V.D.; Sir Nathaniel Dunlop, LL.D.; Sir James Fleming; Rear-Admiral Charles R. Arbuthnot, R.N.; Rear-Admiral John E. Bearcroft, R.N., C.B., M.V.O.; Major Henry Barnes, R.F.A.; Mr Alex. Findlay, M.P.; Principal Donald MacAlister, M.D., M.A., B.Sc., LL.D.; Deacon-Convener A. McDonald; Mr Peter Denny; Mr James Gilchrist; Mr W. H. Dugdale, President, North-East Coast Institution of Engineers and Shipbuilders; Mr C. P. Hogg; Mr John J. McMurdo; Prof. F. G. Baily, M.A., President, Institution of Electrical Engineers (Glasgow Section); Prof. Archibald Barr, D.Sc.; Prof. John W. Gregory, D.Sc., F.R.S.; Mr W. M. Alston, President, Glasgow Association of Students, Institution of Civil Engineers; Mr T. B. Rogerson, President, West of Scotland Iron and Steel Institute; Mr James Weir; Mr Thomas Kennedy; Lieut. F. J. Meyrick, R.N.; Mr L. MacBrayne; Mr J. Kirkwood; Eng.-Com. J. H. Jenkin, R.N.; Mr A. D. Wedgwood; Mr James Nicol, City Chamberlain; Mr James McKechnie; Col. William Shanks; Mr Joseph Barrow; Mr C. C. Scott; Mr Robert Lang; Mr W. W. May; Mr T. J. Dodd; Mr Henry Mechan; Mr P. N. Cunningham, and Mr. H. F. Stockdale.

The loyal toasts having been duly honoured,

Lord INVERCLYDE proposed "The Imperial Forces," remarking that the present policy of the Admiralty in giving out orders for war vessels, only when these could not be built in the dockyards, was not one that met with acceptance in this part of the world. Those shipbuilders who at great expense had laid down plant so as to be ready to meet the requirements of the Government, had some ground of complaint now that orders were not being given to them. One of the assets of the country was the private yards, with their modern, up-to-date equipment, and he thought those in charge of these establishments were entitled to expect orders. He had heard that firms buying obsolete warships were willing to give higher prices for ships built in private yards than for those built in dockyards. Possibly the supervision was more strict in private yards, and the inspectors saw that the Government got full value for its money. They heard a great deal about the Navy being on a war footing at all times. Of course, that was a most excellent thing, but there was no doubt that, in a country like Britain, the Navy had very important duties in peace time. It was very important that the British flag should be in evidence in all parts of the world. The reply probably was that in time of war it would be a weakness to have men-of-war that were not quite up-to-date in the far-off parts of the world. But it was believed that where the British flag was, there would British trade be found. Britain should have a sufficient and an efficient Navy. As to the Army, it was in the melting-pot at present, and everyone hoped that it would come out a very good mould. He believed the new scheme was a good scheme, but he had noticed that very little was said about cost, and he was very much afraid that when the cost was realised there would be a hitch, and possibly it might not be carried through. But if it could be adopted for the money set aside for it, they wished it all success.

Rear-Admiral Arbuthnot and Major Henry Barnes replied.

Rear-Admiral Arbuthnot.

Rear-Admiral ARBUTHNOT said that it might be suggested to the Admiralty that one of the new battleships to be built on the Clyde might be called " James Watt," as one of the battleships existing in the service when he joined it bore that name. The Navy was splendidly organised, but he thought that efficiency had been sacrificed to organisation, and that it was not now so fitted as it should be to perform its duties in all parts of the world. The organisation of its battle squadrons in home waters had been accompanied by a wholesale reduction of the number of small craft in distant parts of the world. The fleets in home waters were, however, capable of dealing with any combination that might be brought against them.

Mr EDWARD H. PARKER, the Secretary, at this stage read a cablegram from Mr R. L. Gaine, Tokio, Japan, conveying greetings from the company at the " James Watt " dinner held by the Steam Users of Japan, and the reply to the same. The following is the text of the cablegrams which passed between Tokio and Glasgow:—

" The Steam Users in Japan, and others representing many different nations, gathered together in Tokio — in the Island Empire of the East—to do honour to the memory of the great James Watt on the 171st anniversary of his natal day, send to our comrades, assembled for a like happy purpose, in the land of his birth—the Island Empire of the West—our heartiest greetings and expressions of goodwill, coupled with a sincere wish that for all time, as on the present occasion, national distinction may be set aside in the interests of science and the advancement of knowledge."

" The Members of the Institution of Engineers and Shipbuilders in Scotland, assembled to honour the memory of James Watt, send hearty congratulations to their confreres in Tokio — who, prompted by the same spirit, are at this time met for the same purpose—and hope that between the engineers and shipbuilders of Japan, and the engineers and shipbuilders of Scotland, the hinges of friendship may never rust, and that mutual respect and support may bind them together in one common cause—the welfare of humanity."

Subsequently, on the call of the CHAIRMAN, the company pledged in silence "The Immortal Memory of James Watt."

Sir JOHN BINGHAM proposed "The City of Glasgow," which was acknowledged by Deacon-Convener MACDONALD.

Mr PETER DENNY, in proposing "Kindred Institutions," said—It was with a feeling of modesty that he approached the duty placed upon him, for he held that nothing, not even the toast of the Society under whose care this memorial dinner was continued, was more important than that of the numerous kindred associations which the engineering and social ability of this old country of theirs had built up in every part of the kingdom. Around them that evening they saw representatives of many societies covering all branches of the engineering profession. The civil engineer spanning the mighty ocean or bridging the deep ravine, burrowing under the dangerous river bed, or crossing the equally treacherous morass. The electrical engineer joining the countries of the world by submarine cable, or tossing messages from land to land and from ship to ship with no other medium than the surrounding ether. Every branch of electrical engineering, covering endless applications of this mighty force, ranging from the criminal seat in the lethal chair to the removal of the most ghastly form of disease by the beneficent rays of curative light. Triumphs on sea of the latest additions to the great Cunard fleet gave marine engineers every right to be present that evening, and they had also to remember the Society which numbered so many marine engineers in its association which was resident in London. That Society was composed of men in the daily use and practice of marine engineering, and, therefore, specially qualified to pass opinion and criticism on the many practical questions constantly arising. Also the Engineering Student Associations of Universities, composed of young men eager and anxious by constant application and study to fit themselves

Mr Peter Denny.

to take their place in one of the great companies he had named. All these were present, and he asked them to honour the toast in the most special manner. They had been called there that night, and had had laid before them, through the eloquent medium of the Chairman, the position of their Society. They had called over the list of their dead, one especially, summoned to his last home covered with every honour and glory which could fall to the lot of mortal man, and others young as regards years, but eminent as regards professional ability, and destined to great things had such been permitted by the all-powerful decree from above. They had also before them their present roll of members, always increasing, and full of zeal for the great profession they had chosen. Truly "we have mourned unto you, will you not lament?" "We have piped unto you, will you not dance?" No further words of his could in any way increase the value of that most important toast, except that he had to couple it with the name of Mr Dugdale, President of the North-East Coast Institution of Engineers and Shipbuilders. No one was more fitted by his great experience and the universal respect in which he was held to reply, and in coupling it with his name he asked them to drink, upstanding, with the utmost enthusiasm, the toast which he had the honour to lay before them.

Mr W. H. DUGDALE, President, North-East Coast Institution of Engineers and Shipbuilders, in reply, cordially thanked the gentlemen present for the manner in which the toast had been received, and said it was a very great pleasure for him to be there that evening to support the Chairman. He felt very strongly that Kindred Institutions should support one another, because they were not only of national, but international, importance, and he sometimes thought that this was not sufficiently realised, although he felt sure it would be if those interested, only for a moment, thought of the work which had been done by scientific institutions and the disabilities under which engineering and applied science existed before the advent of such institutions. Mechanical appliances were in use centuries before the Christian era, but it was somewhat difficult to know to what extent they were based upon scientific principles, although their existence was proved by various results which were common knowledge. To take but one well-known example, namely, the obelisk which was incorrectly described as Cleopatra's Needle and which now stood upon the Thames Embankment. That block of red syenite, 68½ feet long and 186 tons in weight, could not have been extracted from a quarry by someone standing and whistling for it, nor yet was it transported from Heliopolis to Alexandria and there put on end without mechanical assistance. Engineering might be considered as one of the learned professions from about 400 B.C., when Archytas, the reputed inventor of the screw, and who died about 394 B.C., and Eudoxus, who died about 352 B.C., both of whom were geometricians and philosophers, turned their attention to mechanics and applied science. Archimedes, also one of the most learned geometricians of the day, and who died about 212 B.C., was induced by his relative, King Hiero of Syracuse, to apply his knowledge in rendering mechanical assistance during the siege of that city. Steam, too, was experimented upon by Hero, the son of a Greek who lived in Alexandria about 140 B.C., but owing to various causes which would take too long to describe, very little attention was paid to it until towards the end of the 16th century. Branca, an Italian architect and engineer, designed a practical application of steam as a motive power for a stamping machine in 1629. The first Englishman who devoted himself with any degree of enthusiasm to mechanical arts was the Marquis of Worcester, who died in 1667, but owing to various disabilities, such as court patronage, or opposition, priestly interference, the limited facilities for acquiring and diffusing knowledge, the art of printing being practically confined to London, and circulating libraries and scientific institutions being unknown, there was no real progress made in engineering until the in-

Mr W. H. Dugdale.

ception of the Royal Society, which was organised in 1660 and incorporated in 1661. He thought that real industrial progress in this country dated from this period, and acquired an additional impetus and encouragement by the Society of Arts, which was founded in 1754, and the stimulus which was given to industrial progress by these two Societies had been maintained and further developed by the Royal Institution, the Institution of Civil Engineers, Naval Architects, Mechanical Engineers, etc. These institutions were still doing most important work, and they were the media for diffusing knowledge and enabling students to discuss questions which had not yet arrived at the text-book stage. The Standardisation Committee owed its formation to scientific institutions. This Institution, together with other enginering institutions in the country, had also representatives upon the Technical Committee to Lloyd's and the Board of Trade, and were doing most useful work. A great deal, however, still remained to be done. Britain was at one time the engineering workshop of the universe, and had been the training school for foreign engineers, and now everyone had to realise that foreign competition was no transitory phenomenon, but must be recognised and coped with, and it was the scientific institutions of this country which had to assist in maintaining our industrial prestige. It was said by some that this country had lost ground and must reform its fiscal arrangements, but even the question of tariff reform was a statistical and economic question, and a question for scientific institutions to discuss, rather than a question of party politics.

Sir John Ure Primrose, Bart., proposed "The Institution of Engineers and Shipbuilders in Scotland," remarking that the shipbuilding and engineering industries constituted the backbone of the commercial prosperity in Glasgow. He felt that the present cloud of depression would not be of long duration. There were already indications that a period of further advance lay before them. One thing that would bring this advance earlier would be the reasonableness of labour. There could be an unreasonableness of labour that might defeat its own impulses and aspirations, and defeat the schemes of those who sought the increasing prosperity of the community. There should be a community of thought and aspiration between the captains of industry and those who formed the indispensable adjunct of their capital, the just consideration of whose claims would be an element in the further progress of the industry.

Mr JOHN WARD, President of the Institution, in reply, said that it was natural that this toast should be received with great cordiality, inasmuch as it was the celebration of another anniversary in the history of the Institution, which had as its patron saint, James Watt. In some degree the sentiment of Longfellow's "Village Blacksmith" was theirs, in having "something attempted, something done" during the year, not so much to earn each night's repose, as in proving themselves responsible factors in the world's work. This world was the one for work; the other, doubtless, the one for rest; and so they strove as individuals, and as an Institution, to plant their professional banner high on the ramparts of industrial and scientific progress, and to keep the Clyde and this country in the forefront of engineering and naval and mercantile advancement. Last year the Institution celebrated its Jubilee, and Sir John Ure Primrose, in his eloquent proposing of this toast, referred to some of the work and progress in which, during that period, they had taken part. In the name of the Institution, he desired to thank Sir John for his remarks. Since its inception, the growth of the Institution had been steady and continuous. In the first session, 1858, the total number of Members, Associates and Graduates, was 127; at the close of the tenth session, 386; at the close of the twentieth session, 478; at the close of the thirtieth session, 636; and at the close of the fortieth session, 887. At the present time the total roll strength was 1,620. Such industrial sciences as they represented were not exclusive delights, the benefits of which were

Mr John Ward.

for themselves alone. Indeed, one of the most impressive characteristics of human thought, as it had moved along practical lines during the last century, had been its concern about the advance of good already gained, and the elimination of all that hindered legitimate development. Their aim was to encourage that spirit. They were not theorists, content only to spin webs for their own entertainment. They had a very vital stake in the national and the international well-being. The centenary of steam navigation coincided with the opening of their present session, and his Presidential Address was chiefly devoted to the progress made in engineering and shipbuilding during that period. Two facts strongly appealed to him in his researches, as they would to everyone who made a thoughtful survey of the applied sciences during the last 100 years. The first was the complacency with which people now received news of any invention or discovery that was likely to effect a revolution in man's way of doing things. There was a time when every improvement in the commonest piece of mechanism would have been hailed with exuberant gladness, or chilling terror; interest of some sort was evoked, and excitement was created, and people talked for days of the wonder. That spirit had in large part vanished, or was found only among those immediately concerned in the matter. It was different to-day. The most startling discoveries were accepted as things occurring in the natural course of events. The second was the unfettered freedom with which the worker in science was permitted to carry on his labours. It was difficult for them to realise that in the early days the atmosphere amid which scientific experiments were carried on was very different. There was suspicion, fear, dislike, and opposition, often of the bitterest kind. That condition of things had happily passed away. Investigation was not suspected, and one could hardly imagine a return to such a state of things, *e.g.*, as existed in this country in 1847, when the late Sir James Simpson advocated the use of anæsthetics in surgical operations, and how his action was hailed with a storm of opposition and abuse. There was now more charity, tolerance, and willingness to believe that what was being attempted and achieved was for the permanent happiness and rightful progress of mankind. It was in that spirit and belief that the existence of the Institution was justified, and its being honoured in having on the roll of Hon. Members some whose intellectual attainments had added lustre and fame to the Institution, this country, and the world. Their oldest and most distinguished Hon. Member, the late Lord Kelvin, who joined in 1859, might truthfully be said to have spent his long and honoured life in the service of his fellows. He lived that he might place the fruits of science on every man's table. He (Mr Ward) could not pretend to estimate his work in the domain of pure science. It was possible for every one to understand and feel something of his greatness, but only those who worked with him in the same province could have any adequate idea of what he was in personal charm of character and intellectual achievements. His love of scientific learning was a passion, and his idea of knowledge was that it might be applicable to human affairs. The strange play of forces in nature and the possibilities of matter were his daily vision. Other scientific men had had the practical eye, but Lord Kelvin's renown lay in this, that while he "could move on the heights with the best of them, he had a shrewd eye for the needs of our common life." He could descend from the misty regions of the atomic theory to invent an improved "water tap." And with all his learning and high honours, so justly bestowed on him by the great and learned in many lands, he remained to the last the modest, but tireless, student of nature. He scarcely seemed to know that he was famous. He was ever content to do his work thoroughly, even if it should win no recognition. And even when world-wide fame and recognition came, he was still the humble student of the secrets of nature, reverently waiting until he was able to penetrate further into the heart of her mysteries. As he said at his

Mr John Ward.

Jubilee in 1896—"One word characterises the most strenuous of the efforts for the advancement of science that I have made perseveringly for 50 years—that word is 'failure.' I know no more of electric and magnetic forces, or of the relation between ether, electricity, and ponderable matter, or of chemical affinity, than I knew and tried to teach my class students in my first session as professor." This was no insincere modesty. Lord Kelvin was as fully and as clearly conscious as any one could be of the value of his researches and discoveries. And because he knew so much he felt that much was little after all, and that it was true of all his labours and exploits that "all experience is an arch through which gleams that untravelled world, whose margin fades for ever and for ever as we move." They honoured and cherished his memory as that of a great, noble and disinterested servant of his fellows. During the year a number of their younger and most promising members had stepped out of the ranks at the imperative summons of death, and this week two similar and very heavy bereavements had come upon them. On the 15th inst., Sir David Richmond, an esteemed and honoured member, was suddenly called to his rest, while that day their much-loved friend and Member of Council, Mr David McGee, of Clydebank, had also passed away. In Sir David Richmond they realised that the community and the Institution had lost an able and esteemed citizen and member, and many of them a loyal and trusted friend. His fellow-citizens had long since tested his work and worth, and paid him, both on land and water—as Lord Provost and as Chairman of the Clyde Trust—the highest honours in their power to bestow. In Mr McGee, those who knew him best loved him most, and their profession and the Institution were all the poorer for his loss. His representative and outstanding work as a director and manager of the great Clydebank shipyard would remain as a testimony to his great professional skill and fidelity to duty. It was for them to say whether they should add to the splendid traditions which men like their

Mr John Ward.

friends had created round the Institution, and hand them down to generations after them undimmed and untarnished. The changes in life gave the younger men among them chances—chances to do better than had yet been done; or, if not that, to show that the resolute will, the hearty enthusiasm, the kindly fellowship that marked the life and labour of those men who were gone, were still to be found unabated and unquenched in the men of to-day.

"Our Guests," proposed by Mr JAMES GILCHRIST, Past President of the Institution, and replied to by Principal MACALISTER, closed the toast list.

The proceedings concluded with the singing of "Auld Lang Syne."

SMOKING CONCERT.

On the evening of Saturday, 29th February, 1908, at 7-30 o'clock, members of the Institution and their friends met at a Smoking Concert in the Banqueting Hall of the Grosvenor Restaurant, Glasgow. The chair was occupied by Mr John Ward, President. The toast of "The King" having been submitted, an excellent programme was rendered by well-known local artistes. Upwards of 400 gentlemen were present.

MINUTES OF PROCEEDINGS.

FIFTY-FIRST SESSION,

THE FIRST GENERAL MEETING was held in the Lecture Hall, at 207 Bath Street, Glasgow, on Tuesday, 22nd October, 1907, at 8 p.m.

Mr JAMES GILCHRIST, the retiring President, occupied the Chair.

The Minutes of the General Meeting, held on 23rd April, 1907, having been printed in the billet calling the Meeting, were held as read, and signed by the Chairman.

ANNUAL REPORT OF THE COUNCIL.

The CHAIRMAN said the Council had pleasure in submitting the Annual Report, and called upon Mr William Brown to move its adoption.

Mr BROWN, in moving the adoption of the Report and Treasurer's Statement, said he thought the financial position of the Institution was very satisfactory. The surplus from revenue for the year was £735 16s. 2d., and from the New Buildings' Account it was evident that the Institution would be able to meet its liabilities in connection with the new buildings for some time to come. The members might feel perfectly pleased at the report of the Library Committee. It was quite satisfactory, and the Committee had done its work during the last session in a thorough manner. He had much pleasure in moving the adoption of the Report.

The motion, having been seconded by Mr CLEGHORN, was unanimously adopted.

INSTALLATION OF THE PRESIDENT.

The retiring PRESIDENT thanked the members of the Institution for the kindly support which they had given him during his term of office as President, and said he could not but feel sorry in vacating the Presidential Chair, for many reasons, but one in particular was that he would not be so often with them in the future as he had been in the past. However, he did not intend to lose interest in the Institution with which he had been so long connected. The chief duty which he had to perform that evening was an exceedingly pleasant one, namely, to bring to their notice, if that was at all necessary, his worthy successor, Mr Ward. It was altogether unnecessary to speak about Mr Ward in his shipbuilding capacity, for everyone knew the talent he had displayed in the numerous vessels which he had built, and his name was one to conjure with, especially in connection with fast turbine vessels. In his official capacity as President of the Institution he would be a great honour to the chair, and would add quite a dignity to the Institution in holding that office. He trusted that Mr Ward might be spared to carry through his labours in a way which would be satisfactory to them, and he was well qualified to do that. He called upon Mr Ward to take the chair as their new President, and he was sure they all wished him every success.

The PRESIDENT thanked Mr Gilchrist, and also the members, for the great cordiality with which they had been pleased to receive the far too appreciative remarks of his predecessor. He could only say in a single sentence that if the members gave him the same loyalty, support, and sympathy that had been given to Mr Gilchrist and to all past Presidents, he in turn would promise to do all in his power to justify their choice.

The new Members elected at the previous Meeting were duly admitted.

PREMIUMS OF BOOKS.

A premium of books was awarded to Mr W. L. SPENCE, for his paper on "The Mechanism of Power Transmission from Electric Motors," and to Mr ROBERT ROYDS, M.Sc., for his paper on "The Most Economical Mean Effective Pressure for Steam Engines," read during Session 1906-07.

Thereafter the PRESIDENT delivered his address.

On the motion of Prof. A. BARR, D.Sc., the President was awarded a vote of thanks for his address.

A paper by M. VICTOR CREMIEU, D.Sc., "On an Apparatus for Extinguishing the Rolling of Ships," was read.

The following Candidates were elected:—

AS AN HONORARY MEMBER.

His Grace the Duke of ARGYLL, K.T., P.C., G.C.M.G., G.C.V.O., LL.D., D.Sc., Kensington Palace, London.

AS MEMBERS.

ALEXANDER, DAVID, Electrical Engineer, 43 Mains Street, Glasgow.

CARTMELL, J. MONKHOUSE, Consulting Engineer, 69 Buchanan Street, Glasgow.

CHEW, ANDREW TOM, Engineer, Manager, 9 Walmer Terrace, Ibrox, Glasgow.

COCKBURN, DAVID, Engineer, Messrs. Cockburn's Ltd., Cardonald.

CORBU, JACK, B.A., Naval Architect, 9 Regent Moray Terrace, Glasgow.

CROAD, ALFRED KNIGHT, Manager, Patents Department, Inventions and Patents Development Co. Ltd., 44 West George Street. Glasgow.

DUNLOP, WILLIAM CLARK, Engineer, Albert Engine Works, Greenland Street, Liverpool.

GRANT, COLQUHOUN FRASER, Engineer, 191 Hyndland Road, Glasgow.

HUNTER, ADAM, Engineer, Dalmarnock Ironworks, 85 Preston Street, Glasgow.

JENKINS, JAMES GRAHAM, Engineer, 124 St. Vincent Street, Glasgow.

JOHNSTON, WILLIAM A., Engineer, Glenrose, Albany Drive, Rutherglen.

LANGLANDS, SAMUEL H. B., Gas Engineer, 3 Stevenson Drive, Langside, Glasgow.

MACDONALD, WILLIAM, Engineer, Dalmarnock Iron Works, 85 Preston Street, Glasgow.

MCINTYRE, JOHN H. A., Engineer, 2 Ashgrove Terrace, Partickhill.

MACLEAN, JAMES BORROWMAN, Engineer, 2 Ralston Terrace, Ibrox, Glasgow.

MCLUCAS, DAVID MAITLAND, Electrical Engineer, 370 North Woodside Road, Glasgow.

MCPHERSON, JOHN, Brassfounder, 1 Veir Terrace, Dumbarton.

MILLER, JAMES, Engineer, Manager, 15 Walmer Terrace, Ibrox, Glasgow.

MINCHIN, WILLIAM GORDON, Engineer, Lloyd's Register, 22 Banchory Gardens, Hyndland, Glasgow.

MORTON, THOMAS, Engineer, 6 North Gardner Street, Partick.

MUNRO, ALLAN, Engineer, The Hope, 33 Kyle Park, Uddingston.

MUNRO, JOHN M. M., Electrical Engineer, 136 Bothwell Street, Glasgow.

Park, Richard, Electrical Engineer, 15 Oswald Street, Glasgow.

Purden, Peter, Forgemaster, Lambhill Forge, Glasgow.

Richards, Edgar J. Windsor, Engineer, Manager, The Glengarnock Iron and Steel Co. Ltd., Glengarnock.

Rush, Charles F., Engineer, Chief Draughtsman, Newfield Terrace, Johnstone.

Shaw, John H., Superintendent Engineer, Arizona, East Clyde Street, Helensburgh.

Stevenson, John G., Manager, Iron Workers' Department, Messrs. John Brown and Co., Atlas Cottages, Clydebank.

Thomson, Alfred M., General Manager, Argyll Motors Ltd., Alexandria.

Waddell, Thomas S., Engineer, Messrs. Clifton and Waddell, Machine Tool Makers, Johnstone.

AS ASSOCIATE MEMBERS.

Adam, James Robb, Engineer, Draughtsman, c/o Petrie, 1 Dunolly Gardens, Ibrox, Glasgow.

Lochhead, John Finlay, Electrical Engineer, 14 Comely Bank Avenue, Edinburgh.

Macewen, James E., Electrical Engineer, 8 Oakfield Terrace, Hillhead, Glasgow.

McGill, William James, Structural Engineer, 10 Gleneagle's Terrace, Scotstoun, Glasgow.

Morton, Campbell, Engineer, 16 Radnor Street, Glasgow.

Owen, William Selkirk, B.Sc., Naval Architect, 97 Queensborough Gardens, Hyndland, Glasgow.

Simpson, David Craig, Engineer, 3 Middleton Terrace, Ibrox, Glasgow.

Thomson, John, B.Sc., Engineer, Draughtsman, 74 Parkhead Street, Motherwell.

From Students.

Dias, Christopher W., Civil Engineer, Warri, Central Province, Lagos, West Africa.

Grenier, Joseph R., Civil Engineer, c/o Smith, 25 St. Vincent Crescent, Glasgow.

Henningsen, Svend, Naval Architect, Charlottenborg, Copenhagen, Denmark.

Henricson, John A., Naval Architect, Helsingfors, Finland.

Niven, John S. S., Superintendent Engineer, 19 Woodrow Road, Pollokshields, Glasgow.

Schoetensack, Frederick F., Naval Architect, 47 Scott Street, Garnethill, Glasgow.

Tod, William, Engineer, 948 Sauchiehall Street, Glasgow.

AS ASSOCIATES.

Barrett, Harry G., Agent, 43 Durward Avenue, Crossmyloof, Glasgow.

Grier, Robert P., Shipowner, 7 Royal Bank Place, Glasgow.

McLay, Archibald, Steel Merchant, 50 Wellington Street, Glasgow.

Primrose, Sir John Ure, Bart., Redholme, Ibrox, Glasgow.

Purdie, T. Paterson, Shipowner, 55 West Regent Street, Glasgow.

Smith, John Drake, Cashier and Estimator, 57 Clifford Street, Ibrox, Glasgow.

Waddell, William, Managing Director, Messrs. John Sutherland & Co., Ltd., Forgemasters, Coatbridge.

Ward, W. J. Cuthbert, Steel Manufacturer, Messrs. R. W. Carr & Co., 149 St. Vincent Street, Glasgow.

Wilson, Thomas, Messrs. Loudon Bros., Ltd., Machine Tool Makers, 39 West Campbell Street, Glasgow.

Workman, William S., Shipowner, 12 University Gardens, Glasgow.

AS STUDENTS.

Brown, George, Apprentice Engineer, 30 Queen's Crescent, Cathcart, Glasgow.

Dupre, James, Apprentice Engineer, c/o Laval, 1232 Springburn Road, Glasgow.

Hall-Brown, Archibald, Student of Engineering, 150 Hyndland Road, Glasgow.

Harding, Donald George, Apprentice Engineer, 25 Drumoyne Drive, Govan.

Hoseason, Daniel Nicholson, Student of Engineering, 13 Gourlay Street, Springburn, Glasgow.

Hutchison, Frederick George, Apprentice Engineer, 26 Newark Street, Greenock.

Maclean, John, Engineer, Draughtsman, 22 Ibrox Terrace, Ibrox, Glasgow.

MacLellan, Alexander Stephen, B.Sc., Apprentice Engineer, West Lodge, Glasgow, W.

Stevens, Frederick, Student of Naval Architecture, 97 Queensborough Gardens, Hyndland, Glasgow.

The Second General Meeting was held in the Lecture Hall, at 207 Bath Street, Glasgow, on Tuesday, 19th November, 1907, at 8 p.m.

Mr John Ward, President, occupied the Chair.

The Minutes of the General Meeting, held on 22nd October, 1907, having been printed in the billet calling the Meeting, were held as read, and signed by the President.

The new Members elected at the previous Meeting were duly admitted.

The discussion on paper by M. VICTOR CREMIEU, D.Sc., "On an Apparatus for Extinguishing the Rolling of Ships," was begun and concluded.

On the motion of the President, M. CREMIEU was awarded a vote of thanks for his paper.

A paper on "The Place of the Laboratory in the Training of Engineers," by Professor A. L. MELLANBY, D.Sc., was read. The discussion on this paper was begun and adjourned.

The following Candidates were elected:—

AS MEMBERS.

CAMPBELL, HENRY DUDLEY, Electrical Engineer, 20 Kelvingrove Street, Glasgow.

DYER, ROBERT MORTON, B.Sc., Assistant Shipyard Manager, 8 Highburgh Terrace, Dowanhill, Glasgow.

GIBSON, JAMES, Chief Engineering Draughtsman, 23 Devon Street, Glasgow.

MARTIN, WILLIAM DALRYMPLE, Superintendent Engineer, 23 Castle Street, Dundee.

WILLIAMSON, ALEXANDER, Engineer, c/o Baird, 175 Byars Road, Partick.

AS A STUDENT.

STRANGE, HENRY, Engineering Draughtsman, 3 Caird Drive, Partick.

THE THIRD GENERAL MEETING was held in the Lecture Hall, at 207 Bath Street, Glasgow, on Tuesday, 17th December, 1907, at 8 p.m.

Mr JOHN WARD, President, occupied the Chair.

The Minutes of the General Meeting, held on 19th November, 1907, having been printed in the billet calling the Meeting, were held as read, and signed by the President.

The new Members elected at the previous Meeting were duly admitted.

PREMIUMS OF BOOKS.

A Premium of Books was presented to Mr WILFRID L. SPENCE, for his paper on "The Mechanism of Power Transmission from

Electric Motors," and to Mr ROBERT ROYDS, M.Sc., for his paper on "The Most Economical Mean Effective Pressure for Steam Engines," read during Session 1906-07.

The discussion on paper by Professor A. L. MELLANBY, D.Sc., "The Place of the Laboratory in the Training of Engineers," was resumed and concluded.

On the motion ot the President, Professor MELLANBY was awarded a vote of thanks for his paper.

A paper on "Wireless Communication Over Sea," by Mr J. ERSKINE-MURRAY, D.Sc., was held as read.

The following Candidates were elected:—

AS MEMBERS.

EADIE, JAMES MCGREGOR, Engineer, Manager, Kilmeny, Greenlaw, Paisley.

FILSHIE, JUN., WILLIAM, Superintendent Engineer, Carron Coy., Grangemouth.

THOMPSON, WILLIAM SMELLIE, Engineer, Manager, Thornbank, Dundee.

TITTENSOR, WALTER HARRISON, Electrical Engineeer, Manager, 19 Waterloo Street, Glasgow.

From Associate Members.

LOWE, JAMES, Gas Engineer, Manager, Gas Works, Auckland, New Zealand.

WARD, GEORGE K., Assistant Ship Yard Manager, Garmoyle, Dumbarton.

WARD, JUN., JOHN, Engineer, Garmoyle, Dumbarton.

AS ASSOCIATE MEMBERS.

COWIE, JOHN ROBERT, Electrical Engineer, c/o Black, 262 Bath Street, Glasgow.

GUNN, JAMES, Engineer, Draughtsman, 38 Garturk Street, Crosshill, Glasgow.

MACKINTOSH, WILLIAM ALEXANDER, Engineer, 174 Great Western Road, Glasgow.

WILLIAMSON, JOHN W. R., Engineer, Draughtsman, c/o Maclean, 22 Ibrox Terrace, Ibrox, Glasgow.

From Students.

AP-GRIFFITH, YWAIN GORONWAY, Engineer, Draughtsman, c/o Logan, 128 Byres Road, Glasgow, W.

HILL, GERARD LEADER, Ship Draughtsman, 4 Thornwood Terrace, Partick.

WADDELL, ROBERT, Ship Draughtsman, 19 Kelvinside Terrace, S., Glasgow, W.

AS STUDENTS.

Andrew, Harry T., Engineer, Draughtsman, 4 Thornwood Terrace, Partick, W.

Brown, John McDougall, Apprentice Ship Draughtsman, 7 Whittingehame Gardens, Kelvinside, Glasgow.

Burns, Robert, Apprentice Engineer, Nettlehirst, Beith.

Campbell, Farquhar Clark, Apprentice Engineer, 86 Cartside Street, Langside, Glasgow.

Cleghorn, Jun., Alexander, Student of Engineering, 14 Hatfield Drive, Kelvinside, Glasgow.

Harris, George Stafford, Apprentice Engineer, Farley Lodge, Bowdon, Cheshire.

Lee, Frank, Engineer, Draughtsman, 304 Bath Street, Glasgow.

Macaulay, Jun., James M., Apprentice Engineer, 52 Abbey Drive, Jordanhill, Glasgow.

Marshall, R. A., Engineer, 89 Crossloan Road, Kelvinside, Glasgow.

Wilson, William Wallace, Electrical Engineer, 41 Queen Mary Avenue, Crosshill, Glasgow.

THE FOURTH GENERAL MEETING was held in the Lecture Hall, at 207 Bath Street, Glasgow, on Tuesday, 21st January, 1908, at 8 p.m.

Mr ALEXANDER CLEGHORN, Vice-President, occupied the Chair.

THE LATE MR DAVID McGEE.

Before proceeding to the business of the evening, the Chairman said it was his sad and painful duty to refer to the loss the Institution had sustained by the death of Mr David McGee, Member of Council. As a shipbuilder Mr McGee was well-known to the Members of the Institution, and in his profession he was regarded as one of the foremost shipbuilders of the day. His friendship was greatly valued, and as a colleague he was ever ready to give his help and support to his co-workers in the affairs of the Institution. He was an able administrator, and the Institution, the shipbuilding industry, and the country were all the poorer that day for his loss. In conclusion, the Chairman moved that an expression of their sympathy with his sorrowing relatives be recorded in the Minutes of the Institution and that an excerpt minute be sent to Mrs. McGee.

The motion was adopted.

The Minutes of the General Meeting, held on 17th December, 1907, having been printed in the billet calling the Meeting, were held as read, and signed by the Chairman.

The new Members elected at the previous Meeting were duly admitted.

The discussion on paper by Mr J. ERSKINE-MURRAY, D.Sc., on "Wireless Communications Over Sea," was begun and concluded.

On the motion of the Chairman, Mr ERSKINE-MURRAY was awarded a vote of thanks for his paper.

A paper on "Cost of Power Production," by Mr I. V. ROBINSON, Wh.Sc., was read.

A paper on "The Interrelation of Theory and Practice of Shipbuilding," by Mr J. J. O'NEILL, was read.

The following Candidates were elected:—

AS MEMBERS.

CRANSTON, DAVID, Engineer, Mokanshan, Belmont Drive, Giffnock.

DAMANT, WALTER S., Engineer-Lieut., R.N., H.M. Yacht, "Victoria and Albert."

DONALDSON, ALEXANDER, Engineer, Assistant Manager, 121 Camperdown Road, Scotstoun, Glasgow.

FYVIE, WILLIAM, Engineer, 34 Queen Street, Melbourne, Victoria, Australia.

GILES, ROBERT, Assistant Shipyard Manager, 117 Norse Road, Scotstoun, Glasgow.

KAMO, MASAO, Professor of Marine Engineering, Imperial University, Tokio, Japan.

KEACHIE, DAVID, Engineer, Manager, 5 Park Drive South, Whiteinch, Glasgow.

LYALL, JAMES THOMSON, Engineer, Sussex Street, Kinning Park, Glasgow.

McINTYRE, JAMES C., Engineer, Manager, 5 Porter Street, Ibrox, Glasgow.

MELVILLE, JOHN WRIGHT, Civil Engineer, 231 Nithsdale Road, Dumbreck, Glasgow.

O'DONOVAN, JOHN J., Engineer, Government Bureau of Cold Storage, Manila, P. I.

From Students.

Melville, Alexander, Engineer, Cardonald Bridge Works, Cardonald.

AS ASSOCIATE MEMBERS.

Campbell, James W., B.Sc., Assistant to Professor of Engineering, The Technical College, Glasgow.

Cunningham, James, Engineer, 99 Grant Street, Glasgow.

McMillan, Archibald L., Engineer, Draughtsman, Rosebery Terrace, Kelvinbridge, Glasgow.

Weir, Cecil H., Engineer, Messrs. G. & A. Harvey, Ltd., Albion Works, Govan.

From Students.

McKean, James, B.Sc. (Lond.), Engineer, 3 Buchanan Terrace, Paisley.

Semple, John S., Engineer, 25 Marjorie Grove, Clapham Common, North Side, London, S.W.

AS AN ASSOCIATE.

Taylor, Joseph, Manager, The Edison Swan Coy., 153 West George Street, Glasgow.

AS STUDENTS.

Adamson, William W., Apprentice Engineer, 18 Newton Street, Glasgow, W.

Clark, John H., Student of Engineering, c/o Graham, 2 Merryland Street, Govan.

Jackson, George, Student of Naval Architecture, Rockville, Dumbarton.

McCormack, Robert, Engineer, Beechwood Terrace, Dalmarnock, Glasgow.

Proctor, David, Apprentice Engineer, c/o Richmond, 8 Clarence Street, Paisley.

Robertson, William H., Student of Engineering, 5 Darnley Avenue, Scotstoun, Glasgow.

Sehested, Knud, Student of Naval Architecture, c/o Usher, 12 Glasgow Street, Hillhead, Glasgow.

Steele, James, Jun., Engineer, Greenwood, Wishaw.

Vassiliou, Michael C., Student of Engineering, c/o Matheson, 268 Whitehill Street, Dennistoun, Glasgow.

The Fifth General Meeting was held in the Lecture Hall, at 207 Bath Street, Glasgow, on Tuesday, 18th February, 1908, at 8 p.m.

Mr John Ward, President, occupied the Chair.

The Minutes of the General Meeting, held on 21st January, 1908, having been printed in the billet calling the Meeting, were held as read, and signed by the President.

The new Members elected at the previous Meeting were duly admitted.

The discussion on paper by Mr I. V. ROBINSON, Wh.Sc., on "Cost of Power Production" was begun and concluded.

On the motion of the President, Mr ROBINSON was awarded a vote of thanks for his paper.

A paper on "The Practical Side of Reinforced Concrete," by Mr M. KAHN, was read.

The discussion on paper by Mr J. J. O'NEILL on "The Interrelation of Theory and Practice of Shipbuilding" was postponed.

A paper on "Electric Propulsion of Ships, with Note on Screw Propellers," by Mr HENRY A. MAVOR, was held as read.

The following Candidates were elected:—

AS MEMBERS.

BRUCE-KINGSMILL, Major JULIAN, R.A., Engineer, 11 Queen Victoria Street, London, E.C.

GRAHAM, ARCHIBALD, Jun., Engineer, Manager, 15 Armadale Street, Dennistoun, Glasgow.

STEWART, DAVID MCGREGOR, Consulting Engineer, 166 Buchanan Street, Glasgow.

WEST, GEORGE J. G., Engineer, Messrs Wailes, Dove & Co., 23 Royal Exchange Square, Glasgow.

AS AN ASSOCIATE MEMBER.

THOMSON, WILLIAM, B.Sc., Ship Draughtsman, 210 Glasgow Road, Clydebank.

AS A STUDENT.

LOGIE, WILLIAM, Electrical Engineer, 14 Regent Park Terrace, Strathbungo, Glasgow.

THE SIXTH GENERAL MEETING was held in the Lecture Hall, at 207 Bath Street, Glasgow, on Tuesday, 17th March, 1908, at 8 p.m.

Mr JOHN WARD, President, occupied the Chair.

The Minutes of the General Meeting, held on 18th February, 1908, having been printed in the billet calling the Meeting, were held as read, and signed by the President.

The new Members elected at the previous Meeting were duly admitted.

The discussion on paper by Mr J. J. O'Neill on "The Interrelation of Theory and Practice of Shipbuilding" was begun and concluded.

On the motion of the President, Mr O'Neill was awarded a vote of thanks for his paper.

A paper on "Malleable Cast Iron: Its Evolution and Present Position in the Metallurgical World," by Mr William H. Hatfield, was read.

The following Candidates were elected:—

AS MEMBERS.

Anderson, Robert S., Engineer, Chief Draughtsman, Messrs Marshall, Fleming & Co., Motherwell.

Bocler, Harry, Naval Architect, 19 Azalea Terrace, South, Sunderland.

Campbell, Alexander W., Engineer, Chief Draughtsman, 33 St. George's Square, Regent's Park, London, N.W.

Fleming, James, Chief Draughtsman, Messrs Harland & Wolff, Belfast.

Haig, James, Engineer, Manager, 2 Knowe Terrace, Lambhill, Glasgow.

Ramsay, Alexander, Consulting Engineer, 55 West Regent Street, Glasgow.

Robson, Nathaniel E., Engineer, Manager, Messrs Denny & Co., Dumbarton.

Shanks, John, Sanitary Engineer, Tubal Works, Barrhead.

Steele, James, Engineer, Manager, Greenwood, Wishaw.

Thomson, Robert Govan, Consulting Engineer, 55 West Regent Street, Glasgow.

AS ASSOCIATE MEMBERS.

Laidlaw, Finlayson, Engineer, Draughtsman, Aiknut, West Kilbride.

Maxwell, John M. Scott, B.Sc., Electrical Engineer, Baillieston House, Baillieston.

Scott, William Robert, Electrical Engineer, 104 Queensborough Gardens, Hyndland, Glasgow.

From Students.

Fraser, John A., Engineer, 969 Govan Road, Govan.

Macnicoll, Donald, Engineer, Chief Draughtsman, Gryfe Craig, Kilmacolm.

AS AN ASSOCIATE.

Anderson, Brodie Smith, Commercial Manager, Messrs. A. & J. Main, 8 Caledonian Mansions, Hillhead, Glasgow.

AS STUDENTS.

Hughes, Anwyl, Student of Engineering, c/o Kay, 50 Bank Street, Hillhead, Glasgow.

Lowe, Vincent, Student of Engineering, Bankfield, Bury Old Road, Prestwich, Manchester.

Pirovano, Jose M., Student of Naval Architecture, 1 St. James Street, Hillhead, Glasgow.

An Extraordinary General Meeting was held in the Lecture Hall, at 207 Bath Street, Glasgow, on Tuesday, 31st March, 1908, at 8 p.m.

Mr John Ward, President, occupied the chair.

The Minutes of the General Meeting, held on 17th March, 1908, having been printed in the billet calling the Meeting, were held as read, and signed by the President.

The new Members elected at the previous Meeting were duly admitted.

The following nominations for Office-bearers were then made:—*President*—Mr John Ward; *Vice-Presidents*—Messrs W. M. Alston and W. W. Lackie; *Ordinary Members of Council*—Messrs Thomas Bell, J. Howden Hume, J. Foster King, A. S. Lorimer, and R. A. MacLaren; *Member of Council from Associate Class*—Mr Thomas Whimster.

The discussion on paper by Mr Henry A. Mavor on "Electric Propulsion of Ships, with Note on Screw Propellers," was begun and concluded.

On the motion of the President, Mr Mavor was awarded a vote of thanks for his paper.

A paper on "The Electrical Equipment of the Cunard Express Steamer, 'Mauretania,'" was held as read.

The following candidates were elected:—

AS MEMBERS.

Barron, Samuel, Civil Engineer, 17 Millbrae Crescent, Langside, Glasgow.

Gray, Robert Speir, Civil Engineer, Abbotshall Road, Kirkcaldy.

Hunter, George Burton, D.Sc., Shipbuilder, Messrs. Swan, Hunter & Wigham Richardson, Ltd., Wallsend-on-Tyne.

McLeod, James, Gas Engineer, Gas Works, Kirkintilloch.

From Associate Members.

Welsh, George M., Engineer, 3 Princes Gardens, Dowanhill, Glasgow.

AS ASSOCIATE MEMBERS.

Johnston, John, Engineer, 33 Finlay Drive, Dennistoun, Glasgow.

From Students.

Cameron, Charles, Engineer, The Shanghai Dock and Engineering Company, Shanghai.

Houston, David S., Engineer, Draughtsman, 83 Kilmarnock Road, Shawlands, Glasgow.

McFarlane, John Kidd, Engineer, Levenbank, Kelvinside Gardens, Glasgow.

AS STUDENTS.

Church, Basil Hampden, Apprentice Shipbuilder, 3 Lennox Place, Dalmuir.

MacKillop, Donald, Electrical Engineer, 2 Clutha Street, Paisley Road, W., Glasgow.

Sutton, Ernest, B.Sc., Student of Naval Architecture, 14 Lyndhurst Gardens, Kelvinside, Glasgow.

The Annual General Meeting was held in the Lecture Hall, at 207 Bath Street, Glasgow, on Tuesday, 28th April, 1908, at 8 p.m.

Mr John Ward, President, occupied the chair.

The Minutes of the Extraordinary General Meeting, held on 31st March, 1908, having been printed in the billet calling the Meeting, were held as read, and signed by the President.

The new Members elected at the previous Meeting were duly admitted.

The following gentlemen were elected as Office-bearers:—For Session 1908-09:—*President*—Mr John Ward. For Sessions 1908-11:—*Vice-Presidents*—Messrs W. M. Alston and W. W. Lackie; *Ordinary Members of Council*—Messrs Thomas Bell, J. Howden Hume, J. Foster King, A. S. Lorimer, and R. A. MacLaren; *Member of Council from Associate Class*—Mr Thomas Whimster.

The discussion on paper by Mr M. KAHN on "The Practical Side of Reinforced Concrete" was begun and closed.

On the motion of the President, Mr KAHN was awarded a vote of thanks for his paper.

The discussion on paper by Mr WILLIAM H. HATFIELD on "Malleable Cast Iron: Its Evolution and Present Position in the Metallurgical World," was begun and concluded.

On the motion of the President, Mr HATFIELD was awarded a vote of thanks for his paper.

The discussion on paper by Mr WILLIAM C. MARTIN on "The Electrical Equipment of the Cunard Express Steamer 'Mauretania'" was also begun and ended.

On the motion of the President, Mr MARTIN was awarded a vote of thanks for his paper.

The following Candidates were elected:—

AS MEMBERS.

FRASER, ALEXANDER, Engineer, Waskerley House, Wolsingham, near Durham.

MACMILLAN, CAMPBELL, B.Sc., Electrical Engineer, Cromlech, Clynder, Dumbartonshire.

MUIR, ROBERT HOME, Shipbuilder, 41 Percy Park, Tynemouth.

WATT, ALEXANDER JAMES, Engineer, Manager, Messrs. Palmer's Shipbuilding and Iron Company, Bede House, Jarrow-on-Tyne.

WHITE, JOHN BEAVER, B.Sc., Engineer, 9 Cloak Lane, Cannon Street, London, E.C.

AS AN ASSOCIATE.

RAMSAY, NORMAN FREDERICK, Naval Brass Founder, Charlotte Square, Newcastle-on-Tyne.

AS A STUDENT.

BENSON, FRANCIS WALTER, Ship Draughtsman, Cannielee, Yoker, N.B.

REPORT OF THE COUNCIL.

Session 1906-1907.

At the opening meeting of the fifty-first session, the Council presents to the Members a report of the proceedings of the Institution during the past session, and in doing so has pleasure in stating that the Institution has again made satisfactory progress.

The Roll.

The changes which have taken place in the Roll during the year ending 30th September, 1907, are shown in the following statement:—

	Session 1905-6.	Session 1906-7.
Honorary Members,	7	7
Members,	1,031	1,017
Associate Members,	170	192
Associates,	83	85
Students,	221	224
	1,512	1,525

The elections were Members 54, Associate Members 22, Associates 7, and Students 43; while 4 Associate Members and 2 Students passed into the Members' Section, and 8 Students were transferred to the Class of Associate Members. In respect of deaths, resignations, and deletions the Membership was decreased by 113.

The Council laments the loss by death of the following:—Members—Imrie Bell, Croydon; John R. Bird, Glasgow; Walter Brock, Dumbarton; Andrew Brown, Renfrew; W. G. Clark, Liverpool; George Cockburn, Glasgow; Sir William Robertson Copland, LL.D., Glasgow; William Dobson, Newcastle-on-Tyne; Patrick Doyle, Calcutta; Ernest George Gearing, Leeds; G. L. Gretchin, Nicolaieff; Alexander Govan, Helensburgh; James Murray, Glasgow; John M. M'Kechnie, Glasgow, Henry M. Rait, London; Robert S. Reid, Kilmacolm; Hazelton Robson Robson, Glasgow; James Rowan, Glasgow; James Alexander Smith, Glasgow; and Robert Watson, Glasgow. Associate Member—George Stevenson, Paisley. Associates—Thomas Aitken, Leith; and William Alexander Kinghorn, Glasgow. Student—John C. Ramsay, Glasgow.

WORK OF THE SESSION.

Seven General Meetings of the Institution were held, at which, in addition to the President's Address, the following papers were submitted, and these, together with the discussions thereon, are embodied in Volume L. of the Institution's Proceedings:—

"The Development and Present Status of the Steam Turbine in Land and Marine Work," by Mr E. M. Speakman.

"Suction Gas Engines and Gas Plants," by Mr Hugh Campbell.

"The Stability of Submarines," by Mr J. G. Johnstone, B.Sc.

"The Mechanism of Power Transmission from Electric Motors," by Mr Wilfrid L. Spence.

"The Most Economical Mean Effective Pressure for Steam Engines," by Mr R. Royds, M.Sc.

The "James Watt" Dinner took place on Friday evening, 18th January, 1907, at the Grosvenor Restaurant, and was attended by upwards of 420 gentlemen, including guests. This was a record attendance for the dinner.

A Smoking Concert was held in the banqueting hall of the

Grosvenor Restaurant on the evening of Saturday, 23rd March, 1907. An excellent programme was rendered by local artistes, and the company present numbered 400.

On Wednesday evening, 1st May, 1907, the Jubilee day of the Institution, a conversazione and dance was held in the St. Andrew's Halls; and an interesting collection of shipbuilding and engineering models was exhibited in the Berkeley Hall. The number of ladies and gentlemen present at this function exceeded 1000.

NEW BUILDINGS.

Building operations were commenced in December of last year and despite the somewhat unfavourable weather, work has progressed in a steady manner. The memorial stone was laid on the 3rd May, 1907, by his Grace the Duke of Argyll, K.T. At present the building has reached the level of the main cornice, and, so far, its outward aspect justifies the expectations formed from the original drawings as to its imposing appearance, and the important addition it will make to the public architecture in the locality. It is anticipated that the building will be roofed by the middle of December, and within the course of next year the Institution will be housed in a habitation worthy of its standing and increasing importance.

STUDENTS' SECTION.

Mr R. H. B. Thomson, Chairman of the Section, opened the Session with an address. At the five subsequent meetings the undermentioned papers were read and discussed:—

"Motors and Motor Boats: Some Notes on Choice Design and Installation," by Mr H. J. Hedderwick.

* "Tramway and Railroad Electric Traction," by Mr George G. Braid.

"Notes on the Methods of Constructing Steel Ships," by Mr J. Gow Stevenson.

"The Study of the Properties of Alloys," by Mr T. S. Patterson.

*"Some Details of Albion Motor Cars," by Mr T. Blackwood Murray, B.Sc.

Visits were paid to the works of the following firms:—

Messrs The New Arrol Johnston Car Co., Ltd., Paisley.
Pinkston Generating Station.
Messrs John Lang & Sons, Johnstone.
Messrs The Lanarkshire Steel Co., Ltd., Flemington.
Messrs. J. Dunn & Stephen's, Ltd., Colliery.
Messrs Scotts' Shipbuilding and Engineering Co., Ltd., Greenock, and Messrs. John Walker & Co., Sugar Refiners, Greenock.

The thanks of the Institution are due to the principals and managers of these works for the courtesy and hospitality extended to the Students during the visits.

BOARD OF GOVERNORS OF THE GLASGOW AND WEST OF SCOTLAND TECHNICAL COLLEGE.

The College continues to maintain the high place it has reached among the great technical schools of the country. During last session the number of students was greater than in any previous session. A comparison of the two years is given in the following table:—

	Session 1905-6.	Session 1906-7.
Total day students, - -	535	544
Total evening students, -	3,812	4,512
Total "student-hours," -	399,867	475,950

The figures opposite "student-hours" indicate the aggregate hours of attendance actually made.

The second section of the new building, the foundations of which were laid last year, has now been carried to the third

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* These papers are embodied in Vol. L. of the Institution's Proceedings.

floor, and it is hoped that it will be ready for occupation by session 1908-9. The Governors have arranged to put in the foundations for the third block, completing the frontage to George Street, but they will be compelled to await further contributions to the building fund before entering into contracts for the erection of the superstructure.

The apparatus of the Motive Power Engineering Laboratory, referred to in the last report, has now been installed, and is in regular use. With the aid of Argyll Motors, Ltd., who presented the chassis, an experimental motor-car plant has been added recently. Unexpected delay, owing to strikes, has occurred in the completion of the equipment of the Mechanics' Laboratory, but considerable progress has been made with the hydraulic installation, and it is hoped that the testing machines will be delivered very shortly. The Electrical Engineering Laboratory now contains more than twenty machines, representing all the leading types of dynamos and motors. It is gratifying to note that the opportunities offered by this splendidly equipped laboratory are much appreciated by electrical engineers, and great difficulty is being experienced this year in accommodating all the students who desire to gain admission.

The recent death of Sir William Copland, LL.D., the Chairman of the Governors, has brought into prominence the value of the great work he was instrumental in doing for the College, and though his loss will be keenly felt for a long time, the organisation built up under his fostering care, is such that his successor will find, ready to hand, an Institution well worthy of all the care he may be able to bestow upon it.

THE GLASGOW SCHOOL OF ART.

The Governors are assured that the School is satisfactorily meeting all the demands made upon it. Its sphere of influence extends beyond the city, and includes the counties of Lanark, Renfrew, Ayr, Dumbarton, Stirling, Perth, Inverness, Ross, Kirkcudbright, Wigtown, Dumfries, Argyll, and the Islands of Bute and Arran. The School has been recognised by the Glasgow Provincial Committee as a centre for the instruction of teachers in drawing under Article 55 of the Regulations for the Training and Certification of Teachers.

In the city, the co-ordination of work between the School of Art and the Technical College is such that architectural students receive part of their training in the Technical College, and part in the School of Art, and the scheme is working successfully. The organisation of the classes held in the two institutions is called the Glasgow School of Architecture.

The courses of work in drawing and colour study arranged by the School of Art, and the Glasgow Weaving College for workers in the textile and allied trades, have been fairly taken advantage of. The scheme has the warm sympathy of some of the manufacturers of Glasgow.

The Glasgow School Board takes an active share in the work of the School, and through its co-operation the best students of the continuation classes of the Board are selected to pass on to the evening classes of the School of Art.

The Educational Endowments Board grants bursaries to the value of £30, and the School Board authorised by the Scotch Education Department allows 20 bursaries tenable at the evening classes of the School of Art.

The number of ordinary students for the past session was 660, and students in teachers' classes 553, making a total of 1213 enrolments.

The financial arrangements for the maintenance of the School are similar to those of the previous year. The Scotch Education Department pays one-half of the ordinary expenditure after deducting the amount of class fees, on condition that there is an annual contribution to the funds of the School, from local sources, of a sum equal to the Department's grant.

The Governors, with the sanction of the Scotch Education Department, have decided to complete the building on the general lines of the original plans. A munificent building grant from the Department has been supplemented by generous donations from the Town Council, the Bellahouston Trust, private donors, and other local sources; the total subscriptions amounting to £30,000. A gratifying feature is the sum contributed by the staff and students of the School.

Building operations have commenced, and it is hoped that the completed structure will be ready for occupation in September, 1908.

The Governors propose to entirely complete the building and to furnish it as far as funds permit, with fittings, material for study, casts, and other apparatus, necessary to the most modern requirements of a fully equipped and organised central School of Art.

BOARD OF TRADE CONSULTATIVE COMMITTEE.

The Institution was represented on the Board of Trade Consultative Committee by Mr John Duncan, Mr E. Hall-Brown, Mr Fred. Lobnitz, and Mr George McFarlane.

The following matters have emerged and have been dealt with, or have been considered by this Committe since the date of its last Report:—

Mr Lloyd-George, President of the Board of Trade, having, during the progress of the Merchant Shipping Bill through the House of Commons, intimated his intention of forming one Grand Committee or several Divisional Committees, to advise the Board of Trade on matters relating to shipbuilding, marine engineering, and shipping, the Secretary of this Committee, by its instructions, wrote to Mr Lloyd-George explaining very fully its objects, history, and position.

This was followed up by a deputation to Mr Lloyd-George on the 24th October last, and the proposal that, the new Advisory Committee proposed by the President to deal with shipbuilding and engineering matters could, with advantage, be constituted on similar lines to this Committee, seemed to commend itself to his favourable consideration.

When the Merchant Shipping Bill became Law, the Board of Trade, under Section 79 of "The Merchant Shipping Act, 1906," got power to appoint Advisory Committees; and the subject of the formation of such Committees is at present under consideration by the President.

At this interview with Mr Lloyd-George, the question of getting written approval from the Board of Trade to boiler and other plans submitted to the Board, was agreed to by Mr Howell, Assistant Secretary to the Marine Department of the Board of Trade, and approved by Mr Lloyd-George.

The draft regulations which the Board proposed to issue under Section 10 of The Merchant Shipping Act, was dealt with, and the observations of this Committee communicated to the Board of Trade.

The question of fitting hand deck-pumps as required by the Board of Trade and Lloyd's in the holds and engine and boiler spaces of large steamers was considered, but final consideration of the subject was deferred in order that it might form one of the matters for consideration by the new Advisory Committee.

Several questions as to the measurement of tonnage were considered by the Committee and the Sub-Committee on Tonnage.

The tonnage of hopper barges and light vessels was considered and remitted to the Sub-Committee on Tonnage.

The question of the height of coamings on shelter deck vessels was considered.

Various subjects relating to the weight of stays in boilers; the examination of candidates for Board of Trade certificates; the position of the lamp room in steam fishing vessels; the fitting of freeing ports in shelter deck vessels; the question of poop openings; and the submission of designs for turbines, when special certificates were required by the Board of Trade, were considered and advanced a stage.

A Bill presented by the Marine Engineers Association for the consideration of the Board of Trade was submitted to the Institution of Naval Architects, The North-East Coast Institution of Engineers and Shipbuilders, and The Institution of Engineers and Shipbuilders in Scotland, and referred by them to this Committee. The matter is still under consideration, but the Committee has submitted to the Board of Trade the conditions which it considers should be fulfilled before an engineer is eligible as a candidate for a Board of Trade certificate, and a report to a similar effect upon the proposed bill was duly made to the Board.

LLOYD'S TECHNICAL COMMITTEE.

The usual and statutory meetings of the Committee were held in London during the months of November and March, at which the following matters were discussed:—

Amendments of the rules in regard to deck plating.
Limits of tensile strength of steel.
The inspection and manufacture of shaft forgings.
Amendments of the rules consequent upon the adoption of the specification of the Engineering Standards' Committee in regard to boiler steel.
Rules and tables for yachts.
Rudders and steering gear.
Amendments of the rules relating to double bottoms.

Where alterations in the Rules referring to any of the above subjects were approved by the Technical Committee, and adopted by the General Committee, they will be found embodied in the new issue of Lloyd's Rules.

Mr John Inglis, LL.D., and Mr Sinclair Couper having completed their terms of service on the Committee, retired in December, 1906, and the Council appointed in their stead, Mr James Gilchrist and Mr John Ward as representatives of the Institution. Owing to the death of Mr. James Rowan, the Council had to elect another representative, and Mr Thomas

Bell was appointed to fill the vacancy thus caused. Mr Richard Ramage is the other representative of the Institution upon the Technical Committee.

It should be noted also that Sir John Glover, who had been Chairman of Lloyd's Register since 1899, retired in June last, and that Mr James Dixon has been elected to succeed him in the office of Chairman.

The Council has decided to discontinue the publication of the monthly Proceedings, and to issue instead advance proofs of papers to all Members, Associate Members, Associates, and Students, who may apply for copies. After each Meeting the paper read, with the discussion thereon, will be printed, and a copy will be supplied to any one applying for the same. At the close of the Session the volume of proceedings will be issued as at present.

The Council desires to urge every Member to use his best efforts towards promoting the welfare of the Institution, by regularly attending the Meetings, by contributing papers or taking part in discussions, and by securing new Members.

FINANCE.

The surplus revenue for the session ending 30th September, 1907, as shown by the Treasurer's Statement, appended hereto, is £735 16s. 2d.

TREASURER'S
INCOME AND EXPENDITURE ACCOUNT
GENERAL

ORDINARY INCOME.		1906-1907.	1905-1906.
I. *Annual Subscriptions received—*			
Members, ...	£1786 0 0		
Associate Members, ...	174 0 0		
Associates, ...	121 10 0		
Students, ...	96 10 0		
		£2178 0 0	*£2113 10 0*
II. *Arrears of Subscriptions recovered, less expenses,*		86 7 3	*67 14 4*
III. *Sales of Transactions,*		8 13 0	*8 3 6*
IV. *Interests and Rents—*			
Interest on Clyde Trust Mortgages, less tax, ...	£27 10 8		
Interest on Deposit Receipts, *less* Income Tax, ...	62 4 0		
Interest on Glasgow Corporation Loan, ...	31 8 9		
West of Scotland Iron and Steel Institute, for use of Library,	7 7 0		
Students, Institution C.E., for use of Library, ...	11 10 4		
		140 0 9	*212 13 1*
EXTRAORDINARY INCOME.			
Surplus on Conversazione, Surplus on James Watt Dinner, ...		. . .	*15 8 8*
		£2413 1 0	*£2417 9 7*

STATEMENT.
FOR YEAR ENDING 30TH SEPTEMBER, 1907.
FUND.

ORDINARY EXPENDITURE.				1906-1907.	*1905-1906.*
I. *General Expenses—*					
Secretary's Salary, ...	£450	0	0		
Clerk's Salary, ...	82	1	0		
Institution's proportion of net cost of maintenance of Buildings at Bath Street, ...	11	11	8		
Library Books, ...	42	14	8		
Binding Periodicals and Papers,	12	13	0		
Stationery and Postages, etc.,	66	18	4		
Office Expenses, ...	35	15	7		
Advertising, Insurance, etc., ...	5	5	6		
Travelling Expenses, ...	10	4	8		
Expenses of Students' Opening Meeting, ...	4	2	6		
Law Expenses, ...	7	5	8		
Rent of Rooms, ...	220	0	0		
				£948 12 7	*£828 17 9*
II. "*Transactions*" *Expenses—*					
Printing and Binding,	£416	16	7		
Lithography, ...	180	5	3		
Postages, ...	68	3	1		
Reporting, ...	14	10	0		
Delivery of Annual Volume, ...	26	0	0		
				705 14 11	*796 9 3*
EXTRAORDINARY EXPENDITURE.					
Deficit on Conversazione, ...	£12	7	4		
Portrait of James Watt, ...	5	0	0		
Furnishings, ...	5	10	0		
				22 17 4	*250 8 8*
Surplus carried to Balance Sheet, ...				735 16 2	*541 13 11*
				£2413 1 0	*£2417 9 7*

BALANCE SHEET, AS AT

	LIABILITIES.			As at 30th Sept., 1907.	*As at 30th Sept., 1906.*
I.	*General Capital Account—*				
	As at 1st Oct., 1906, ...		£7322 5 8		
	Deduct—				
	Transferred to New Buildings Account:—				
	Net proceeds of Bath Street premises,	£3946 17 11			
	Interest to 30th September, 1906,	58 15 10			
		£4,005 13 9			
	Less extraordinary expenses in connection with Competitive Plans, etc.,	250 8 8	3,755 5 1		
			3567 0 7		
	Entry money, ...		73 0 0		
	Surplus from Revenue, ...		735 16 2	£4,375 16 9	*£7322 5 8*
II.	*New Buildings Account,*	...	...	. . .	*3651 13 4*
III.	*Life Members' Subscriptions,*	...	..	425 0 0	*350 0 0*
IV.	*Sundry Creditors,* ...	...	...	30 10 0	*30 10 0*
V.	*Subscriptions paid in advance,*	...	..	69 0 0	*48 10 0*
VI.	*Medal Funds—*				
	Marine Engineering—				
	Balance as at 1st Oct., 1906,	£610 13 11			
	Interest, £18 14s 6d, less Premiums of Books £10, ...	8 14 6	£619 8 5		
	Railway Engineering—				
	Balance as at 1st Oct., 1906,	£394 16 4			
	Interest, ...	12 2 0	406 18 4		
	Students'—				
	Balance as at 1st Oct., 1906,	£19 17 7			
	Interest, ...	0 12 2	20 9 9		
				1046 16 6	*1025 7 10*
				£5947 3 3	*£12428 6 10*

30TH SEPTEMBER, 1907.

ASSETS.			As at 30th Sept., 1907.	*As at 30th Sept. 1906.*
I. *New Buildings Account—*			£409 3 9	*£8638 2 4*
II. *Furniture and Fittings—* Valued at, say			20 0 0	*20 0 0*
III. *Books in Library—* Valued at, say			500 0 0	*500 0 0*
IV. *Investments—*				
Clyde Trust Mortgages, and Interest, ...		£810 11 9		
Glasgow Corporation Loan and Interest, ...		1011 6 2		
			1821 17 11	*1922 12 6*
V. *Medal Funds', Investments—* On Deposit Receipt and Interest, ...			1043 11 2	*1021 7 8*
Note.—Balance of £3 5s 4d since lodged on Deposit Receipt.				
VI. *Arrears of Subscriptions—*				
Session 1906-1907—				
Members, ...		£94 0 0		
Associate Members, ...		15 0 0		
Associates, ...		4 10 0		
Students, ...		14 10 0		
		£128 0 0		
Previous sessions—				
Members,	£80 0 0			
Associate Members,	6 0 0			
Associates, ...	3 0 0			
Students, ...	4 0 0			
		43 0 0		
Total,		£171 0 0		
Valued at, say			50 0 0	*50 0 0*
VII. *Sundry Debtors—*			1 0 0	*11 19 0*
VIII. *Cash—*				
In Bank, on Deposit Receipt and interest, ...		£2061 13 5		
Do, on Current Account,		23 8 5		
In Secretary's hands, ...		16 8 7		
			2101 10 5	*£264 5 4*
			£5947 3 3	*£12428 6 10*

GLASGOW, *18th October, 1907.*—Audited and certified correct

DAVID BLACK, C.A., *Auditor.*

NEW BUILDINGS ACCOUNT.

RECEIPTS.

	£	s.	d.	£	s.	d.
Donations, ...				£12,828	6	0
Interest on deposit receipts, *less* interest on purchase price of site and buildings in Elmbank Street and Elmbank Crescent,				118	12	2
Price realised from Institution's share of buildings at 207 Bath Street, and interest to 2nd Feb., 1906,	£4,029	17	6			
Less law expenses, ...	82	19	7			
				3,946	17	11
Proceeds of sale of old materials from buildings in Elmbank Street and Elmbank Crescent, *less* expenses, ...				220	8	6
				£17 114	4	7

EXPENDITURE.

	£	s.	d.	£	s.	d.
Competitive plans, ...				£245	4	4
Purchase price of subjects in Elmbank Street and Elmbank Crescent, ...				5,382	2	7
Borings at site, James Main, ...				11	16	4
Foundations, R. Murdoch & Son, ...	£1,022	7	7			
James Allison, Inspector,	20	0	0	1,042	7	7
Barricading, ...				57	11	1
Mason and Steel Work, Morrison & Mason, to account, ...				4,300	0	0
Clerk of Works, W. G. Peddie, ...				76	10	0
Architect's and Measurers' fees to account—						
J. B. Wilson, Architect, ...				400	0	0
D. Wilkie & Son, Measurers, ...				150	0	0
Miscellaneous Expenses—						
Memorial Stone Ceremony,	£79	17	11			
Printing, Stationery, Advertising, etc., ...	13	13	7	93	11	6
Total expenditure to 30th Sept., 1907,				£11,759	8	5
Funds in hand—						
In bank on deposit receipt	£5,624	15	0			
„ „ current account	139	9	11			
	£5,764	4	11			
Less due Institution, General Fund, ...	409	3	9	5,355	1	2
				£17,114	4	7

GLASGOW, *18th October, 1907.*—Audited and certified correct.
DAVID BLACK, C.A., *Auditor.*

REPORT OF THE LIBRARY COMMITTEE.

During the session just closed the additions to the Library include 9 volumes, 12 pamphlets, and 58 Board of Trade Reports on boiler and steam-pipe explosions, by donation; 59 volumes by purchase; and 64 volumes received in exchange for the Proceedings of the Institution. Of the periodical publications received in exchange, and which lie on the tables in the reading-room, 27 were weekly and 26 monthly. Seventy-six volumes were bound.

The Institution possesses a complete set of the Abridgments of Specifications of Patents dating from 1617, which is available for reference purposes in the Library.

The thanks of the Committee are due to the donors of the following works to the Library:—

Donations to the Library.

Engineering Standards' Committee Publications—

British Standard Specifications for Material used in the Construction of Railway Rolling Stock.

British Standard Specification for Steel Conduits for Electrical Wiring.

Report on British Standard Nuts, Bolt-Heads, and Spanners.

British Standard Specification for Steel Conduits for Electrical Wiring.

British Standard Screw Threads and Pipe Threads.

British Standard Specification for Carbon Filament Glow Lamps.

Second Report of the Locomotive Committee on Standard Locomotives for Indian Railways.

British Standard Specification for Portland Cement.

British Standard Specification for Structural Steel for Marine Boilers.

British Standard Specification for Material used in the Construction of Railway Rolling Stock.

British Standard Specification for Ingot Steel Forgings for Marine Purposes.

British Standard Specification for Steel Bars (for use in Automatic Machines.)

From the Committee.

Hiller, E. G. Notes in Material Construction and Design of Land Boilers. From the Author.

Julius, G. A. Western Australian Timber Tests. 1906. From the Government of Western Australia.

Meldola, Raphael. Position and Prospects of Chemical Research in Great Britain. 1906. From the Author.

Notes *re* Timbers of Western Australia suitable for Railways, Engineering Works, and Constructional Purposes generally. 1900. From the Government of Western Australia.

Papers read before the Institution of Civil Engineers, Glasgow Association of Students, during session 1905-1906. From the Association.

Proceedings of American Forest Congress. Washington. 1906. From James Palethorpe.

Rowan, F. J. Producer Gas Plant. Pamphlet. From the Author.

Sothern, J. W. Marine Steam-Turbine, 2nd edition. 1906. From the Author.

Stromeyer, C. E. Manchester Steam Users' Association, Memorandum of Chief Engineer. 1905. From the Author.

The Glengarnock Iron and Steel Co., Ltd. Section Book. 1907. From the Company.

BY PURCHASE.

Beaumont, W. W. Motor Vehicles and Motors. their Design, Construction and Working by Steam, Oil, and Electricity. Vol. 2. 1906.

Benjamin, C. H. Modern American Machine Tools. 1906.

Biles, J. H. The Steam Turbine as Applied to Marine Purposes. 1906.

Birkmire, W. H. Architectural Iron and Steel, and its Application in the Construction of Buildings. 3rd edition. New York. 1903.

Booth, W. H. Steam Pipes: Their Design and Construction. 1905.

Boulnois, H. P. Municipal and Sanitary Engineers' Handbook. 3rd edition. 1898.

Burgoyne, A. H. Submarine Navigation, Past and Present. 2 Vols. 1903.

Church, I. P. Hydraulic Motors. New York. 1905.

Cole, W. H. Notes on Permanent-Way Material. 5th edition. 1905.

Copperthwaite, W. C. Tunnel Shields and the use of Compressed Air in Subaqueous Works. 1906.

Crocker, F. B. Electric Lighting: A Practial Exposition of the Art. 6th edition. Vol. I. New York, 1904.

Dowson, J. E., and Larter, A. T. Producer Gas. 1906.

Eichhorn, Gustav. Wireless Telegraphy. 1906.

Ellis, George. Modern Practical Carpentry. 1906.

Farnsworth, A. W. Constructural Steelwork: Being Notes on the Practical Aspect and the Principles of Design. 1905.

Fleming, J. A. Handbook for the Electrical Laboratory and Testing Room. 2 Vols. 1901.

Fleming, J. A. Measurement of High Frequency Currents and Electric Waves. Pamphlet. 1906.

Fleming, J. A. Hertzian Wave Telegraphy. Pamphlet. 1906.

Foster, Frank. Steam Turbines and Turbo-Compressors: Their Design and Construction.

Fowler, C. E. Ordinary Foundations, including the Cofferdam Process for Piles. 2nd edition. New York. 1905.

Garnett, W. H. S. Turbines. 1906.

Greene, C. E. Structural Mechanics. 2nd edition. New York, 1905.

Griffin & Co. Official Year-Book of the Scientific and Learned Societies of Great Britain and Ireland. 1906.

Grossman, J. Ammonia and its Compounds. 1906. 12mo.

Grossman, J. Elements of Chemical Engineering. 1906.

Guttmann, Oscar. Blasting. 1906.

Halliday, George. Belt Driving. 1894.

Hanchett, G. T. Modern Electric Railway Motors. New York. N.A.

Harrison, Newton. Electric-Wiring, Diagrams and Switchboards. 1906.

Haupt, H. Street Railway Motors. Philadelphia. 1903.

Hobart, H. M. Elementary Principles of Continuous-Current Dynamo Design. 1906.

Jones, H. C. Electrical Nature of Matter and Radio-Activity. 1906.

Jones, Walter. Heating by Hot Water. 3rd edition. 1904.

Jude, Alexander. Theory of the Steam Turbine. 1906.

Lamb, C. G. Alternating Currents: A Text-Book for Students of Engineering. 1906.

Parshall & Hobart. Electric Machine Design. 1906.

Pearn, S. & F. Workshop Costs for Engineers and Manufacturers. 2nd edition. 1905.

Pratt, M. D., and Alden, C. A. Street-Railway Roadbed. New York, 1898.

Reid, George. Practical Sanitation. 13th edition. 1906.

Reynolds, M. Continuous Railway Brakes. 1882.

Roberts, John, Jun. Laboratory Work in Electrical Engineering. 1906.

Ross, H. M. British Railways, their Organisation and Management. 1904.

Rutherford, E. Radio-Activity. 2nd edition. 1905.

Sankey, H. R. The Energy Chart: Practical Applications to Reciprocating Steam Engines. Manchester.

Schnabel, Carl. Handbook of Metallurgy. Trans. by Henry Louis. 2nd edition. Vol. I. 1905.

Solomon, H. G. Electricity Meters. 1906.

Stevens & Hobart. Steam Turbine Engineering. 1906.

Stodola, A. Die Dampfturbinen. 4to. Berlin. 1905.

Sutcliffe, G. L. Concrete: Its Nature and Uses. 1905.

Thomas, Carl C. Steam Turbines. 2nd edition. New York. 1906.

Thompson, S. P. High-Speed Electric Machinery, with Special Reference to Turbine Machines. Pamphlet. 1906.

Thorn, W. H. Reed's Guide to the Board of Trade Examinations. 4th edition, with Plates. 1902.

Tinney, W. H. Gold Mining Machinery. 1906.

Traill, T. W. Boilers, Marine and Land: Their Construction and Strength: A handbook of Rules, Formulæ, etc. 4th edition. London. 1906.

Turner, H. W., and Hobart, H. M. Insulation of Electric Machines. 1905.

Turner, Thomas. Lectures on Iron-Founding. 1904.

Wilda, Hermann. Marine Engineering, the Calculation, Designing and Construction of the Modern Marine Steam Engine, including the Marine Steam Turbine. Hanover. 1906.

Woods, R. J. Strength and Elasticity of Structural Members. 2nd edition. 1906.

Zimmer, G. F. Mechanical Handling of Material. 1905.

THE INSTITUTION EXCHANGES TRANSACTIONS WITH THE FOLLOWING SOCIETIES, &C.:—

Aberdeen Association of Civil Engineers, Aberdeen.

American Institute of Electrical Engineers, New York.

American Institute of Mining Engineers, New York.

American Philosophical Society, Philadelphia.

American Society of Civil Engineers, New York.

American Society of Mechanical Engineers, New York.

American Society of Naval Engineers, Washington.

Association des Ingénieurs sortis des Écoles Spèciales de Gand, Belgium.

Association Technique Maritime, Paris.

Bristol Naturalists' Society, Bristol.

British Association for the Advancement of Science, London.

British Corporation for the Survey and Registry of Shipping, Glasgow.

Bureau of Steam Engineering, Navy Department, Washington.

Canadian Institute, Toronto.

Canadian Society of Civil Engineers, Montreal.

Collegio degli Ingegneri e Architetti in Palermo, Palermo.

École Polytechnique, Paris.

Edinburgh Architectural Association, Edinburgh.

Electric Club, Pittsburgh.

Engineering Association of New South Wales, Sydney.

Engineering Society of the School of Practical Science, Toronto.

Franklin Institute, Philadelphia.

Geological Survey of Canada, Ottowa.

Hull and District Institution of Engineers and Naval Architects Hull.

Institute of Marine Engineers, London.

Institution of Civil Engineers, London.

Institution of Civil Engineers of Ireland, Dublin.

Institution of Electrical Engineers, London.

Institution of Junior Engineers, London.

Institution of Mechanical Engineers, London.

Institution of Naval Architects, Japan.

Institution of Naval Architects, London.

Iron and Steel Institute, London.

Literary and Philosophical Society of Manchester, Manchester.

Liverpool Engineering Society, Liverpool.

Lloyd's Register of British and Foreign Shipping, London.

Magyar Mérnök es Épitesz-Egylet, Budapest.

Manchester Association of Engineers, Manchester.

Massachusetts Institute of Technology, Boston.

Midland Institute of Mining, Civil, and Mechanical Engineers, Barnsley.
Mining Institute of Scotland, Hamilton.
North-East Coast Institution of Engineers and Shipbuilders, Newcastle-on-Tyne.
North of England Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne.
Nova Scotian Institute of Science, Halifax, N.S.
Österreichische Ingenieur-und Architekten-Verein, Wien.
Patent Office, London.
Royal Dublin Society, Dublin.
Royal Philosophical Society, Glasgow.
Royal Scottish Society of Arts, Edinburgh.
Rugby Engineering Society, Rugby.
Schiffbautechnischen Gesellschaft, Berlin.
Scientific Library, U.S. Patent Office, Washington.
Smithsonian Institution, Washington.
Société d'Encouragement pour l'Industrie Nationale, Paris.
Société des Ingénieurs Civils de France, Paris.
Société des Sciences Physiques et Naturelles de Bordeaux, Bordeaux.
Société Industrielle de Mulhouse, Mulhouse.
Society of Arts, London.
Society of Engineers, London.
Society of Naval Architects and Marine Engineers, New York.
South Wales Institute of Engineers, Cardiff.
University of Texas Mineral Survey, Austin.
West of Scotland Iron and Steel Institute, Glasgow.
Western Society of Engineers, Chicago.

PUBLICATIONS RECEIVED PERIODICALLY IN EXCHANGE FOR INSTITUTION TRANSACTIONS:—

Weekly.

American Machinist.
Automobile Club Journal.
Automotor Journal.
Colliery Guardian.

Contract Journal.
Electrical Review.
Engineer.
Engineering.
Engineering Record.
Engineering Times.
Indian Engineering.
Industrial World.
Iron Age.
Iron and Coal Trades' Review.
Iron and Steel Trades' Journal.
Ironmonger.
L'Industria : Rivista Tecnica ed Economica.
Mechanical Engineer.
Mechanical World.
Nature.
Nautical Gazette.
Practical Engineer.
Public Health Engineer.
Revue Industrielle.
Railway Gazette.
Shipping World.
Stahl und Eisen.

Monthly.

African Engineering.
American Marine Engineer.
Bulletin of the International Engineering Congress.
Cassier's Magazine.
Cold Storage and Ice Trades Review.
Electric Journal.
Electrical Magazine.
Engineering Magazine.
Engineering Press Monthly Index.
Engineering Review.

Light Railway and Tramway Journal.
Machinery.
Machinery Market.
Marine Engineer.
Marine Engineering.
Mariner.
Mines and Minerals.
Page's Weekly.
Petroleum World.
Portefeuille Économique des Machines.
Science Abstracts.
South African Engineering.
Steamship.
The Indian and Eastern Engineer.
Tramway and Railway World.
Zentralblatt fuer Eisenhuetten Wesen.

The Library closes for the Summer Holidays from the 11th July till 31st July inclusive.

Except during holidays and Saturdays, the Library is open each lawful day from 1st May till 30th September inclusive, from 9.30 A.M. till 5 P.M. On Saturdays the Library is open from 9.30 A.M. till 1 P.M.

On the 1st October and thereafter throughout the Winter Session, the Library is open daily (except Saturday) from 9.30 A.M. till 8 P.M., and on Meeting nights of the Institution and Royal Philosophical Society till 10 P.M., on Saturdays it is open from 9.30 A.M. till 2 P.M.

Members have the privilege of consulting the Books in the Library of the Royal Philosophical Society.

The use of the Library and Reading Room is open to Members, Associate Members, Associates, and Students.

The Portrait Album lies in the Library for the reception of Members' Portraits. Members are requested when forwarding Portraits to attach their Signatures to the bottom of Carte.

The Library Committee is desirous of calling the attention of Readers to the "Recommendation Book," where entries can be made of titles of books suggested as suitable for addition to the Library.

A List of the Papers read and Authors' Names, from the First to the Thirty-Third Sessions, will be found in Vol. XXXIII. of the Transactions.

As arranged by the Council, a Register Book for Students lies in the Library for the inspection of Members, the object being to assist Students of the Institution in finding suitable appointments.

ALEXANDER CLEGHORN,
Hon. Librarian and Convener.

OBITUARY.

Honorary Members

Archibald Campbell Campbell, Baron Blythswood of Blythswood, LL.D., F.R.S., was born on 22nd February, 1835, and died at Blythswood House, Renfrew, on 8th July, 1908. He was a son of Archibald Douglas, of Mains, in the County of Dumbarton, who, in 1838, assumed the name and arms of Campbell of Blythswood as heir of entail. The Douglases of Mains formed one of the most important branches of the illustrious house of Douglas. Lord Blythswood also claimed descent from the famous Campbells and from the same ancestor as the Dukes of Argyll. He was educated for the Army, and in 1854 joined the Scots Guards. With his regiment he was sent to the Crimea, and the historic siege of Sebastopol was among the first of his engagements, in which he was severely wounded while in the trenches. This campaign was not his last, for in 1862 he was despatched to Canada, and took part in the fighting there. On the death of his father in 1868, he retired from the Army with the rank of Lieutenant-Colonel. Though retired from active service he continued to take a keen interest in military affairs. For some years he was Lieutenant-Colonel of the 4th Battalion of the Argyll and Sutherland Highlanders, and when he resigned in 1904, he was appointed Honorary Colonel. He was also Honorary Colonel of the 3rd V.B.H.L.I., after having been in command of that regiment. He was an aide-de-camp to Queen Victoria, and subsequently to His Majesty King Edward.

In politics Lord Blythswood took an active part. He unsuccessfully contested Paisley in 1868, but was returned at a bye-election in 1873 as Member of Parliament for the County of Renfrew. At the General Election in the following year he was defeated, and he had a similar experience in 1880, but five years later he again entered Parliament as the member for Renfrewshire, retiring in 1892. In 1880, Colonel Campbell, as he then was, received a Baronetcy from Queen Victoria, and twelve years later he was raised to the peerage. Perhaps in no capacity during his varied and strenuous life did Lord Blythswood more distinguish himself than as a scientist. His private laboratory and engineering shop were splendidly equipped and contained many masterpieces of mechanical skill. One notable feature of the laboratory is the large statical electrical machine with 160 plates, the largest ever built. Electricity was with him a favourite subject of study, and in this department he occasionally worked in co-operation with Lord Kelvin. During recent years he devoted himself to pure scientific research, and many subjects claimed his attention, including the Röntgen rays, photo-electricity, spectroscopy, the application of liquid air, and radio-activity. He was a Fellow of the Royal Society, President of the Röntgen Society, and a member of several learned societies. In recognition of his scientific work the Senators of the Glasgow University conferred upon him the degree of Doctor of Laws.

Lord Blythswood was elected an honorary member of the Institution in 1891.

William Thomson, Baron Kelvin of Largs, O.M., P.C., G.C.V.O., D.C.L., F.R.S., was born at Belfast on 26th June, 1824, being the second son and fourth child of James and Margaret Thomson. James Thomson, who was at that time Professor of Mathematics in the Royal Academic Institute of Belfast, was the son of a small farmer at Ballynahinch, County Down, where his ancestors had settled about the year 1641 when they migrated from the lowlands of Scotland. Professor Thomson would never send his two boys, James and William, to school, but kept their education in his own hands. When William was eight years old, his father was offered the

Chair of Mathematics in Glasgow University. He accepted the offer, and with his family of six children left Belfast. After removing to Glasgow, Professor Thomson still superintended the education of his sons, and at the age of ten William entered the University classes without having previously been at school. He made rapid and wonderful progress in Mathematics and Physical Science, and in 1840 won the University Medal for an essay "On the Figure of the Earth," a subject which at that time had a peculiar attraction for him. In that year he began to study Fourier's remarkable book, "La Théorie Analytique de la Chaleur," a work published in 1822, full of new theorems and mathematical processes. The result was his first original paper, "On Fourier's Expansions of Functions in Trigonometrical Series," written before he was seventeen, and published in the Cambridge Mathematical Journal in 1841. In October of that year Thomson entered St. Peter's College, Cambridge, and began a course of study for mathematical honours. In a short time he mastered the contents of the text-books then in use, and was writing original contributions for the "Cambridge Mathematical Journal" on points in pure and in applied mathematics. During his career at Cambridge he took part in the athletic exercises of his College; he won the Colquhoun Silver Sculls, and rowed in the winning boat in the Oxford and Cambridge boat race in 1844. He helped to found the Cambridge University Musical Society, and played the French horn in the original Peterhouse band. In 1845 he went up for the Tripos examination, and came out Second Wrangler, beating the Senior Wrangler in the subsequent examination for Smith's Prizes, which was generally regarded as a better test of original ability than the Tripos. Shortly after these examinations, Thomson left Cambridge with a College Fellowship of £200 a year to maintain him, and went to Paris to work in the famous laboratory of Regnault at the College de France, where he remained four months, during which time he made the acquaintance of French mathematicians of the day, and attended meetings of the Académie des Sciences.

In 1846 the Chair of Natural Philosophy at Glasgow became vacant by the death of Professor Meikleham, and Thomson was, at the early age of twenty-two, appointed by the Faculty of the University to fill it. This professorship he continued to hold till 1899, when he resigned after a continuous service of fifty-three years. Early in his career as professor he established the first laboratory for students in this country, in which was carried out much research work that proved of great importance in later years. By the end of 1850 he had published no fewer than fifty original papers, principally of a mathematical character, several of them being in French. The atomic theory was, perhaps, the most notable contribution to mathematical physics, but within the domain of physics his researches in heat, magnetism, and electricity, were truly remarkable. In 1824, Carnot published a book on the motive power of heat, which attracted little notice till William Thomson drew attention to it. Up to this time physicists had a difficulty in accepting the dynamical theory of heat, as they had been unable to define temperature with sufficient exactness. In collaboration with Joule, he worked at the "Thermal Effects of Fluids in Motion," and in a paper on that subject, published in the Philosophical Transactions for June, 1854, an absolute scale of temperature was proposed. Another addition was made to scientific knowledge by his statement of the theory of dissipation or degradation of energy.

In 1843 Professor Morse suggested that it was possible to lay an electric cable between this country and America, but the proposal met with hostile criticism. Submarine telegraphy was, however, in the air, and Professor Thomson strongly opposed the objections raised, stating that a cable *could* be laid, and when laid messages *could* be sent through it. The Atlantic Telegraph Cable Company was formed; Professor Thomson became a director, and took an interest in the work of laying the first cable in 1857. The first attempt was a failure, the cable breaking in two thousand fathoms of water, about three hundred and thirty miles from Valentia, in Ireland. A second cable was laid in the following year, and congratulations were exchanged between Britain and the United States. The results, however, were not encouraging, for a month after it ceased to work. During the next seven years Professor Thomson played a prominent part in the preparation for laying another cable, which, through a disheartening mishap when 1000 miles of the cable were lost, ended in failure. In 1866 a new cable was successfully laid, and the lost one recovered from the ocean bed and completed. For his services rendered in this connection he was knighted. It was largely due to the prolonged struggle to make submarine telegraphy a success that led up to the invention, by Professor Thomson, of instruments and appliances for exact measurement which made general electrical engineering at all feasible.

Among the numerous inventions of Sir William Thomson it is difficult to select one, and stamp it as the most important. Without taking into consideration those patented since 1900, they number fifty-six. Of these, twenty-five relate to electric measuring instruments, eleven to telegraphy, a similar number to compasses and navigation appliances, six relate to dynamos and electric lamps, two to valves for fluids, and one to the electrolytic production of alkali. The variety of his activities was astonishing, and with the advent of electric lighting, at the close of the seventies, he turned his attention to this subject, and gave evidence before a Parliamentary Committee on Electric Lighting. His mind was unprejudiced regarding the application of science to practical ends. "There cannot," he wrote, "be a greater mistake than that of looking superciliously upon practical applications of science. The life and soul of science is its practical application; and just as the great advances in mathematics have been made through the desire of discovering the solution of problems which were of a highly practical kind in mathematical science, so in physical science many of the greatest advances that have been made from the beginning of the world to the present time have been made in the earnest desire to turn the knowledge of the properties of matter to some purpose useful to mankind."

In 1892 Sir William Thomson, while President of the Royal Society, was raised to the Peerage, and later was created a Member of the Order of Merit and a G.C.V.O. His foreign distinctions were numerous. He was a Knight of the Order Pour le Mérite of Prussia, a Foreign Associate of the Institute of France, and a Grand Officer of the Legion of Honour. He was a member of every foreign Academy, held honorary degrees from almost every University, and was a member of nearly every existing learned Society of importance. In 1896 the City and University of Glasgow celebrated his jubilee as Professor of Natural Philosophy. Three years later, at the age of seventy-five, he retired. In 1904 he was elected Chancellor of the University in which he had so long laboured. To the last Lord Kelvin investigated most vigorously the properties of matter, and took an intense interest in the most recent scientific discoveries. On 23rd November, 1907, Lord Kelvin was seized by a chill, and after about a fortnight of prostration he gradually sank and passed away at Netherhall, Largs, on the evening of the 18th December. Five days later he was laid to rest, with national honours, in Westminster Abbey, close by the grave of Newton.

Lord Kelvin was elected an honorary member of the Institution in 1859.

Members.

PETER HOGG ADAMSON was born at Dundee, on the 15th October, 1861, where he served his apprenticeship, both practically and theoretically, with Messrs Gourlay Brothers & Company. Thereafter he migrated to Maryport, where he remained for about seven years as naval architect to Messrs Ritson & Company, leaving there to take up a similar position with Messrs Mackie & Thomson, Govan. During the seventeen years he spent in the service of the latter firm he devoted much attention to the improvement in design and construction of vessels for the fishing industry. Mr Adamson possessed an amiable disposition which secured for him, both in business and in private life, innumerable friends and great popularity. His death, which took place suddenly at Partick, on 12th April, 1908, came as a great shock to all who had been in any way associated with him.

Mr Adamson became a member of the Institution in 1901.

Robert Allan was born at Troon, Ayrshire, where his father was Harbour-master for many years. Young Allan, after serving his apprenticeship with Messrs Denny & Co., engineers, Dumbarton, entered into employment with the firm of Messrs Mirrlees & Tait, Glasgow, now known as the Mirrlees, Watson Company, Limited. By this firm he was sent out on a special mission to Jamaica, and it so happened that while he was in the island the historic disturbances with which the names of Gordon and Governor Eyre are inseparably associated took place. As a member of the mounted police, young Allan assisted in quelling the riot. During his stay in Jamaica he was stricken with yellow fever, and after recovering returned home. The year 1869 found him taking full charge of the drawing office of Messrs Mirrlees & Tait. In 1873 he went out to British Guiana, seeking new surroundings. About this time Mr John Young, manager of the Demerara Foundry, resigned his position to take up an appointment in New Zealand, and Mr Allan was appointed his successor. Subsequently Mr Allan assumed full charge of the business and kept it going through all vicissitudes, which, by the nature of the concern synchronized with the vicissitudes of the sugar industry. His connection with the business was uninterrupted until his life ended. By constitution Mr Allan was unobtrusive. He took a keen interest in political life, but he sought no honours in that arena. He was a man not only of great technical skill, but an excellent man of business. He was true as steel, and his word was regarded as his bond. Courteous and kind, he possessed in a large degree those qualities and that temperament which go to make the gentleman in the old-world sense of the term. He died at Georgetown, Demarara, on 21st January, 1908, aged 74.

Mr Allan became a member of the Institution in 1895.

William Clark was born in the parish of Kirkofwald, Turnberry, on 3rd November, 1851, and was educated at the Girvan Public School. He served an apprenticeship with Mr Murdoch, civil engineer, Ayr. In 1872, he entered the service of Messrs McCreaths & Stevenson, civil and mining engineers, Glasgow, and became a partner in that firm in 1897. He was largely responsible for the planning and carrying out of the Airdrie and Coatbridge water works scheme; and towards the latter part of his career he was frequently engaged as arbiter in the settlement of disputes in connection with building construction and mining operations. He died at Glasgow on 2nd September, 1908.

Mr Clark joined the Institution as a member in 1893.

James Denholm was born at East Barns of Clyde, near Yoker, on 11th November, 1841, and served his apprenticeship with Messrs Tod & McGregor at Meadowside and the Clyde Foundry. He was foreman patternmaker and later on foreman engineer with this firm up till 1872, when the works were purchased by Messrs David & William Henderson & Co., who retained his services at Meadowside for some years, and afterwards appointed him works manager of their Finnieston Steamship Works in Elliot Street, which position he held up to the time of his retiral from business at the latter end of 1907. Between the two firms, he was for about fifty-three years connected with Meadowside, the Clyde Foundry, and the Finnieston Steamship Works. He died on 25th May, 1908.

Mr Denholm was elected a member of the Institution in 1883.

Andrew Gibb was born at Glasgow in 1850. In early youth he was apprenticed to Messrs Barclay, Curle & Co., Glasgow, and after having gained experience at sea he left the engine-room to occupy a position as draughtsman with a firm of engineers at Millwall. Shortly after the foundation of the firm of Messrs Rait & Gardiner, Mr Gibb was appointed their works manager and ultimately became managing partner. The operations of the firm grew in a remarkable manner, and branches were opened at Cubitt Town, Albert Dock, and Tilbury. Having such a wide area of interest to command, the work executed by the firm was considerable, especially in connection with ship repairs due to damage by collision or otherwise. Mr Gibb was an alderman of the borough of Greenwich, and his capacity for business was highly esteemed in the Council Chamber. He was a generous giver, and the services he rendered to the municipality will not soon be forgotten. His death took place on 3rd April, 1908.

Mr Gibb joined the Institution as a graduate in 1873, and became a member in 1882.

Edwin Griffith, who, at the time of his demise on December 7th, 1907, was a partner in the firm of Messrs Denny & Co., engineers, Dumbarton, was a native of Holyhead. Having acquired a sound scientific education, in the course of which he won a Whitworth scholarship, he commenced his professional career as an engineer in the Fairfield Shipbuilding & Engineering Co.'s Works, at Govan. Subsequently he became chief draughtsman with the Wallsend Slipway & Engineering Co.

In the early autumn of 1904, Mr Griffith returned to the Clyde as manager in the engineering department of Messrs Barclay, Curle & Co., Glasgow, in whose employ he only remained about a year and a half. Early in 1906 he went to Dumbarton to act in a similar capacity with Messrs Denny & Co., of the Dumbarton Engineering Works, taking up the position and duties of the deceased Mr Henry Brock, son of Mr Walter Brock, principal of the firm, whose lamented demise followed shortly upon that of his talented son. Mr Griffith was assumed a partner in the old-established firm before the demise of Mr Walter Brock, but had only occupied the position for about a year, when, at the beginning of December last he became seriously unwell. On the 6th of that month he was operated upon for appendicitis, and it was the shock supervening the operation which caused the sad termination to his career. He was only in his 40th year. In his death, the younger race of marine engineers lost another member of outstanding promise.

Mr Griffith joined the Institution as a member in 1906.

John Guthrie was a native of Greenock, where he was born on 6th September, 1845. He received his early education at the Greenock Academy, after leaving which he worked for a few years in the office of Mr. William Paton, writer. He then accepted a post in the Greenock branch of the British Linen Company Bank. In 1865 he was transferred to Glasgow, and remained with the British Linen Company Bank till 1873, when he was appointed agent of the Laurieston branch of the Commercial Bank of Scotland. In 1882 he became manager and secretary of the Crown Iron Works, belonging to Messrs L. Sterne & Co., engineers, Glasgow, latterly becoming managing director, a position he continued to occupy till death overtook him on the 23rd June, 1908.

Mr Guthrie joined the Institution as a member in 1896.

ROBERT LAIDLAW, principal of the firm of Messrs R. Laidlaw & Son, engineers and founders, Glasgow, and Chairman of the Barrowfield Iron Works Company, Glasgow, died at Ascog, Bute, on 19th October, 1907. He was born at Edinburgh on 9th September, 1837, and at an early age went to reside in Glasgow, where his father laid the foundation of the business in which the subject of this notice spent the major portion of his life. He passed through the various workshops as an apprentice, made himself acquainted with business methods, and, in 1861, was assumed a partner. During his career, he successfully carried out many important contracts for gas and water-works' plant all over the world, among which may be mentioned the gas works' plant and machinery, and the pumping engines, and distribution water mains for the city of St. Petersburg. In business his high sense of responsibility and integrity caused him to be respected by a wide circle of friends. On more than one occasion he was pressed to stand as a candidate for Parliamentary honours, but being of a somewhat quiet disposition he was not disposed to activity in public life, and declined. In local affairs, however, he took an interest, and for some time was a director of the Glasgow Chamber of Commerce and a Governor of Anderson's College, while at the time of his death he was a director of the Merchants' House. He was also one of the pioneers of the Volunteer movement, and was appointed Major of the 19th Lanarkshire Volunteers in 1868.

Mr Laidlaw joined the Institution as a member in 1862.

WILLIAM TODD LITHGOW, who was born at Port-Glasgow on the 24th September, 1854, was intimately connected with the shipbuilding industry from his youth. He served an apprenticeship as draughtsman with Messrs. John Reid & Co., Port-Glasgow, now of Whiteinch, and while quite a young man he joined Mr Joseph Russell and Mr Anderson Rodger in extending the firm of Russell & Co. in the eastern district of Port-Glasgow. Subsequently, owing to the rapid development of the business, an additional shipbuilding yard was established at Kingston in the west end of the town. On the dissolution of the firm, in 1891, and the retirement of Mr Russell from business, Mr Rodger took over the control of the eastern yard, while Mr Lithgow remained sole partner of the Kingston establishment. Under the guidance of Mr Lithgow, the prosperity of the establishment was phenomenal, and the amount of work turned out annually truly remarkable.

Mr Lithgow was a man of keen and untiring business capacity, and although principally absorbed with the management of his own affairs, he was not oblivious to claims of a public and social nature. As showing his generous nature, it is worthy of mention that, he gifted a sum of £10,000 for the demolition of the slums of his native town, and the reconstruction of the more congested parts, in accordance with a scheme for the better housing of the working class. He took a keen and personal interest in ambulance work, and it was almost entirely due to his sympathy and encouragement that the Kingston yard occupies a leading place in this respect among the Clydeside yards. Although he did not take an active part in the affairs of the Institution, he was in full sympathy with the new housing scheme, and was among the first subscribers to the Building Fund, to which he donated £500. After a brief illness he passed away at his residence, Drums, Langbank, on the 7th June, 1908, in the fifty-fourth year of his age.

Mr Lithgow joined the Institution as a member in 1893.

George McFarlane was born at Glasgow on the 22nd day of June, 1846. On leaving school, he entered the engineering department of Messrs James & George Thomson as an apprentice, and after his period of training in that establishment was over he joined the service of the Cunard Company. In the early seventies the State Line of steamships was started, and he became associated with that concern as superintendent engineer, filling that office until the steamers of the Company were purchased by the Allan Line in 1891. Shortly after he commenced business on his own account, and conducted a very successful practice as a consulting engineer and naval architect. On the formation of the British Corporation for the Survey and Registry of Shipping, Mr McFarlane became its chief engineer-surveyor. He was frequently commissioned by the Japan Mail Steamship Company in connection with their numerous fleet of passenger steamers, and when, in 1900, the Glasgow agents of the Company floated the business under the Limited Liability Companies' Act, Mr McFarlane became the managing director of the engineering department. The firm traded under the name of Messrs A. R. Brown, McFarlane & Company, consulting engineers, and agents of the Japan Mail Steamship Company. The duties of the Consulate of Japan were also discharged by the firm. During his career he was frequently consulted by leading Glasgow firms in connection with the design and construction of steamers; and on the North-East coast of England he was well known in a professional capacity. Mr McFarlane was a member of the principal technical institutions of this country. He took an active interest in the affairs of the Institution, and during sessions 1902-04 he was a Member of Council. While holding office he was selected to represent the Institution on the Consultative Committee appointed to confer with the Marine Department of the Board of Trade. About a month prior to his death Mr McFarlane was confined to his residence, Dunsloy, Bellahouston, suffering from peritonitis, to which he succumbed on the 6th April, 1908.

Mr McFarlane joined the Institution as a graduate in 1874, and became a member in 1885.

DAVID McGEE was born at Govan in 1856, and began his connection with shipbuilding in the yard of the now defunct firm of Messrs James & George Thomson, when they had their yard in Govan. His father for many years was head foreman joiner with the firm, and David began as an office boy, rising by dint of perseverance and natural abilities through all the stages of shipbuilding experience. With many of the existing staff he went to Clydebank when the Thomson firm laid out their new establishment there about the year 1880. He rose to the position of under-manager to the late Mr Samuel Crawford, on whose departure, in 1893, to take up a partnership in and management of Kinghorn Shipyard, he was promoted to the managership. This was while the British battleship "Ramillies" was undergoing completion. He retained his position during the period the business was being carried on under the name of the Clydebank Shipbuilding & Engineering Company, and about eight years ago, when the establishment was acquired by Messrs John Brown & Co., Ltd., of the Atlas Works, Sheffield, he was made a director of the works. Ingenuity and practical thoroughness, with marked powers of initiative and administration, characterised Mr McGee in all his work, and the many battleships, cruisers, first-class ocean liners and high-class channel steamers completed during his term of management are eloquent testimonies to his abilities. The latest and greatest of these productions, of course, was the Cunard turbine liner "Lusitania," and with this great vessel the name of Mr McGee—no less than those of his associates in the management of the Clydebank concern, Mr John G. Dunlop, managing director, Mr Thomas Bell, engineering manager, and Mr W. J. Luke, naval architect—will long be honourably connected. Deceased was held in high esteem by every member of the staff at Clydebank and in every department of the works, and his presence and counsel inspired confidence in the carrying out of every important contract.

He was a member of the Clyde Shipbuilders' Association, and about four years ago was elected chairman. In this important position he always evinced readiness to take a fair and moderate view on points of dispute between masters and men. He was a Member of Council of the Institution, and took an active part in the work of the Committee in charge of the erection of the Institution's new buildings in Elmbank Crescent. He took a deep and personal interest in the public affairs of Clydebank and district, being a member of the County Council of Dumbartonshire and of the School Board of the Parish of Old Kilpatrick. His advice and counsel were at all times available in matters connected with educational work, and especially with the evening science classes. Mr McGee, who had been laid down with influenza and erysipelas for about six weeks, succumbed to his severe ailment on January 17th, 1908, his demise in the prime of life and in the thick of active enterprise and achievement being generally mourned.

Mr McGee joined the Institution as a member in 1896.

John Finlay Maclaren, second son of the late Mr Robert Maclaren, ironfounder, Glasgow, was born in 1868, and educated at the Bellahouston Academy and the Glasgow University. He graduated as Bachelor of Science in 1888, and thereafter entered the pipefounding business carried on by his father at Port Eglinton, under the title of Robert Maclaren & Sons, of which firm he latterly became a partner along with his brother, Mr Robert Maclaren. Here his energy and ability were shown by the many improvements he introduced with respect to the machinery and methods employed in the manufacture of cast iron pipes. In 1907 he was appointed a director of Messrs. James Dunlop & Sons, Clyde Iron Works, but did not live long to carry out the duties of his new office. His promising career was suddenly cut short by the outbreak of enteric fever which visited the west-end of Glasgow in December, 1907, and he died on the 9th of January, 1908, in his 40th year.

Mr Maclaren became a member of the Institution in 1892.

ROBERT F. MILLAR was born at Glasgow in 1869 and received his education at the Glasgow Academy. He served an apprenticeship with Messrs Wharrie, Colledge & Brand, civil engineers, Glasgow, and thereafter filled a position under the late Mr Daniel Cunninghame, contractor. Later, he entered the service of the Glasgow Corporation, becoming an assistant to the late Mr James M. Gale, chief engineer of the Water Department. Subsequently he started in business on his own account as a civil engineer, and acted for some time as consulting engineer for the Renfrew County authorities. He died at the Kilmacolm Hydropathic on 16th January, 1908.

Mr Miller joined the Institution as a graduate in 1890, and became a member in 1903.

JOHN NORMAN was born at Port-Dundas, Glasgow, and served an apprenticeship with Messrs. Norman & Clinkskill, engineers and millwrights, Dobbie's Loan, Glasgow, of which firm his father was a partner. In their employment he continued for some time as a journeyman, subsequently becoming a foreman. Severing his connection with the firm, he became associated with various individuals in engineering and machine making, he returned after a few years to become a partner. Shortly afterwards Mr Clinkskill retired from the business, and the title of the firm was changed to William Norman & Sons. Later, Mr Norman retired, and, conjointly with Mr James Copeland, inaugurated a new business which was known as John Norman & Co., Pulteney Street Engine Works. On the dissolution of partnership, Mr Copeland retained the works, and Mr Norman removed to premises at Keppochhill where he carried on business with partners for some years. He then ceased from manufacturing, and for the remainder of his days practiced as a consulting engineer and valuator in Glasgow. He was widely known as an able engineer, practical rather than theoretical, solving the problems which came to him more by intuition than calculation. A few weeks before he died his health began to fail, but he continued to attend to his business even to the day previous to his death, which took place at his residence, Beechmount, Lenzie, on the 2nd July, 1908, in his seventy-ninth year.

Mr Norman joined the Institution as a member in 1861.

Sir **David Richmond**, chairman and managing director of Messrs David Richmond & Co., Ltd., died at his residence, Broompark, Pollokshields, on 15th January, 1908. Born in the village of Deanston, Perthshire, in the year 1843, he was brought to Glasgow in infancy, and his early years were spent in Monteith Row. He received his education first at St. James's Parish School and at the Glasgow High School, then in John Street. Later he attended classes at the Mechanics' Institute, which is now merged in the Technical College. At the age of twenty-one his health was not satisfactory, and he spent three years in New Zealand and Australia. Soon after returning, in the year 1867, he started the business of iron tube making at the City Tube Works in Aytoun Court, and from the first this venture was successful. The railway operations here, however, caused the Tube Works, like the College, to be transferred elsewhere, and the Clutha Works of Messrs P. & W. MacLellan, in Rose Street, Hutchesontown, were bought and remodelled for the work of tube making. The North British Tube Works were added in 1882, and in 1900 the business was converted into a limited liability company with Sir David Richmond as chairman.

For over a quarter of a century he was closely identified with the public service of Glasgow, having been elected in 1879 to represent Hutchesontown Ward in the Town Council. He soon took a leading part in city affairs and during his municipal career filled the offices of magistrate, city treasurer, and chairman of the Parliamentary Bills Committee. In 1896 he was elected Lord Provost of the "Greater Glasgow" Council, then increased by the extension of the city. It was fortunate, indeed, that the chair was at this time filled by a man of experience in municipal works. For many years Sir David Richmond was one of the representatives of the Council on the Clyde Trust, and he became chairman *ex officio* on his election as Lord Provost. On the expiry of his tenure of office as Lord Provost, he was again returned to the Clyde Trust as a representative of the Chamber of Commerce, and on the retiral of Sir Nathaniel Dunlop, he was unanimously elected chairman. He was knighted in January, 1899, and was a Deputy-Lieutenant for the City of Glasgow. Besides his many other public duties he was the leader of the movement for the reconstruction of the Royal Infirmary, deacon of the Incorporation of Hammermen, and a member of the South African War Hospitals' Commission, to which he was appointed by the Government. In addition to his business of tube making, Sir David was also intimately associated with other large industrial and commercial concerns, including the Broxburn Oil Co., and the Clyde Valley Electrical Power Co., of which he was chairman.

Sir David Richmond joined the Institution as a member in 1897.

Sir **John Shearer**, head of the shipbuilding and repairing firm of John Shearer & Sons, Elderslie Works, Scotstoun, died at Glasgow on 28th February, 1908. Sir John Shearer was born at Glasgow and received his early education in his native city. On leaving school, he was apprenticed as a joiner to his father, who carried on business in a shop adjacent to Kingston Dock, where eventually, under the title of John Shearer & Sons, a ship-repairing works was established. About the year 1891, the old-established shipbuilding and repairing works, formerly carried on by Messrs Aitken & Mansell, became vacant, and his firm entered into occupancy, carrying on an important business till 1905, when the site was required by the Clyde Navigation Trustees for dock and harbour extensions. Anticipating this removal, the firm, a year or two previously, acquired ground at Scotstoun and laid out there a new shipyard and graving dock. Owing to the nature of the subsoil, considerable difficulties were experienced during the construction of the dock, involving a much heavier expenditure than was originally anticipated. It also became apparent that the development of business in the new works would be slower than at first expected. For these reasons, during the latter part of Sir John Shearer's life there was a temporary check to his commercial prosperity. He took an active interest in the municipal affairs of Glasgow, and for nearly a quarter of a century he served in the Town Council, acting as convener of many committees appointed to conduct various undertakings. He will be long remembered for his work in connection with the International Exhibitions held in Glasgow in 1888 and 1901, of which he was vice-chairman and chairman of the Committee on Buildings. For his public services, His Majesty the King conferred upon him the honour of Knighthood, in 1903.

Sir John Shearer joined the Institution as a member in 1900.

JOHN ALEXANDER GOWANS TAINSH, eldest son of the Rev. John Tainsh, was born at Aberdeen, on 15th August, 1879, and received his education mainly at the Glasgow High School and the Glasgow University, where he graduated B.Sc. in 1903. He served an apprenticeship of five years with Messrs. Muir & Houston, engineers, Glasgow, passing through the various shops and the drawing office of that firm. At the termination of a most successful university career, he became an assistant engineer with Messrs Biles, Gray & Co., engineers and naval architects, London and Glasgow. While with this firm, he was principally engaged as inspector of machinery for several high-speed passenger vessels and the Khedive's yacht "Mahroussa," in charge of which he was sent to Egypt. In October, 1907, he was appointed assistant superintendent of Dalla Dockyard, Rangoon. Eight months later his health broke down, and he returned to Scotland to recruit, but was again seized with dysentery and died on 30th August, 1908.

Mr Tainsh joined the Institution as a member in 1905.

James Welsh was born at Glasgow in 1865, and was educated at the Glasgow Academy, the Glasgow and West of Scotland Technical College, and the Glasgow University. He received his early practical training as an apprentice with Messrs Robert Napier and Sons, Govan. Shortly after completing his apprenticeship, Mr Welsh entered the drawing office of Messrs A. & J. Inglis, engineers, Glasgow, and some seven years later was appointed chief draughtsman with that firm. On the death of his father, Mr Thomas M. Welsh, he became the engineering manager with Messrs A. & J. Inglis, and this position he held at the time of his death. Mr James Welsh was gifted with the inherited instinct of the true engineer and the ability to apply a sound theoretical knowledge to practice. His work, to which he gave untiring energy, was well known in the branch of engineering with which he was associated. He died, after a brief illness, on 28th December, 1907, in his 43rd year.

Mr Welsh joined the Institution as a graduate in 1885 and took an active part in the work of that section as its Hon. Secretary, and Vice-President. He became a Member in 1897.

Associate Member

JOHN SHAW STEWART NIVEN, third son of the Very Rev. Dr. Niven, was born at the Manse, Linlithgow, in October, 1873, and was educated at Glasgow. He served an apprenticeship with Messrs James Howden & Co., engineers, Glasgow, and subsequently sailed as an assistant engineer between Bombay, and China and Japan for about five years. In 1902 he settled in Basreh in the Persian Gulf, having been appointed superintendent of the Tigris and Euphrates Line of Steamers owned by Messrs Leitch. After occupying this position for a period of five years, he became assistant manager with Messrs Alcock, Ashdown & Co., Bombay. Death overtook him suddenly at Bombay on 12th June, 1908.

Mr Niven joined the Institution as a graduate in 1898, and became an associate member in 1907.

Associate

JOHN CAMPBELL WHITE, Baron Overtoun of Overtoun, was born at Hayfield, Rutherglen, on 21st November, 1843, and died at Overtoun, Dumbartonshire, from pneumonia accompanied by heart complications, on 15th February, 1908, in his sixty-fifth year. He received his early education at the Glasgow Academy, and afterwards at Glasgow University, where he graduated Master of Arts in 1854, taking high prizes in both the Logic and Natural Philosophy classes. While in the latter class he spent a session in the laboratory of the late Lord Kelvin. After his university career, Lord Overtoun entered the Shawfield Chemical Works at Rutherglen, which came into the possession of Messrs J. & J. White in 1810, the principal of the firm at that time being his great-grandfather. In 1867 he was assumed a partner, and on the death of the elder members of the firm, he occupied the position of sole proprietor of the works, which are considered the largest of the kind in the world. Although latterly the practical management was in the hands of his two nephews, he took an active part in the commercial side of the business up to the last. He was created a Baron in 1893, and took the title of Overtoun, after the name of his estate. He was a man remarkable among his compeers, and filled the roll of merchant prince, county magnate, evangelist, and philanthropist; the number of religious and philanthropic bodies with which he was connected being legion. He also took an active interest in the county administration of Dumbartonshire.

Lord Overtoun joined the Institution as an associate in 1903.

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7 3 B.H.P. DE LAVAL STEAM TURBINE.
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14 AIR RECEIVERS do. do.
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39 GANGWAY TO BOILERS.

NORBURY, NATZIO & CO. LTD., ENGINEERING LITHOGRAPHERS, GLASGOW.

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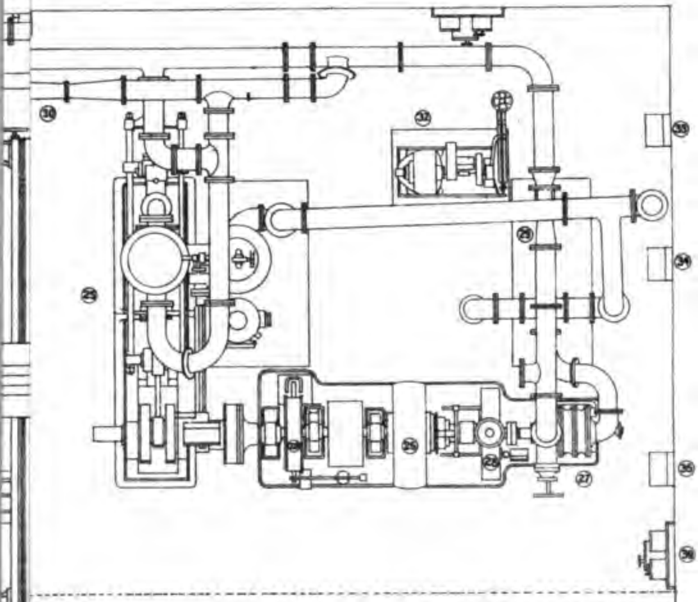
PLATE II.



PLAN BELOW PLATFORM.

REFERENCE TABLE.

TORY, 70 ft. × 41 ft.
NG LABORATORY
G MACHINE
NSION-TORSION TESTING

ION-TESTING MACHINE
MACHINE
FROM ROOF TANK
D ROOF TANK

BINE

E
MN
S

TANKS

KS
VES
NK VALVES
PELTON WHEEL

23 HYDRAULIC RAM
24 SMALL ORIFICE TANK
25 DIFFERENTIAL RECIPROCATING PUMP
26 VARIABLE SPEED MOTOR
27 EXPERIMENTAL TURBINE PUMP
28 BRAKES
29 LEEDS METER
30 6-INCH VENTURI METER
31 DIFFERENTIAL MANOMETERS
32 JOURNAL FRICTION AND OIL TESTING MACHINE
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34 DIFFERENTIAL AIR GAUGE
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37 PIPES FOR EXPERIMENTS ON LOSS OF HEAD
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39 SWITCH BOARD
40 HYDRAULIC PRESSURE PIPES
41 CEMENT TESTING MACHINE
42 SETTING CUPBOARDS
43 WATER TANKS
44 TABLE
45 SINK

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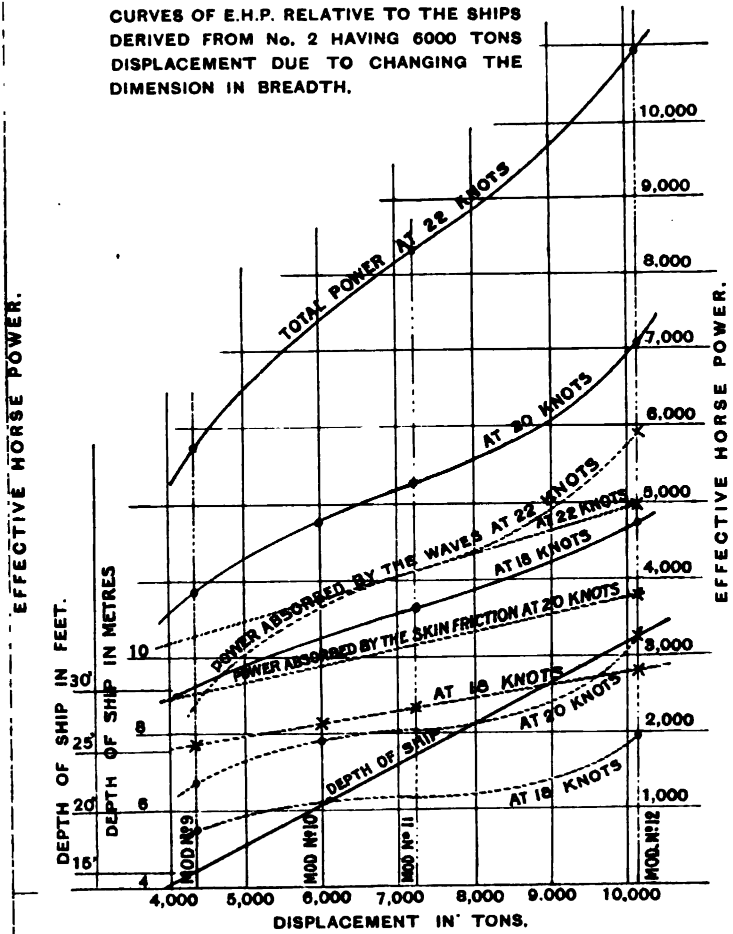
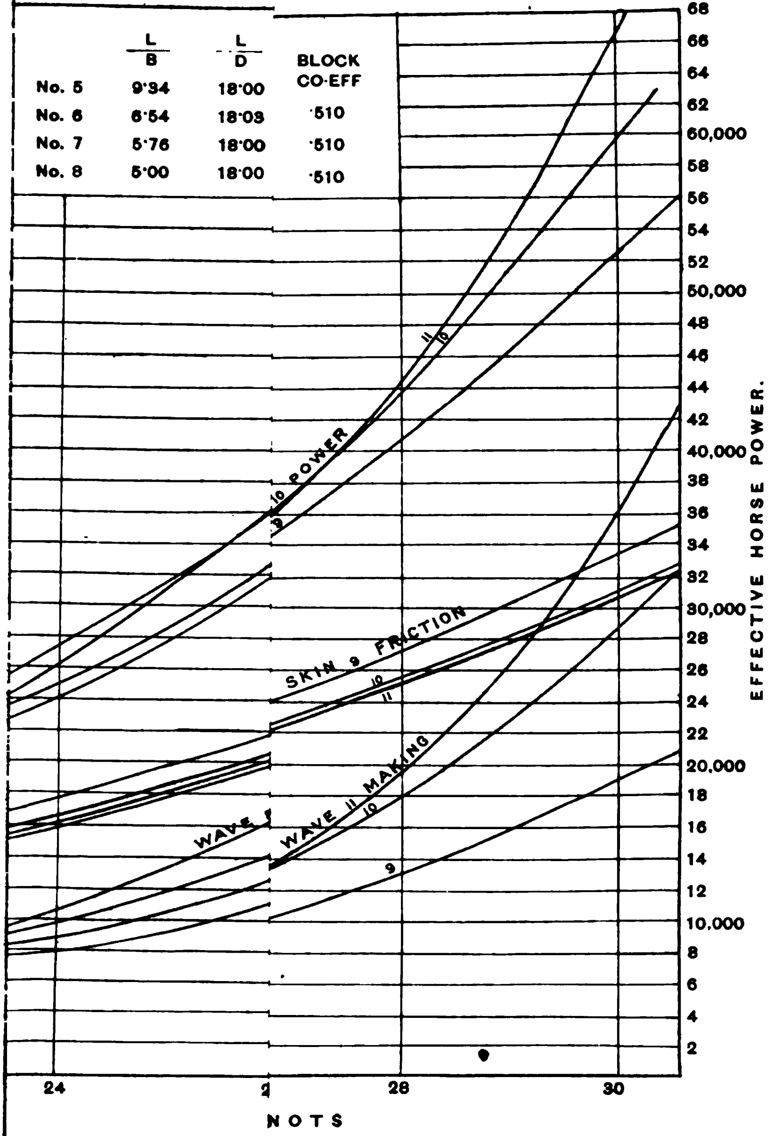
NORBURY, NATZIO & CO. LTD., ENGINEERING LITHOGRAPHERS, GLASGOW.

Fig. 3.


CURVES OF E.H.P. RELATIVE TO THE SHIPS DERIVED FROM No. 2 HAVING 6000 TONS DISPLACEMENT DUE TO CHANGING THE DIMENSION IN BREADTH.

NORBURY, NATZIO & CO. LTD., ENGINEERING LITHOGRAPHERS, GLASGOW

6



	$\frac{L}{B}$	$\frac{L}{D}$	BLOCK CO-EFF
No. 5	9·34	18·00	
No. 6	6·54	18·03	·510
No. 7	5·76	18·00	·510
No. 8	5·00	18·00	·510

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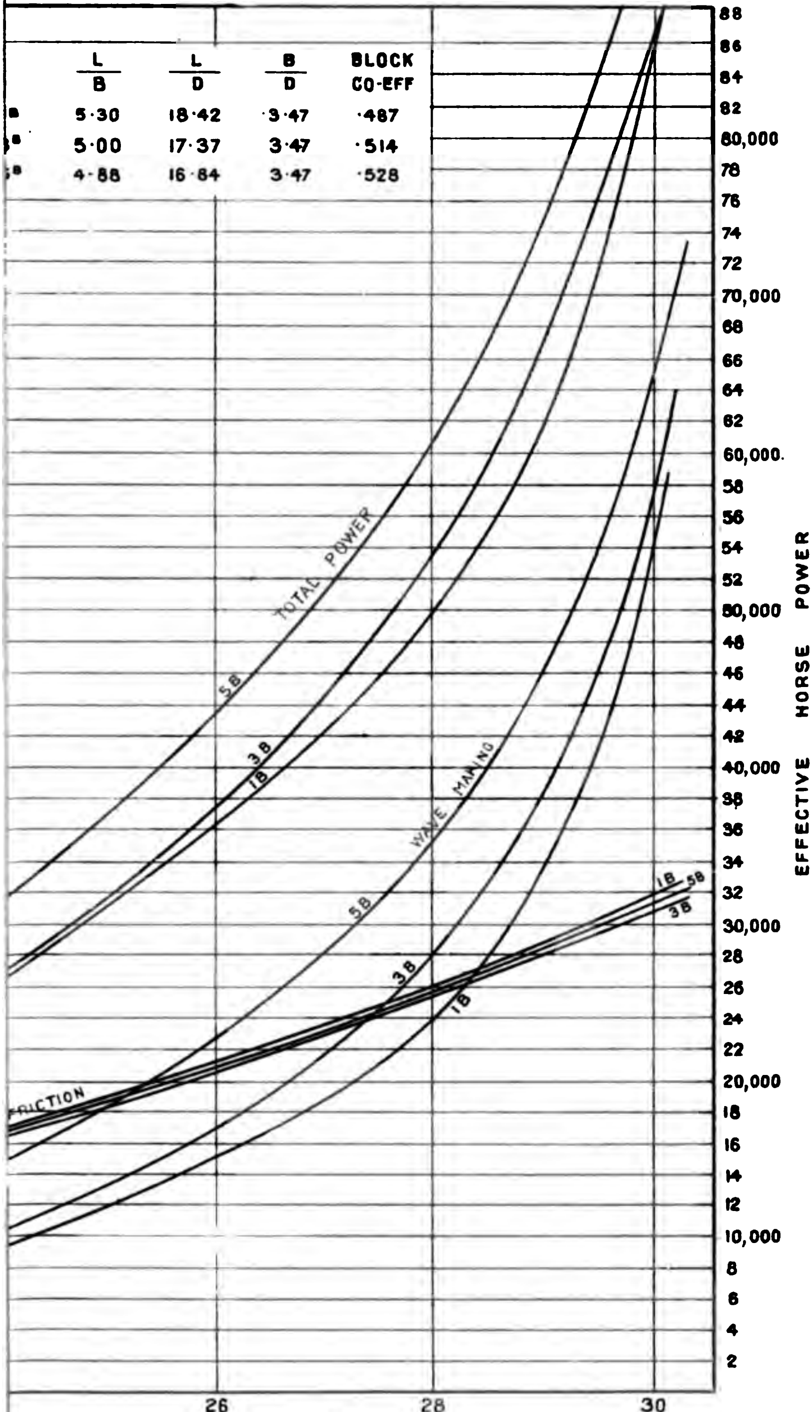
Fig. 8.


L/B
L/D
B/D
BLOCK CO-EFF
5·30 18·42 3·47 ·487
5·00 17·37 3·47 ·514
4·88 16·84 3·47 ·528
TOTAL POWER
5B
3B
1B
WAVE MAKING
5B
3B
1B
FRICTION
1B
5B
3B
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86
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82
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EFFECTIVE HORSE POWER
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KNOTS

RELATI

PLATE VI

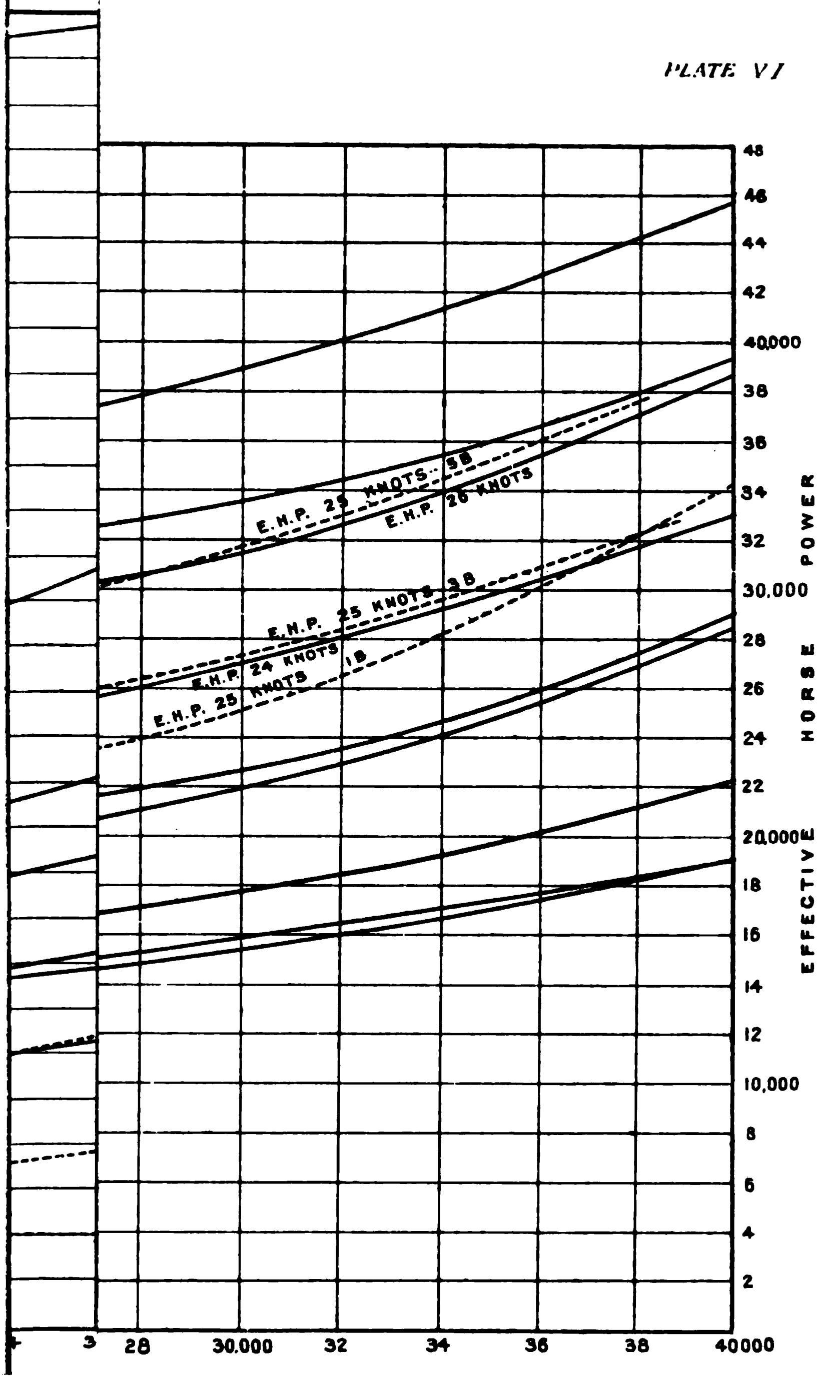

PLATE VII

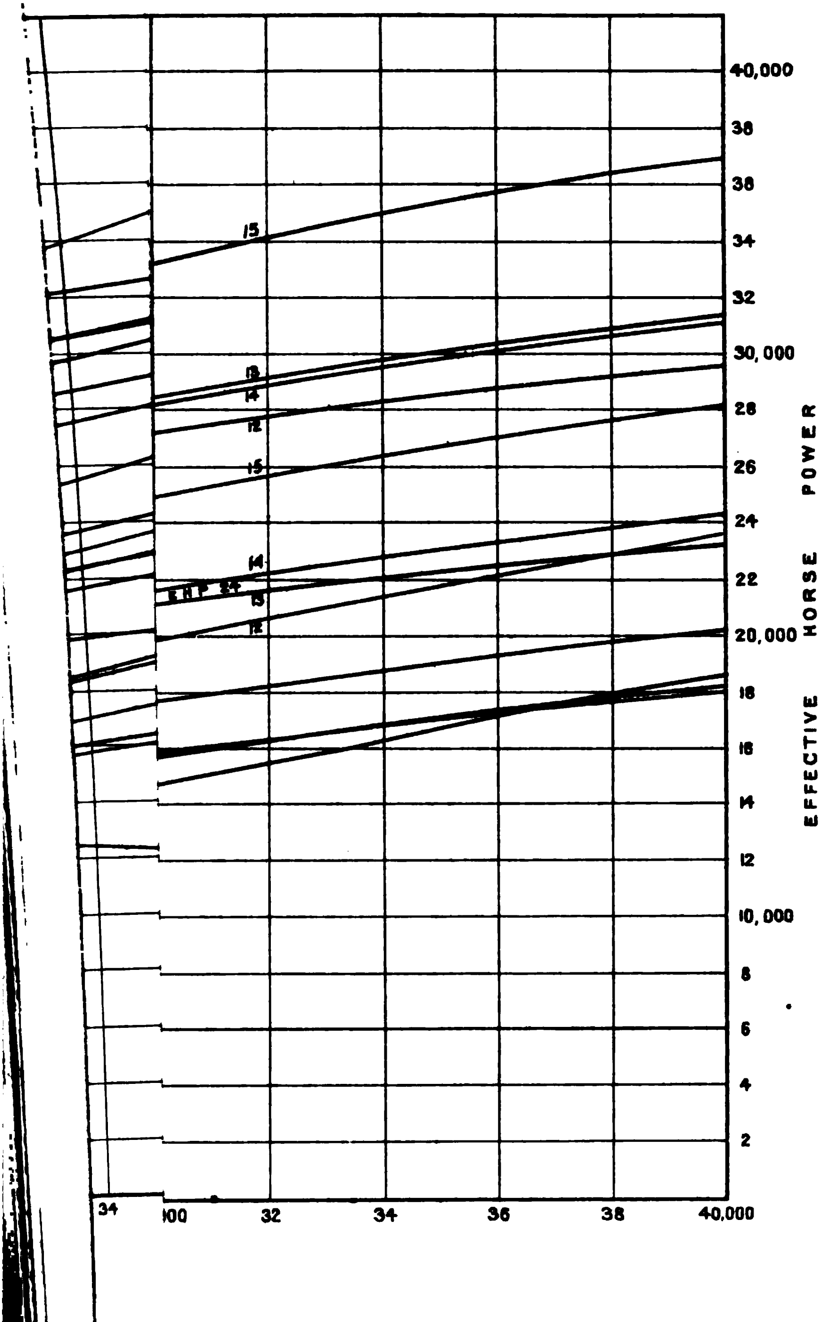

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Fig. 16.

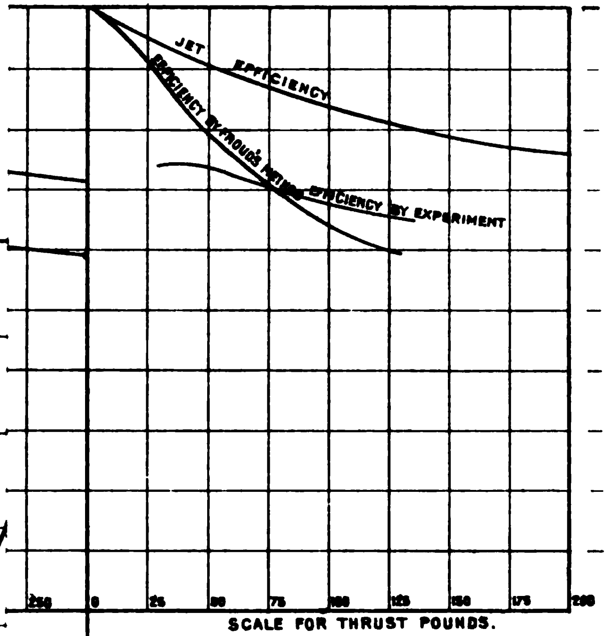
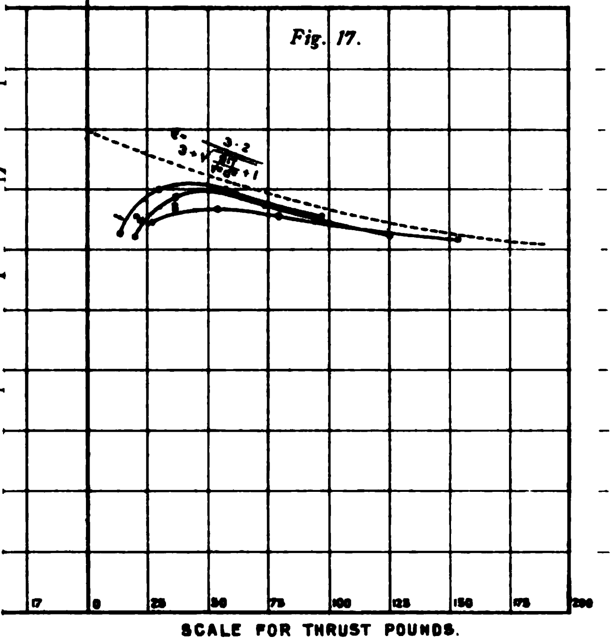


Fig. 17.



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WITH NO

PLATE IX.

NORBURY, NATZIO & CO. LTD., ENGINEERING LITHOGRAPHERS, GLASGO

G. 6.

GEAR.

P. = 800

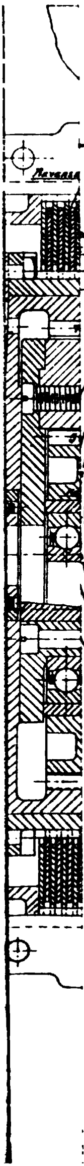
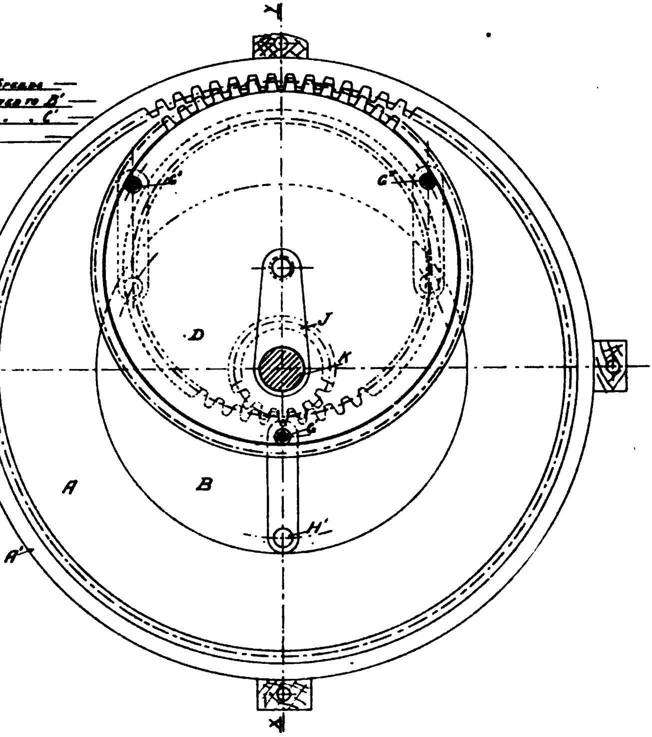


FIG. 7.

LLITE CRANK MOVEMENT.



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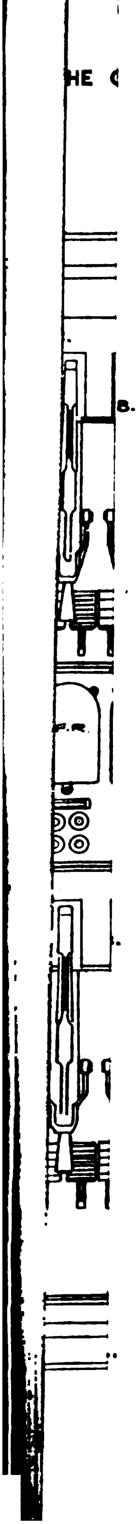

Fig. 3.

RACK FOR CABLES
ON
BUNKER SIDE PLATING.

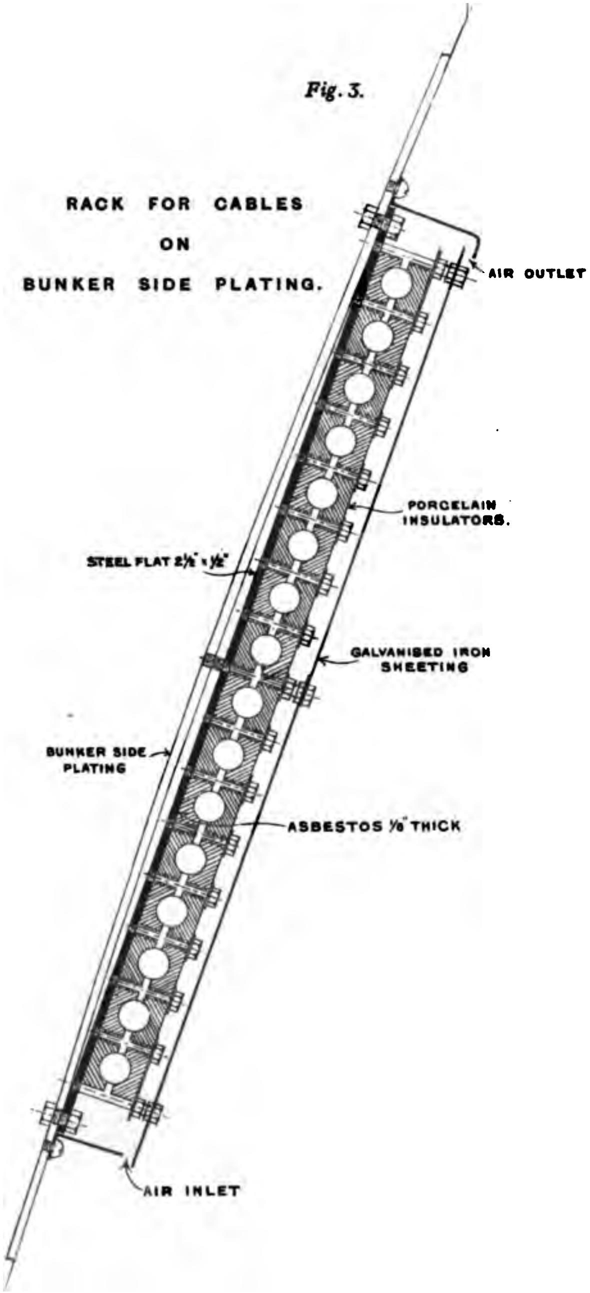

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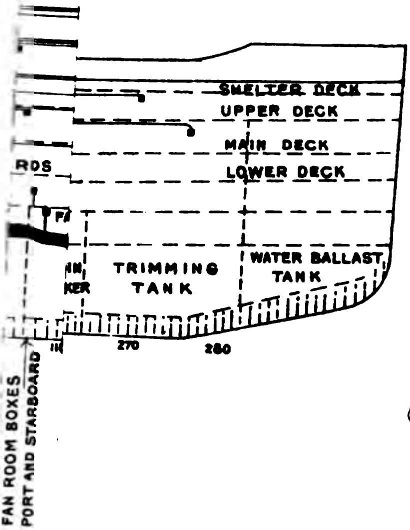
PLATE XII



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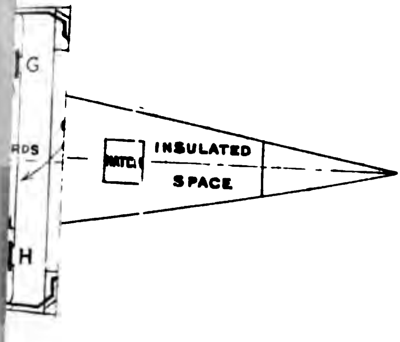
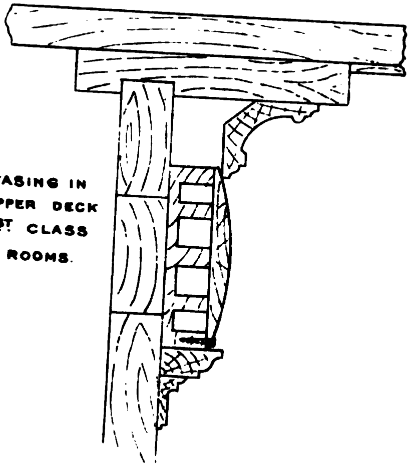


Fig. 7.



CASING IN UPPER DECK 1ST CLASS ROOMS.

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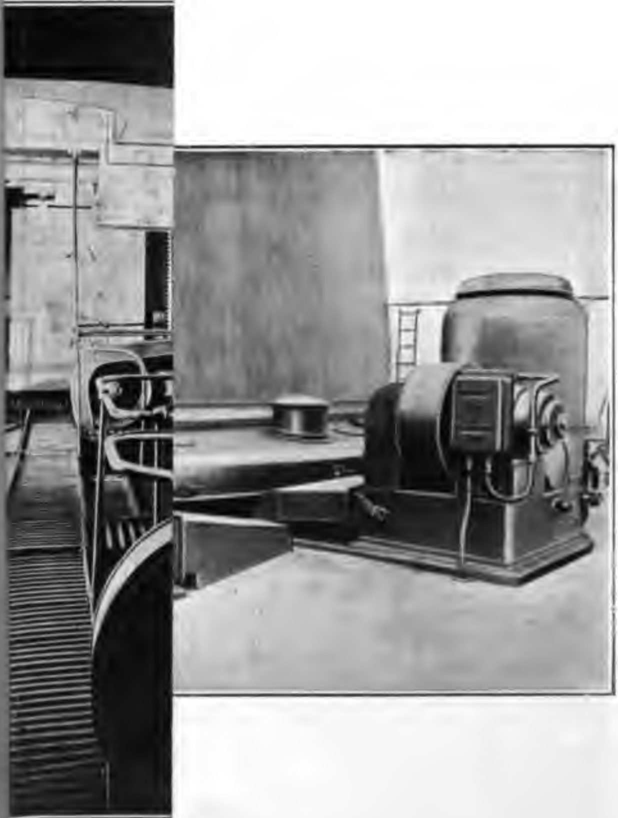
OF THE CUNA

PLATE XIII.



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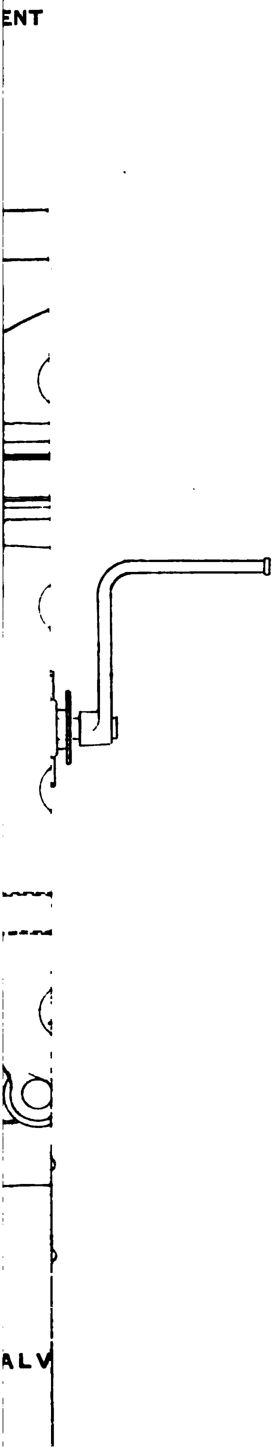
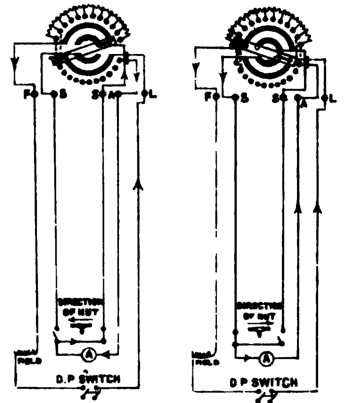


Fig. 12.



SHEWING VALVE COMMENCING TO SHUT.

SHEWING VALVE COMMENCING TO OPEN.

DIAGRAM OF WIRING OF MOTOR AND SWITCHES FOR SLUICE VALVES.

16

Fig. 18

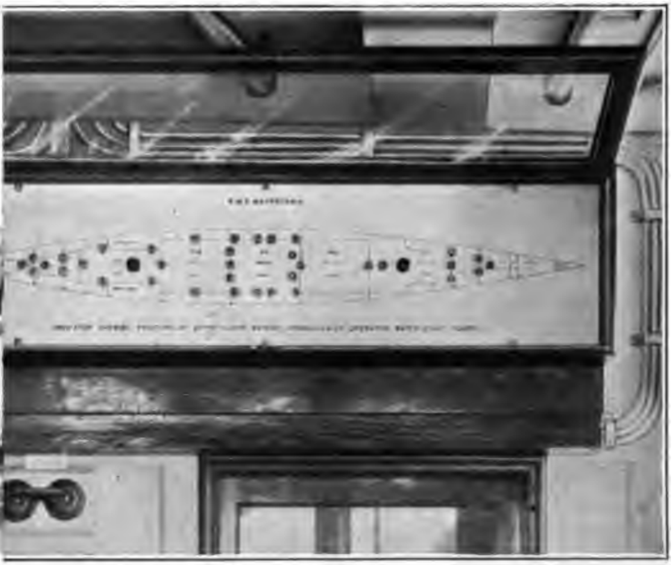


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PLATE XVI

L ARRANGEMENT.

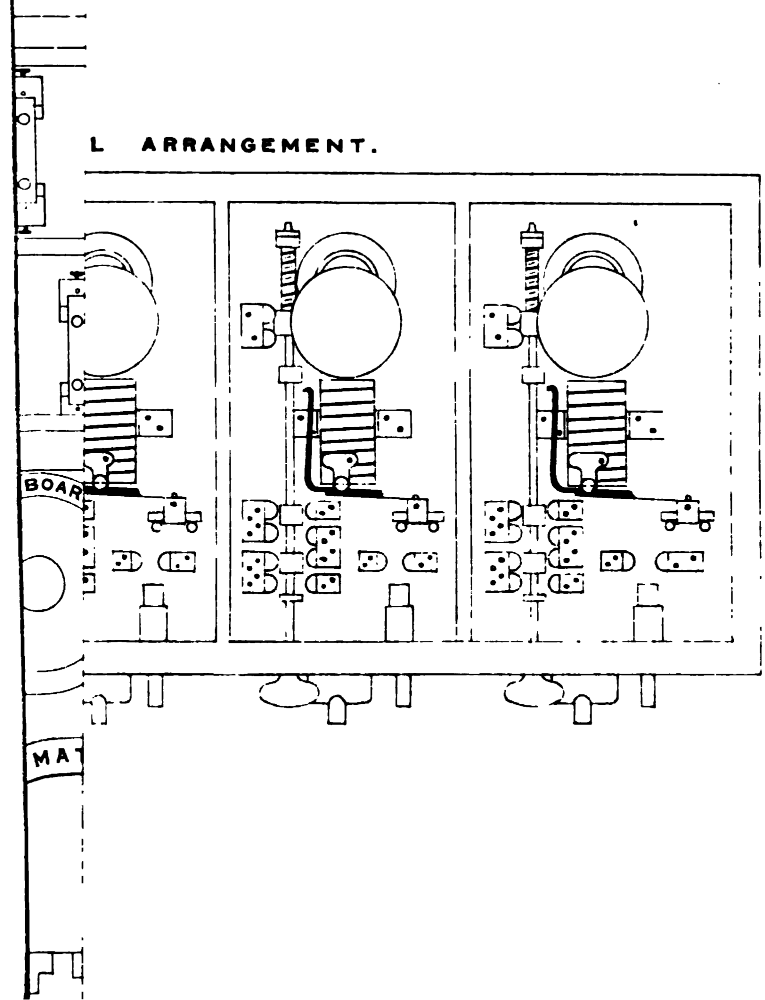

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Fig. 4.