TRANSACTIONS

OF THE

Institution of Engineers and Shipbuilders

IN SCOTLAND

(INCORPORATED).

VOLUME XLVIII.

FORTY-EIGHTH SESSION, 1904-1905.

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FORTY - EIGHTH SESSION, 1904-1905.

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SINCE FOUNDATION IN 1857.

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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1863-65 JAMES ROBERT NAPIER, Engineer and Shipbuilder, Glasgow.

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1889-91 EBENEZER KEMP, Marine Engineer, Glasgow.

1891-93 ROBERT DUNDAS, C.E., Resident Engineer, Southern Division, Caledonian Railway, Glasgow.

1893-95 JOHN INGLIS, LL.D., Engineer and Shipbuilder, Glasgow.

1895-97 SIR WILLIAM ARROL, LL.D., M.P., Engineer and Bridge Builder, Glasgow.

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.

1902-04 ARCHIBALD DENNY, Shipbuilder, Dumbarton.

Elected
2nd May, 1903, JAMES GILCHRIST, Marine Engineer, Glasgow.

CONTENTS.

Errata and Additions to Professor Gray's Paper on "Gyrostats and Gyrostatic Action."

Page 287, line 8 from foot, *for* A B, *read* O A.

" 288, " 4 from top, *after* O E *insert*

, following these axes as they move, though, as stated above, the acceleration about O A or O B is the same as that about a fixed axis coinciding with O A or O B, that is, also with O D or O E at the instant.

" 290, " 1, *for* in, *read* perpendicular to

" 290, " 2, *after* Z O C, *insert*

when that acceleration is taken following O D as it moves,

PLATES.

PREMIUMS AWARDED

FOR

PAPERS READ DURING SESSION 1903 - 1904.

PREMIUM OF BOOKS.

1.—To Mr John G. Johnston, B.Sc., for his paper on "The Uses of the Integraph in Ship Calculations."

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 were substituted.

The following Articles were registered with the Registrar of Joint Stock Companies on 28th October, 1902.

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.

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

SECTION II.—CONSTITUTION.

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

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 Members.**

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

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.

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 until one year has elapsed from the date of retiral.

Retiral of Members of Council.

Office-Bearers to 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 contain the name of the proposed President, and not less than two names of persons proposed by the Council for each vacancy in the class of Vice-Presidents, Ordinary Members, and Associate Members of Council. 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 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. The Council shall

Investments

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 State-

ment 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.

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

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*.

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

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.

Voting.

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. 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.

Annual Subscription payable.

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.

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.

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

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. Librarian to keep Accession Book.

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. Register of books lent kept.

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. Borrower to sign for books.

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

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

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. Number of books which may be borrowed at one time.

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

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.*	F. HALL-BROWN.
WM. M. ALSTON.	WILLIAM MELVILLE.
PROF. A. BARR, D.Sc.	JOHN STEVEN.
W. A. CHAMEN.	JOHN WARD.
	EDWARD H. PARKER, *Secretary.*

21*st April*, 1903.

INSTITUTION

OF

ENGINEERS AND SHIPBUILDERS

IN SCOTLAND

(INCORPORATED).

FORTY-EIGHTH SESSION—1904-05.

Mr John Ward, Vice-President, in the Chair.

25th October, 1904.

The Chairman said that the opening of a new Session, like the opening of a New Year, might be fitly looked upon as a fresh mile stone on life's journey. And so their good wishes for one another and their desire for the continued prosperity of the Institution found, he trusted, a responsive echo in the hearts of them all on that, the opening night of the 48th Session of its history. A perusal of the report which had just been adopted, told of steady and continuous growth in membership and finance. For the past nine years that had been their happy experience, and they might justly look upon it as a better index and earnest of the Institution's influence and endurance, than if these had been spasmodic or fitful. The roll was at the high water mark of 1404 all told, while the surplus balance last year amounted to £725 15s 8d. The report covered a large amount of interesting ground, and revealed a thoughtfulness and energy on the part of many of their Members which were worthy of all commendation, and betokened a fruitful future. The

Members who were affiliated to the various technical and educational bodies named in the report had done good work, and had taken an active interest in the discharge of the duties devolving upon them. Much lasting benefit should result from co-operating in work of that nature, and their connection with it through their representative Members was a bond uniting them in the spread of technical and educational work, the value of which was greater and wider reaching than they could possibly gauge. The tentative character of much of their work must always be a large part of its commendation. They were experimenting and feeling their way as much for others as for themselves; but in science, as in other fields, one had the happiness sometimes of being both a sower and a reaper. It was to be hoped that such work as they had tried to accomplish during the past year would be an incentive to the Members to make the Institution a greater storehouse of original and initiative force than it had been in the past.

One noteworthy feature of the report was the record of the work done in the Students' Section. Their friend and colleague, Mr Hall-Brown, deserved their heartiest thanks for the enthusiasm and energy which he, as chairman, had thrown into that work. The object lessons given to the Students through the visits paid to representative works, were of an educative character, while the papers read and discussed by them during the session were of marked ability, and worthy of even larger audiences than those which had the privilege of hearing them. Some of these papers were of outstanding merit; and of as instructive a nature as those read at the monthly meetings to the Members.

Mr Gilchrist, when occupying the chair on the opening night a year ago, emphasised the duty devolving upon their younger Members of taking a more active and energetic part in the work of the Institution than they had yet done. He endorsed most heartily all that Mr Gilchrist said on that important matter. Young and vigorous blood was essential to vitality and progress; whether it was as a nation, as an Institution, or as individual members of a profession, or a community. The world's work would more and more be done by young men, and part of their education for worthily acquitting themselves, apart from thoroughly mastering their professions, was by helping on, and taking part in, the work of institutions such as their own, both as authors and speakers. He had heard it stated that the average middle aged or elderly business man of to-day was younger in mind and business application than was his father at a similar age. That might be so, yet the fact remained that the seniors who were wearing to the westward were not so nimble at doing the work they used to do in the old unfettered days. As years crept on, and the elasticity of youth was but a memory, the pace became slower and the pulse duller. They all recognised it more or less vividly, and they all thought of it more or less seriously. A blend, therefore, of the matured judgment and experience of age, guiding wisely and well the enthusiasm and forceful energy of youth, was to be desired in business, as in institutions; and the adoption of that belief in recent years by the Members was, he thought, one of the reasons for the growth and popularity of the Institution to-day. That that should continue and expand was most desirable. Their Institution—representative of engineering and shipbuilding in Scotland, and centred within hail of the birthplace and training ground of James Watt, its Patron Saint—required it; their membership warranted it; their progress as a living and ever-advancing profession largely depended upon it; and the Clyde which still maintained its high position as the home of much that had been achieved in the continued advancement of engineering and shipbuilding, specially deserved it. All those reasons, and others, which might be cited, warranted their striving unitedly and earnestly, to make the Institution, through its "work and worth," an ever-growing power in their midst.

The growing membership had made it imperative on the Council to seriously consider the question of the house accommodation. As most of them knew, the building was the joint property of the Royal Philosophical Society and themselves. Both Societies had been steadily growing in numbers and influence, and what was large enough in the way of accommodation for both twenty-four years ago, when the building was erected, had become inadequate for the needs of both Societies to-day. Negotiations of a friendly nature were in progress between Committees of the Societies, and he had no fear but that the good feeling and friendship which had linked them together in the past would continue long after the dissolution of partnership, when one most likely remained as the occupant of the present building, and the other had sought and found safe anchorage in good holding ground elsewhere within the confines of the city.

It was fitting that he should record the indebtedness of the Council to their friend and colleague, Mr James Gilchrist, for the valuable help and guidance he had, in the absence of their President. given them during the past year. The illness which overtook Mr Denny more than a year ago gave silent warning that duties of every kind must for a time be laid aside. He accordingly requested Mr Gilchrist (one of their oldest and greatly valued Members) to accept the position of Chairman of Council until his return. That request was endorsed by the whole Council, and Mr Gilchrist, like the warm-hearted and loyal colleague they all knew him to be, most cheerfully assented. For all the help he had already given, as well as for its continuance until the President took up his work again, he asked them to accord him now their warmest and heartiest thanks.

With a membership such as the Institution possessed, it was inevitable that some should fall from their ranks year by year. Among those who had passed away during last Session, Mr James M. Gale stood out as one who was long and honourably connected with them. For 23 years he served the Institution as Honorary Treasurer, and Volume VII. of the Transactions was enriched by a most interesting paper, which he read, giving detailed records of professional engineering work designed and carried out by him for the city, and its water supply from Loch Katrine. Other notable members had passed away, including Mr W. T. Courtier-Dutton, the able and talented Chief Surveyor of the British Corporation; and Sir William Allan, the genial and stalwart member of Parliament for Gateshead, To Sir William Allan his profession of engineering was very dear, and his voice was raised and his influence used for the due recognition by Government of the status of naval engineers when they had few friends in court, and help was greatly needed to redress existing ills.

At the opening meeting a year ago, Mr Gilchrist, in the absence of the President, read a letter from him saying how much he regretted, through illness, his inability to be with them that night. None of them anticipated, and he probably least of all, that his illness would run such a long and weary course. It had lasted now for over a year, and the end was not yet. He was thankful to say Mr Denny was now improving, and that complete recovery would come in due time. No one knew better than he did how dear to Mr Denny's heart were the interests of the Institution. He believed in it, he thought about it, and planned for it; and it only added to the pain of his regret that the condition of his health was such as to prevent him being with them that night and delivering his Presidential Address. That he had their sympathy and forbearance, he knew; and that had comforted him when comfort was sorely needed. There was no one in their profession who had gained a heartier esteem than he had; no one of his years who was more confided in, or looked up to with more kindly regard. A born shipbuilder, he had lived for the good name and honour of their calling. He had placed his services unstintedly at the disposal of the Government and public bodies, when these services were asked; and he had never failed to prove himself a thoroughly capable adviser and helper, as he had done to all who had known him as a genuine warm-hearted and loyal friend. The isolation caused by his illness was bad to bear in any case, but doubly so in the case of a man who, like Mr Denny, had spent so much of his strength generously for the benefit of others and the advancement of his profession. He wanted to assure Mr Denny, speaking from the chair and in their name, of the warm place he had in their regard, and of their fervent hope that he might soon regain his lost health and strength, and be spared for many years to the advantage of the profession which by his ability and energy he had done so much to adorn.

THE SMOKE PROBLEM.

By Mr F. J. Rowan (Member).

SEE PLATES I. AND II.

Read 25th October, 1904.

The presence of smoke in the atmosphere, in anything but minute proportions, is objectionable on both æsthetic and sanitary grounds. The æsthetic is perhaps the point of view from which smoke is most objectionable to the general public, but the sanitary aspect of the subject increases in importance as the value of pure air and brightness in our surroundings is better understood. No one can pretend to believe that the breathing of smoky air is good for human lungs, or that the taking of carbonaceous matter into the human frame by that method is advantageous, although it is well known that carbonaceous foods are heat producing. And our environment should not embrace blackened and decaying vegetation, the walls of houses whose colours are reduced to a dead level of dismal grime, obscured sunlight, and increased rainfall. These, however, are matters the discussion of which is beyond our province here, and, as engineers, we have to consider the no less important economic aspect of the subject, and to bring the resources of science to bear on the problem so that smoke may be prevented.

No one who knows anything about combustion can deny that smoke is so much coal wasted, and yet manufacturers sometimes use the argument that because certain industries have in the past flourished in proportion to the amount of smoke they have made, therefore to abolish smoke would be to kill them. This argument is misleading, because these industries have flourished *in spite of* the waste represented by the smoke, which only served to give a material indication of the volume of business being done. If with the same amount of business and the same prices there had been added the value of all the coal and potential heat lost in the form of smoke, then an undoubtedly large addition to the profits would have been made.

For the sake of clearness, the subject may be considered under the following four divisions, viz. :—

The Production of Smoke,
The Estimation of Smoke,
The Prevention of Smoke, and
Some Considerations Affecting Municipal Control.

Production of Smoke.

The term "smoke," as popularly used, includes smoky hydrocarbon gases, which are undecomposed tarry vapours, and the cloud of sooty carbonaceous particles which constitute true smoke, black or grey, according to their degree of dilution with steam, air, or other invisible gases. The smoke from domestic fires consists principally of the former, with a small proportion of the latter; but this result is in general reversed in the case of the smoke escaping from furnaces.

It is not necessary to enter minutely into the chemistry of combustion, but one or two points must be noted.

Professor Vivian Lewes has remarked that "If we take the smoke from a cigar or a cigarette, blow it into a thin glass chamber highly illuminated from below by means of an electric lantern or a lime light, and examine it under a high-power microscope, it presents a most remarkable and wonderful appearance. Such smoke contains no particles of free carbon, but appears to consist of an immense number of little round particles in the wildest condition of commotion and movement, each particle rushing about and never coming into contact with its neighbour. It, in fact, presents a beautiful picture of the molecular movement with which theorists have endowed matter. On still further examination, these little particles prove to be tiny vesicles, the skins of which are formed of condensed vapour and liquids from the burning substance which gave rise to them.

Being filled with gases they are extremely light, and float in the atmosphere until brought forcibly into contact with some surface, when they burst, and deposit the liquid film, setting the contents free. The tar vapour which escapes during the distillation of coal, either in gas retorts or upon an open fire, consists of a mass of vesicles of this character. When the temperature at the top of the fire has been sufficient to ignite the gas escaping from it, they are not formed, and then only a small portion of the escaping smoke is of this character, the bulk consisting chiefly of carbon particles. When the fuel has been put on in sufficient quantity to cool the top of the fire below the ignition point of the gas, the smoke which escapes consists chiefly of steam and the tar cloud; while all smoke contains dust and ash from the grate."

The high temperature in furnaces, as in some gas flames, causes the decomposition of hydrocarbons, such as acetylene, into carbon and hydrocarbon, which would burn if the necessary temperature were continued along with the proper quantity of oxygen; but in practice the diluting influence of the nitrogen of the air and other products from the fire beneath, and the cooling influence of the chimney draught upon the flame, so check and hamper the completion of the combustion of these products of the decomposition of the acetylene, that the top of the flame is cooled and finally extinguished before the carbon particles can be consumed, and they form the sooty smoke which passes to the chimney. This action is to some extent illustrated by the familiar experiment of the late C. Wye Williams, represented in Figs. 1, 2, and 3, in which he used to show the effects produced by different methods of introducing air. In Fig. 1 the whole supply of air was admitted to the outside of the flame at the top of the glass chimney, and in Fig. 2 air was admitted below alongside of the gas, but distinct from it, so that the flame was still supplied from the outside, and in these cases smoke was produced from unburnt products of hydrocarbon decomposition. In Fig. 3, the air was diffused through the gas, and produced a short flame of high temperature without smoke.

These considerations show, roughly, how the two qualities of "smoke" are produced, so that practically there are four sets of particles forming the smoke from coal fires, viz.: —1, Carbon particles escaping unconsumed from the burning hydrocarbons, and forming the soot; 2, tar vapours; 3, steam; and 4, dust particles mechanically carried by the chimney draught, and these exist in different proportions in the various kinds of smoke. Another consideration must be noted, and that is that the gases escaping from the chimney, cooled and diluted as they are, are to all intents practically imcombustible, whatever may have been their condition in the immediate vicinity of the fire. If, however, they were collected from the immediate surface of the fire, and used undiluted by products of complete combustion or excess of air, they could be consumed in suitable apparatus.

A complete review of this part of the subject would most probably lead to the conclusion that the formation of a large proportion of the smoke is in most cases chargeable to the imperfect action of our present system of chimneys when combined with coal-fired furnaces. A chimney provides a very imperfect, and, from a heat-expenditure point of view, costly method of causing a current of air to enter and pass through a furnace. Once built its capacity is fixed, and remains the same whether one furnace is, or a dozen that may be attached to it are, being worked. Its control of draught, or the "ascensional force" of the column of gas within it, depends upon the temperature of that column relatively to that of the outside air, and is affected by friction and by atmospheric conditions. To produce the same movement of an equal volume of air, it requires the expenditure of from 30 to 80 times the quantity of heat which would be required by an engine and fan, and yet it cannot control the delivery of that air in the furnace in the best way.

Estimation of Smoke.

The estimation of the density of smoke escaping from chimneys is a very crude affair as at present practised. A chimney may be built for only one furnace, or there may be no more than one for a considerable number of furnaces. Then, again, furnaces are built of different sizes, for different temperatures and processes, and consequently require very different amounts of fuel. Yet the quantity of smoke that may be escaping from a chimney at any given time is seriously affected by the number of furnaces at work, the rates of combustion in them, and the quality of fuel used at the time. Does an inspector take a note of these things in making a report about smoke?

The result may also be affected by diffusion of the smoke either amongst steam or with the air. Sometimes a large volume of exhaust steam is discharged into a chimney, and in the extreme case of a large number of smithy fires collected under one roof without chimneys, a large volume of smoke may escape from them through the ventilators and apertures in the roof without being noticed by him, whereas if the same quantity were led away by one chimney it would catch the eye of the intelligent inspector. Yet it cannot be argued that the smoke is more objectionable in one form than in the other, as far as regards its general, or dust-producing, effect on the local atmosphere. It is the quantity or volume that tells, and yet a larger volume may be spread, unnoticed, in the diffused state, than would be permitted in the concentrated form. Estimation by means of the eye alone is, therefore, wholly illusory, and is often unjust. It is the sum of several uncertain factors, and is, further, entirely dependent upon the observer's power to discriminate between different degrees of density or shades of colour. It is affected by the observer's position relatively to the sun or a bright cloud, and by the total amount of diffused light at the moment, as well as by the moisture in the air.

Diagrams or "scales" of density have been introduced as an aid to observation, or to afford a basis of comparison between the different shades, but as yet no one scale has been adopted as a universal standard. Three degrees have been used in some cases;

the English Smoke Abatement Committee of 1895 used four shades; the Paris Municipal Commission of 1897 employed five degrees; ten degrees have been tried in American experiments; whilst in the Ringelmann and Bryan Donkin charts there are six divisions, ranging between "no smoke" and "very black smoke." The Ringelmann chart is shown in Figs. 4 to 9, the various divisions from No. 1 to No. 4 being formed by drawing black lines of different thicknesses at different distances apart.* In Bryan Donkin's chart different shades of colouring were used, so that this chart could be placed close to the observer, instead of at a distance of 50 to 100 feet from him, according to the light in which it is exposed, which is necessary in using Ringelmann's chart.

Further aid to observers has been attempted by preparing a tube by means of which the light is passed through one or more pieces of coloured (or "smoked") glass, or through any desired thickness of a prism filled with coloured liquid, to one eye, whilst the other eye observes the smoke. When the two shades coincide, the number of pieces of smoked glass, or the width of the prism used, gives the degree of density of the smoke.

The neatest and most reliable of all these smoke density indicators is the one shown by the Austrian Society of Steam Boiler Owners of Vienna, at the Paris Exhibition in 1900. It is illustrated in Figs. 10 and 11, and is formed of two concentric tubes, the inner one, A, having glass ends and two branches, C and D, by which the smoke or furnace gases are led continuously into and through it. At E (inside the funnel F, which shields it from extraneous illumination), a transparent disc fits the annular space between the two tubes, and at the opposite end of the apparatus

*Ringelmann's rule for constructing his scale is:—

No. 0, All white.							
No. 1, Black lines of	1	mm. thick,	and white spaces of	9 mm.			
No. 2,	,,	,,	2·3	,,	,,	7·7 mm. apart.	
No. 3,	,,	,,	3·7	,,	,,	6·3	,, ,,
No. 4,	,,	,,	5·5	,,	,,	4·5	,, ,,
No. 5, All black.							

there is an incandescent electric lamp in a closed lantern. The annular disc has the Ringelmann scale reproduced upon its sectors, and both the smoke and the scale are seen by means of the same amount of transmitted light, and simultaneously with both eyes. The appearance of the tube A when containing very black smoke, and that of the smoke density scale, are shown in Figs. 12 and 13. By means of this apparatus the smoke may be examined from moment to moment, if necessary, at each furnace, and not merely at a chimney common to several furnaces. It thus not only shows the smoke density accurately, but also furnishes a means of furnace control, which is not to be hoped for from an inspector's report of observations of a chimney.

In the interesting remarks on "The Smoke Problem," read by Sir John Ure Primrose, Bart. (the Hon. Lord Provost of Glasgow) to the recent Sanitary Congress in Glasgow, the connection of this subject with dust in its action in fog and rain production was touched upon, and the author made some valuable suggestions regarding the observation of what he termed the rate of "smut fall" in cities, and gave a table of results of observations made in Glasgow from March 1st to June 8th of this year. It is to be hoped that the enquiry which he thus inaugurated will be systematically carried out in both towns and country places, so that complete records may be obtained, and a basis of comparison may be supplied. In order, however, to make the enquiry at which Sir John Ure Primrose aimed a complete one, it would be advisable, in addition, to estimate periodically, by means of Mr John Aitken's dust-counter, the quantity of solid particles floating in the air, because it is more than likely that only a proportion of these find their way to the ground at any time. According to Mr Aitken the dust particles floating in the pure air of the Western Highlands range from a minimum of 16 particles to a maximum of 7,000 particles per cubic centimetre, whilst the air of London or Paris contains from 60,000 to 210,000 particles per cubic centimetre. This shows that city air may be anything from 15 times to 13,125 times more dust laden than pure country air under existing methods of regulating dust production.

The intimate relation between dust and fog and rain production has been pointed out by Dr Alfred Carpenter,* by Mr John Aitken, F.R.S.E.,† and by Mr W. Ernest F. Thomson, M.A., M.B.‡ The classic researches of Mr Aitken cover the whole ground. They show, however, that the real *crux* of the matter is dust, and that smoke is only one of the sources, though perhaps a serious one, of dust production. And even in connection with smoke production, the chimneys of domestic fireplaces, which scarcely ever emit black smoke, are still responsible for a very large proportion of what Sir John Ure Primrose happily termed the "particulate matter" which goes to provide the offensive features of what would otherwise be white mist. His own table also bears out the conclusion that the major portion of the "smut-fall" may be due to other sources of dust than smoke, because 58·25 per cent. proved to be mineral and incombustible matter.

Prevention of Smoke.

Most of the efforts made in the past to arrive at the abatement of smoke seem to have chosen the wrong starting point. They assumed the accomplished formation of smoke, and started to destroy it in some way. This was a fundamental mistake, but it explains the continually repeated appearance of smoke "consumers," "smoke washers" and "annihilators," with their often promised returns and valuable products.

Actually formed smoke *can* be removed from furnace gases by washing with water, but at a sacrifice of chimney draught or power, and with the production of a worthless residue. In the endeavour to burn or consume smoke, some appliance having that object was added to furnaces which had not been, in the first place, designed to secure complete combustion. It is, of course,

* Journal Society of Arts, 10th Dec., 1880.

† Transactions, Royal Society of Edinburgh, Vols. XXX. to XXXVI.

‡ Proceedings, Philosophical Society, Glasgow, 3rd February, 1892.

quite easy to understand how in some cases good results were obtained in consequence of a collateral improvement in the method of the combustion of the fuel, because none could be obtained by a secondary combustion of true smoke once its formation was completed.

In his book on "Steam Boiler Economy," Mr William Kent endeavours, by means of a partial and totally inadequate experiment, to prove that smoke can be profitably burned. "A short piece of candle was placed inside of a tall, narrow, tin cylinder. The deficient supply of air the candle thus received caused it to give off a column of black smoke. This was caused to pass into the central draught tube of a Rochester kerosene lamp, and as it passed up into the flame of the lamp it was completely burned, not a trace of smoke being visible in the lamp chimney. The experiment was also made with a still larger column of smoke produced by burning paper under the lamp, with the same result." The smoky gases thus produced cannot, however, be properly compared with the completely formed smoke which passes from the chimneys of industrial furnaces fired with coal, or even with that issuing from domestic chimneys, although in constitution it probably approaches more nearly to the latter. Moreover, if the great heat and pure flame of a kerosene lamp were required to deal with the infinitesimal amount produced by a single candle wick or a small piece of paper, the smoke from a factory chimney would demand something like a steel-melting furnace for its similar treatment. A "treatise on the theory and practice of fuel economy in the operation of steam boilers" would be more usefully occupied, as this one is in a later chapter, in showing the practical method of smoke *prevention*.

Theoretically the prevention of smoke is simply a question of obtaining complete combustion, but practically it is a good deal more, because of the varying conditions under which combustion has to be carried on in furnaces, the different temperatures required in them for different processes, and the variety of ways in which heat must be applied in them or abstracted from them.

For a long time the smoke question was dealt with as if steam-boiler furnaces were the only ones to be considered, and even as late as 1890-1893 the efforts of the Glasgow and West of Scotland Smoke Abatement Association were confined to these furnaces, as were those of the Manchester Committee in 1895. In a series of letters on "Smoke Prevention," which appeared in the *Glasgow Herald* in the autumn of 1891, it was, however, pointed out that there are many other kinds of furnaces to be considered, and in a paper on this subject read by Mr Peter Fyfe to the West of Scotland Iron and Steel Institute in 1901, it was announced that, "now that furnaces connected with steam boilers have been, and are being, successfully tackled under the Act,* the attention of the Sub-Committee on Smoke has been directed to the large mass of black smoke which is being constantly discharged from plate, bar, annealing, and such furnaces." The "tackling," no doubt, referred to warnings and prosecutions directed against steam users, and seemed to have resulted in their adoption of mechanical stokers and other so-called "smoke-preventing appliances," enlarged flues and chimneys, and the use of anthracite and coke as fuel. Some steam users evidently considered a new fireman to be the best smoke-preventing appliance. The "tackling," however, apparently still goes on. It is thus all the more necessary that all the elements of the problem should be well understood, and these cannot be learned in a day or set forth in a single paper.

For instance, there are (1) furnaces, both large and small, in which the highest temperatures are wanted, such as open hearth and crucible steel melting furnaces, welding furnaces for forges and rolling mills, and for tube welding, puddling furnaces, glass melting furnaces, and the like; (2) furnaces having a lower range of temperature, such as mill reheating furnaces, angle bar and plate heating furnaces, annealing, case hardening, and ore roasting furnaces, rivet making and rivet heating furnaces; (3) those

* Viz., the 31st Section of the Glasgow Police (Further Powers) Act, 1892.

requiring still lower temperatures, such as lead or zinc melting furnaces, core and mould drying stoves, and kilns of various kinds; (4) furnaces for boiler firing, and those for evaporating generally; and (5) furnaces in which a wide range of chemical operations are carried out, such as decomposing or salt cake furnaces, black ash furnaces, pyrites or sulphur roasting furnaces, and many others.

In many of these the materials remain long enough to permit an accumulation of heat, which greatly assists the completion of the combustion of the fuel, whilst in others the heat is abstracted as rapidly as it is produced, and in some an atmosphere is produced by chemical reactions which directly tends to extinguish flame and prevent combustion. Angle bar furnaces are made up to 65 feet in length, requiring an even temperature throughout their entire length, and other furnaces require a low temperature flame throughout a length of from 20 to 45 feet. In some furnaces an excess of oxygen tends to the wasting and even the destruction of the contents; whilst some require at times an oxidizing, and at others a reducing atmosphere. A sharp draught with coal-fired furnaces generally tends to carry over ash and dust to the deterioration of the furnaces and their products, whilst yet a high temperature, and therefore a strong draught, is wanted in them. Added to these elements, there is the fact that in coal-fired furnaces periodically fed with fuel, as most of these are, the various actions which proceed in routine in the fireplace are such that the temperature must periodically rise and fall, and cannot be maintained at a constant point, nor can a uniform distribution of air be maintained. The first principles of combustion are well known. In his report for 1892, as Chief Inspector of the Local Government Board, Mr A. E. Fletcher said that, as had been often pointed out, "There must be, *firstly*, a sufficiency of air; *secondly*, that air must be brought into contact with the fuel, both solid and gaseous; and, *thirdly*, the mixture of the gases and the air must be maintained for a sufficient time at a temperature of incandescence." He remarked—"These conditions are simple, but the necessity of providing them is not always kept in view;" and, further, "it may with confidence be asserted that consumers of coal in almost all kinds of furnaces have it now in their power to conform with the requirements of the Public Health Act, and prevent the discharge of black smoke from their chimneys." He was, however, careful to say "*almost* all," and not all furnaces, and it is evident that he had before his mind, even with that limitation, only the large class of furnaces applied to steam boilers. Mr William Kent, in the work already quoted, gives, also in view of boiler furnaces, an improved statement of these primary requirements, in saying that "Coal can be burned without smoke provided —1, that the gases are distilled from the coal *slowly;* 2, that the gases when distilled are brought into intimate contact with *very hot air;* 3, that they are burned in a hot fire-brick chamber; and 4, that while burning they are not allowed to come in contact with comparatively cool surfaces, such as the shell or tubes of a steam boiler. This means that the gases shall have sufficient space and time in which to burn before they are allowed to come in contact with the boiler surfaces." It will be noticed that Mr Kent has in these remarks a wider appreciation of the requirements of combustion than Mr Fletcher, but that neither of them has in view any other class of furnaces than those of steam boilers.

Bearing in mind the complex requirements of manufacturing operations, it would be impossible to frame one set of conditions that would be applicable to all, but there are one or two fundamental considerations which, to a very large extent, govern the whole subject, and yet which have been very little, if at all, noticed in connection with it. *Firstly*, as it has been expressed by Professor Lewes, "All flame is supplied by the combustion of gaseous matter." Flame is, in fact, as Dr Percy long ago said, gas or vapour, of which the surface, in contact with atmospheric air, is burning with the emission of light. *Secondly*, in nearly all industrial heating operations the work is done by means of flame and cannot be done without it. And *thirdly*, the major part of the formation of the smoke which we wish to prevent takes place during the cooling caused by the distillation or gasification of coal in open fires. In the majority of such fires in furnaces it is impossible to carry out Mr Kent's first principle in anything like an adequate manner, but that condition can be perfectly complied with by a preliminary gasification taking place in a gas producer, which has the further advantage that it provides means for the securing of other conditions of combustion in the furnaces in a way which is impossible with direct coal-firing, and entirely unaffected by the quality of coal which may be in use. Mechanical stokers have the excellent feature of providing automatic regularity in the feeding of the coal, but they only reach the point of producing steadily the minimum flow of smoke; they cannot abolish it. That can be done only by a system of gas firing.

This, however, entails an additional capital outlay, the cost of gas-fired furnaces being often considerably greater than that of the ordinary coal-fired type, whilst the benefit to be derived in economy of fuel diminishes with the reduction of the degree of temperature at which they are worked. Consequently, it is in our first class of furnaces that the greater number of examples of gas firing are to be found. Yet there are examples in all the other classes which also attest the correctness of the claim that the system is smokeless.

Municipal Control.

Sometimes manufacturers are impatient of any control being exercised over their works, which are undoubtedly productive of many public benefits. That position is, however, untenable, and, with regard to our subject, black smoke has been declared to be a nuisance, and Acts of Parliament have been, at the instigation of public bodies, passed for its suppression, so that it would be useless, even if it were our province, to discuss that point. We may, however, notice the fallacy contained in the reply made by Mr Fyfe to the discussion on his paper, which has already been referred to. Mr Fyfe said.—"The Corporation had only a legal position to maintain. They had to carry out the existing law.

The law was laid down by Parliament. Parliament laid down both Imperial and local enactments, and, therefore, it was not entirely correct to say that the Corporation was at the bottom of the enactments which were passing through the Lords and Commons from time to time. The Imperial laws were there, and had to be administered." Nobody doubts the existence of the laws, and the obligation to administer or to obey them, but the question remains: Who promoted the bills which became Acts of Parliament, and, in particular, who promoted the Glasgow Police Act or the Further Powers Act, under which Mr Fyfe acts, if not the Corporation? Some one, of course, had to take the initiative, but a question like that of smoke prevention, affecting, as it does, manufacturers, who are exposed to competition, should be dealt with by Imperial and not by local enactments, in order that one part of the country should not be placed at a disadvantage compared with another part. The manufacturers of one district should not be hampered by restrictions from which other districts are free.

The great difficulty has, however, been to decide upon the form and character of legal enactments which would suit the peculiar conditions of the smoke problem.

The undoubted success of the Alkali Acts in minimising the escape of noxious fumes, vapours, and other substances from chemical works has repeatedly given rise to the impression that the Legislature has only to apply the same remedy in the case of smoke and an equal success will be obtained.

In the *Glasgow Herald* correspondence which has been referred to, a prominent agitator for smoke abolition instanced the success of some stringent regulations introduced by Lord Palmerston in 1853 and 1856 for the government of London, and urged the passing of an Act of Parliament, simply making it a penal offence to produce smoke, the "worrying of the smoke producers" by prosecutions, and leaving every one to find his own way out of the difficulty, because the Legislature would be in a hopeless fix if asked to indicate the proper means of preventing smoke.

In one of the prize essays on "Smoke Abatement," published in *Gas and Water* in 1883, the author suggested that an amendment of existing Smoke Prevention Acts might be framed in the following sense:—"Any local authority might have power to take cognizance of all new factories requiring the consumption of fuel for trade purposes. It should be for the owners of such proposed undertakings to show how they intend to ensure that their furnaces should be smokeless, with the understanding that the *onus* of showing cause why coal or other smoky fuel should be permitted for their use would rest upon them. In default of such proof, as certified by a competent Advisory Board, smokeless fuel should be insisted on under regular inspection. A sufficient interval (say three years) might be allowed for established manufacturers to alter their furnaces and methods, so as to conform to the requirements of the Advisory Board; after which they should only be allowed to continue their old methods by special licence. These regulations might be made applicable to all trades, in order to embrace any who are outside the scope of the present Acts To provide against the new regulations becoming a dead letter, while at the same time retaining the most valuable principle of local administration, the nomination of Advisory Boards might be confided to the local authority; while the reports of this body might be furnished in duplicate to the local authority, who would be empowered to act upon them, and to the special department of the Home Office, which now so efficiently administered the law in the Metropolis." Domestic fireplaces, although called "the greatest offenders in the matter of atmospheric pollution," were excluded from this proposed control because the owners were not users of fuel for purposes of gain.

On the other hand Mr G. T. Beilby in his communication on "Smoke Abatement" read at the Engineering Conference of the Institution of Civil Engineers in 1903, proposed to impose a chimney tax on every domestic chimney which was made large enough to permit the use of raw coal, and to exempt all chimneys which were too small to do so. His idea was to favour the use of coke or gas fires for domestic purposes, whilst reckoning upon manufacturers being so awakened to the advantages of gas firing for their furnaces that they would adopt that system universally.

Such are some of the views on this important subject, each no doubt containing some good points, but all of them omitting others which are vital to the settlement of such a question. As engineers we must frankly accept the axiom that it is quite possible to prevent smoke in all industries and under all conditions of working. It is, however, not possible to do so by rule of thumb, or to lay down one set of regulations which will apply to more than perhaps one or two kinds of furnaces, or to one kind of fuel. Yet it is quite within the present resources of engineering science to devise means and appliances which will meet every case. These will probably not be the same in any two cases and this is just where those who deal with the subject from the legal or magisterial point of view are likely to go wrong.

An attempt, for instance, to bring the smoke question within the limits of the Alkali Acts would be a huge blunder, because there is no comparison between the practical identity of the causes and remedies dealt with in all Chemical Works, on the one hand, and, on the other, the almost endless variety in the processes involved in the combustion of different kinds of fuel, in different quantities, at different rates, in different kinds of furnaces, whose forms or dimensions, or temperature, or atmosphere must be regulated by the process or manufacture in which they are employed. The designing of new works, under even such restrictions as have been foreshadowed in one of the quotations given, would be a comparatively simple matter, but the authorities are face to face with the fact that very large numbers of coal-fired furnaces of all kinds are in existance, in which smokeless combustion is impossible; yet because of their relatively small cost of construction they are considered necessary for the welfare of the manufacturing operations which are conducted by means of them. It is not a small matter for manufacturers to contemplate an increase of 100 to 200 per cent. in the capital outlay for such appliances, yet that is what may be involved in the introduction of efficient gas-fired furnaces and without these the smoke evil, as regards industrial furnaces, can only be mitigated, it cannot be removed.

It is no mere question of simply changing from one fuel to another, or modifying the admission of air, or the periods of charging fuel, or of fixing a "smoke consumer" to existing furnaces. There is a much larger problem than that before the authorities, and one which will tax a far higher degree of technical skill than can be provided by the ordinary inspectors under a police or sanitary department. Perhaps in another generation domestic heating may be carried out on some plan of general distribution, and the desire to poke a fire may be regarded as a happily lost relic of savage ancestry. Manufacturers, too, may have universally adopted the enlightened plan of having the most efficient and perfect appliances irrespective of their capital cost, looking more to economical working than to small outlay, and generously considering the comfort of their neighbours. In that day, too, Magistrates and Town Councils will, no doubt, have introduced means for preventing the spread of all dust from street cleaning, from destructor furnace chimneys, from locomotives, from grinding and other mills, and from the loading and unloading of ships, wagons, or carts. But until then we shall probably have to endure the presence of both dust and smoke, thankful that if they bring us fog and rain, the rain is at least Nature's cure for that state of matters by washing for us the dust-laden air.

Discussion.

Mr John Ward (Vice-President), said they had listened to a most able and interesting paper, and he hoped the discussion on it would be both ample and fruitful, as the smoke problem was one in which they were closely and intimately wrapped up. Mr Fyfe, the Sanitary Inspector of Glasgow, was present, and as he was a gentleman whose opinion they valued most highly, and who had had an advanced copy of the paper, he would call upon him to open the discussion.

Mr Peter Fyfe.

Mr Peter Fyfe said the first thing he had to do in attempting to criticise and examine Mr Rowan's paper, which had been so kindly sent to him by the Secretary, was to express his gratification at the honour which the Council had done him in asking him to express any views whatever before such a body of experts as he saw before him that evening. Last winter he had had the honour, as doubtless some of them knew, of reading a paper before the Architectural Section of the Royal Philosophical Society, and it was very much on the same lines as the Lord Provost had adopted in his address to the Sanitary Congress in July last. He had had, through the courtesy of Mr Parker, the privilege of possessing Mr Rowan's paper for a few days in advance, and, considering the lateness of the hour, he would simply confine himself to a few words, first, of explanation, so far as Mr Rowan's paper called for explanation; and second, to a few words of criticism, in so far as he might be found to disagree with the opinions which Mr Rowan had expressed. He might say that he had not had much time, on account of the pressure of official work, to give that very excellent paper the serious consideration which it deserved, but he had made some marginal notes, which, perhaps, he might be forgiven for referring to. In his paper, Mr Rowan spoke of the dust particles which had been found in the boxes which had been put on the roofs, between 30 and 40 feet in height, in various parts of the city, and had stated that these dust particles had been carried up the chimney by natural draught in the chimney, and distributed along with the smuts all round. He thought, however, that required to be modified by this explanation, that in several of the furnaces now in the city it had been found by manufacturers to be advantageous to put in forced draught in the ashpit of the furnace (somewhat resembling the draught in the furnaces of His Majesty's navy), caused by a jet of steam issuing at great speed, which worked somewhat independently of the natural draught of the chimney. He found that while it enabled engineers and manufacturers generally to burn a very inferior class of fuel in their boilers, and reduced the cost of steam production, it, at the same time, unless very careful guards or baffles were put in as preventive structures, created such a powerful current as to throw particles three-eighths or one-fourth of an inch in diameter out of the chimney. He did not know whether Mr Rowan would characterise this as dust, but it was certainly dust of a very magnified size, and one did not require a microscope to see it. These particles filled up the gutters of the proprietors who possessed property in the neighbourhood surrounding such chimneys, and who had a great grievance on account of lumps of that description falling like rain upon their roofs. The following sentence he thought a most singular one, and he was sorry personally that Mr Rowan had not had time to enter into an elucidation of it that evening. Mr Rowan said:—"To produce the same movement of an equal volume of air, it requires the expenditure of from 30 to 80 times the quantity of heat which would be required by an engine and fan, and yet it cannot control the delivery of that air in the furnace in the best way." If that statement was correct, and if it could have been followed up by figures and diagrams, he thought it pointed to this fact, that chimneys were not required at all; but engineers present were called upon to exercise their faculties of faith or imagination, because they had no diagrams or figures produced to prove the statement. If Mr Rowan had time in the after discussion, it would improve his paper, and add largely to the value of it if he could point out shortly how that could be done. Then Mr Rowan asked the following question:—"Does an inspector take note of these things in making a report about smoke?" The smoke inspectors in the Sanitary Department not only took observations of those facts mentioned in the paper, but a great many others. Indeed there was nothing at all which might be germane to questions connected with the abatement of smoke which they did not ask about with respect to chimneys, furnaces, and flues in any particular place. Mr Rowan referred to smoke which came from sheds and ventilators and apertures in the roof, and said that

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probably it might catch the inspector's eye, and prosecutions might follow. The Act of Parliament did not permit him to do that, because it mentioned chimneys, and the smoke must come from chimneys; and, therefore, it was not practicable to deal with such smoke, so that if anyone liked to adopt his particular method of securing a draught and pass smoke through ventilators in his roof, he might escape prosecution altogether under the smoke sections. With regard to the next point, although it was very interesting scientifically, Mr Rowan raised a somewhat academic discussion as to how black smoke could be differentiated from yellow, or yellow from light fawn, and so on. Perhaps when he was writing the paper he forgot that the question of the issue of excessive smoke in Glasgow, and he believed also in London, had nothing to do with whether it was black, brown, green, or yellow.* The question was: Was it smoke? The Act of Parliament of 1892 simply said that smoke was not to be produced from the chimney, and if it was produced the onus of the proof lay upon the manufacturer to show the Magistrate or Sheriff that that smoke was absolutely necessary to be made, and that he had used the best practicable means in order to keep it down; and, therefore, while the diagrams that Mr Rowan spoke about were very interesting scientifically, they had no bearing on the question so far as Glasgow was concerned. In fact, the Public Health Act, the Imperial Act which was cited by him, stated that the smoke was not to be produced in such quantities as to be a nuisance or dangerous to health, and, even referring to the Imperial Act his contention was not borne out with reference to the applicability of those diagrams in a case of prosecution. Mr Rowan spoke about the production of smoke by permitting the gases from furnaces, before the hydrocarbons had been lighted up, to impinge on cold surfaces—cold relatively to the heat of the furnace—and he went on to say that that was one of the primary

* Sec. 16, Public Health Act, Sub. Sec. 10:—"Any chimney (not being the chimney of a private dwelling house) sending forth smoke in such quantity as to be a nuisance, or dangerous or injurious to health."

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difficulties in connection with existing boilers. He indicated also that to minimise or reduce the smoke to practically nothing, would involve from 100 to 200 per cent. additional expenditure upon the primary expenditure of the boiler itself.

Mr ROWAN—He practically omitted boiler furnaces at that point, but he dealt with all other furnaces.

Mr FYFE—That very much cleared up the point, because he might mention that furnaces other than boiler furnaces were not subject to prosecution at all. No doubt the law could be brought to bear, but he did not think any support would be received from the Magistrates, because the Burgh Police Act of 1892 had a Section in it which was applicable to burghs all over Scotland other than the burghs of Aberdeen, Dundee, Glasgow, and Edinburgh, and this Section exempted all such furnaces in coal mines, iron works, shipyards, and those particular furnaces in which angle bars and iron of various sections had to be heated in order to be treated under rolling mills or otherwise; and while the Glasgow Act did not limit prosecutions to boilers, he himself quite recognised that if a complaint against plate furnaces went before a Magistrate or Sheriff, it would not only be very unjust to the Glasgow manufacturers, but would not be supported by the General Act, and he did not think that they would endeavour in Glasgow to read into their Private Act what would not pass under the Public Act. Mr Rowan made a very curious statement when he said—"Mechanical stokers have the excellent feature of providing automatic regularity in the feeding of the coal, but they only reach the point of producing steadily the minimum flow of smoke; they cannot abolish it." He supposed the Members present were experts, and knew all about mechanical stokers. He could himself speak of them, having had them under his own control for the last ten years. If anyone looked at the Ruchill sanitary wash-house chimney, he would never see smoke except in the early morning, during the process of firing. Most of them would remember when a large chimney was situated in St Enoch Square, at the time the large engines were built there

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dealing with the formation of the subway. The boilers were of the Lancashire double flue type, with Vickers' stokers, and he never saw the chimney smoking once. He thought, assuming that the boilers were not overloaded, it was quite possible with mechanical stoking to do what Mr Rowan desired to be done in connection with the burning of coal in a boiler furnace. With the experience he had, he did not agree that gas was absolutely necessary as a fuel in furnaces. With coal put into a furnace not already overloaded, and with careful mechanical stoking and attendance, the chimney could be kept quite clear of smoke. He was very glad to hear Mr Rowan's statement that the methods of the Alkali Act were quite unsuitable for the abatement of the smoke nuisance. He hoped the time would never come when manufacturers generally would be subject to the fines exigible under the Alkali Act, amounting to £50 and £100; and he found that the fines under the General Act with respect to smoke production were at the opposite extreme; they were too low. He would like to say just one word in connection with what Mr Rowan stated in the paper to have been impossible. Mr Rowan made out that it was impossible to reduce or abate the smoke nuisance in connection with old existing fuel furnaces except by the production of producer gas. A deputation from Glasgow went to London recently specially to investigate an apparatus to enable the gas to be introduced into the furnace flue. He would not mention names for fear of being accused of advertising, but this was a system whereby the gas was formed in a small producer about four or five feet in length, and 2 feet 6 inches in diameter. The gas was produced from anthracite nuts. It was in order to keep the pipes clear of tarry matter that anthracite was used. The pipes from the producer passed along the front of the producer and the boilers, and were taken down into the ashpit and led towards the bridge. When these were lighted a large Bunsen flame could be seen, which spread itself into a honeycomb of brickwork immediately behind the fire bridge. The heat which was produced in that fire-brick

regenerator at the back was so great, that no matter how the coal was shovelled into the furnace, after the heat got up, black smoke appeared at the top of the chimney. He got a fireman every ten or fifteen minutes to put on 18 shovels of coal, and he watched the chimney for two hours. As long as the producer gas was burning in the honeycomb regenerator behind, and the flaps were open to allow the air to enter, he could defy the furnaceman to produce black smoke at the top of the chimney. He considered that a success, because the particular firm who got this apparatus had previously been continually in the hands of the authorities. He would be able to furnish Mr Rowan with an introduction to the gentleman who had these works, and he was sure that Mr Rowan would be quite surprised at the results. He begged to thank the members of the Institution for the opportunity of addressing them.

Mr David W. Dickie said he would like to ask a question of Mr Fyfe. Did Mr Fyfe think the cost of that producer gas system would pay? He had come across that producer gas furnace a while ago, and was somewhat interested in it. Would Mr Fyfe please give an idea whether the producer gas reduced the cost of burning coal or not? He understood that the coal they were burning was what was technically termed "rubbish" in the coal world.

Mr Fyfe—It was a very important question, and he was sorry he had omitted to mention the capital cost of that producer. Piping the three boilers cost about £150. The first one cost £100, and any others were to be £50 per boiler. The boilers were of the marine type and of very large size. That seemed to point to the fact that the particular work could be done at a great deal less than 100 per cent of the boiler cost, and about 30 per cent would be nearer the mark. In connection with the cost of the fuel, he might state that the manager had been able to burn a very much lower class of fuel, bearing out what Mr Dickie had stated. They were burning Walloton slack, which was a very inferior main dross. Before that, Welsh steam coal had been

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used, in order to avoid falling into the hands of the authorities. They would perceive that the caloric which was obtained from the burning of the gas from the producer, was necessarily utilised along with the ordinary gases in raising the steam, and that was another advantage. The manager told him that before the gas was superadded to the fuel, it was impossible to keep the engine going at the required speed. He saw himself, after the gas was stopped for about 20 minutes, the gauge falling from 175 lbs. per square inch down to 155 lbs. The electric lighting engines were kept going at their normal speed without reducing the pressure in the boiler so long as the gas was on, so that the gas was not only killing the smoke, which was a very advantageous circumstance, but it was doing work itself in adding to the natural fuel in the furnace.

Mr Alexander Cleghorn, (Member of Council) remarked that he would like to solicit Mr Fyfe's forbearance in asking him another question, as from his expert acquaintance with Municipal law he would doubtless be able to favour him, and other interested Members, with an answer. A chimney stalk was frequently connected with two or more kinds of furnaces: for example, with a boiler furnace and with a plate furnace. He understood from Mr Fyfe's previous remarks that a penalty could be imposed in the case of smoke issuing from a chimney connected to a boiler furnace, but not from a plate furnace. Knowing the impossibility of preventing smoke issuing from a plate furnace when a large cold plate had been newly placed in the furnace: Would Mr Fyfe kindly explain how the Police Act would be applied to this combination?

Mr Fyfe—He was afraid that Mr Cleghorn had rather got the better of him, but he would like to state that cases of that description had come under his notice. The fact of the matter was that each case of the kind was treated on its own merits. The inspectors under his supervision were trained engineers, men who had been thorough firemen themselves, and had advanced themselves in the theoretical knowledge pertaining to combustion to a great extent, and therefore, when they went into a place, after having taken simultaneous diagrams, to see the condition of a plate furnace, they could open the door and see what the furnace was doing and what the boiler was doing, and they came to the conclusion then that it might either be the plate furnace or the boiler furnace which was at fault. They placed the case before the Magistrate, and the evidence was adduced, and each case was tried on its own merits. There had been cases where the plate furnace had been to blame and no prosecution followed, and other cases where it was quite innocent and the boiler was to blame.

Mr Cleghorn—They were very much indebted to Mr Fyfe for his reply.

Mr G. C. Thomson (Member) observed that he had read Mr Rowan's paper on the "Smoke Problem" with interest, but he could not agree with all the statements made therein. It might be taken for granted that the production of smoke was one of the easiest parts in the problem, and he had never yet found anyone who failed to produce smoke if he lit a fire and kept it burning. The discussion of that part of the paper might, therefore, safely be left alone. The same might also be done with the estimation of smoke, as the Acts in force only affected the emission of smoke from a chimney, and the colour or density was a matter of no consequence, except as regarded the question of its being a nuisance to the inhabitants. It was only when it affected the health and happiness of the people by polluting the air they breathed, and deprived them of sunlight and its health-giving power that it entered the field as a question of importance. The author referred to the connection between fog and smoke, and to the researches showing that dust was the real crux of the matter. One must not forget that fogs existed here long before a single ounce of coal was burned, and when coal was unknown to the inhabitants who left the traces of their handiwork at Dumbuck. There was, however, one essential difference between then and now in fogs, viz.—the presence of sulphurous acid, owing to the combustion of coal, and which was absent when wood

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was used as fuel. Dust at that period, he believed, was a very small factor in fogs. With regard to the prevention of smoke, it seemed that everyone knew all about it, and by using this or that appliance smoke was sure to be done away with at a considerable profit. The author pointed out that the Smoke Abatement Associations of Glasgow and Manchester confined their work to steam boiler furnaces. That was true, and it was a pity that the Glasgow Association cut short its operations at the very time when the prejudices of the engineers and the firemen of the factories of the district had been overcome, and when the way was paved for testing all manner of furnaces used industrially. He knew it had been in contemplation to consider other furnaces later on in the case of the Manchester Association. In papers read by him before the Institution in November, 1888, and December, 1894, and one read before the Philosophical Society of Glasgow in February, 1895, were given the results of various methods of firing boiler furnaces, showing that boilers could be fired economically without visible smoke emission, two noted examples being the Thornliebank Works and Coats & Company's Mills, Paisley. Mr Rowan stated that "Mechanical stokers have the excellent feature of providing automatic regularity in the feeding of the coal, but they only reach the point of producing steadily the minimum flow of smoke; they cannot abolish it. That can be done only by a system of gas firing. . . . Yet there are examples in all other classes which also attest the correctness of the claim that the system is smokeless." That was a big claim, and in a district where there were so many gas-fired furnaces one would naturally expect to find those furnaces smokeless. He thought he was not overstating it when he said that if anyone looked at the chimneys of their steel works smoke was conspicuous by its presence in first rate quality. He had never seen a gas-fired furnace that could not and did not fail to emit smoke quite as well as its coal-fired brother. The claim of smokelessness had been made on behalf of oil fuel, and there, again, in ordinary practice, the claim had not been made good continuously.

Coal dust firing seemed so far not to have made much claim to smokelessness, and he believed that the highest efficiency, combined with smokelessness, could be attained by an intelligent application of it to boiler and other furnaces. The leader in that branch appeared to have been Wegener, in Germany, and his successors, and the most promising application seemed to be that of Schwartzkopff. Members could consult "Gas and Coal Dust Firing," by Albert Pütsch, in the library of the Institution. The use of forced or induced draught was sometimes recommended to procure smokelessness, but it was not reliable. In all the methods before the coal user, whether in the form of hand firing, mechanical stoking, forced draught, gas, oil or coal dust firing, the practical abolition of smoke could only be attained by the skilled use of the means employed; and until a much wider and higher appreciation of health and comfort obtained, there would be little or no advance despite Acts of Parliament or Acts of Corporations. He quite agreed with Mr Rowan in his view that by the use of gas for domestic heating and use, a very great and needed advance would be made in the Smoke Problem, and it seemed to him that in the use of gas properly washed, so as to free it from sulphur and its compounds, a very bad feature of our fogs would be eliminated. He was at one with Messrs Rowan and Fyfe against putting smoke emission under the Alkali Act, but he would have no objections to an Act on somewhat similar lines if it were carried out by competent and tactful inspectors, as the Alkali Act had been done, and to which it owed its success. With regard to burning of the gases after leaving the fire, he had seen plans somewhat similar to that described by Mr Fyfe tried with varying success, and it appeared to him that no progress in the Smoke Problem could be made without taking into account the human factor, and that was too seldom done. Hence disappointment all round.

Mr Sinclair Couper (Member) said it had for a long time appeared to him that the authorities had made too much of the production of smoke from the furnaces of steam boilers, and that

Mr Sinclair Couper.
too little had been made of the great production of smoke from other furnaces, and especially from the fires of private houses. He thought the latter were responsible for a very large amount of soot and other matters which pervaded the atmosphere of towns and cities. Mr Rowan stated that the production of smoke from house fires was chiefly in the form of hydrocarbon gases, but there were in addition large quantities of genuine soot particles thrown out from domestic chimneys which descended on the streets, and filled the roof gutters of the houses. There were also in this district large quantities of silica carried off from the bitumious coal, which was the chief fuel, and it was this which went largely to make up the 52¼ per cent. of mineral and incombustible matter referred to by Sir John Ure Primrose in his paper, quoted by Mr Rowan. A few months ago he (Mr Sinclair Couper) was in a large manufacturing town in Lancashire, and he observed in the evening, after the factories had closed for the day, that while there was no smoke coming from the tall chimneys, hundreds of chimney cans on private houses were pouring out volumes of smoke, which, in the form of a thick cloud, hung over the whole place. The effect was better seen with the single-storey English houses than would have been the case with the high tenement houses here, the level of discharge being low, and the deposition of soot entirely local, as the particles were not caught by the upper currents of air which carried off the particles from tall chimneys and deposited them over a wide area. This was a case where the "smut-fall" must have been very considerable, and it seemed scarcely fair to penalise the factory owner under the Public Health Act because his chimney discharged smoke from fuel burned in the furnaces of steam boilers, while hundreds of other people escaped simply because they were burning the same fuel in furnaces which were not used "for the purposes of gain." In these remarks he was not, of course, objecting to the Public Health Act in its spirit and intention, but only in its present application, and on the ground that steam boilers were not the only, nor were they always the greatest,

sinners in a town; and further, that in dealing with boiler chimneys the Public Health Act of this country was touching only a partial source of the evil. Paris was not considered to be a city of factories nor a smoky town, for there charcoal was largely burned in private houses, yet the dust particles in the atmosphere, as they saw from page 13 of the paper, might be anything from 60,000 to 210,000 per cubic centimetre. That, he thought, went to show that a non-manufacturing town might have a very dusty or dirt-laden atmosphere, which might come almost entirely from the fires of its private houses. He had come to the conclusion that, so far as steam boilers were concerned, the chief causes of smoke production in this country were ignorance and carelessness in firing, bad design in boilers, flues, chimneys and stoking apparatus, and lastly, insufficient boiler power. It was very seldom, indeed, that one saw a boiler fired by hand in a proper or rational manner. It might be urged that it was scarcely possible with hand-firing to so regulate the working of a furnace that it would not at frequent intervals send large volumes of smoke into the chimney, yet with certain arrangements in the construction of the boiler and furnace, coupled with intelligent and careful firing, very much might be done to minimise the production of smoke. It was in this connection that any advantage due to the use of mechanical stokers came in, because with them the fuel was not thrown into the furnace in large quantities at one time and the door then shut to exclude the air, but it was fed from the mechanical stoker continuously or in regular small quantities, so that with the proper supply of air the fuel was at once seized upon by the heat of the furnace, and the gases given off from it were very speedily consumed. At the same time it must be remembered that smokelessness and economy did not always go together. With some forms of stoking apparatus a huge excess of air was admitted to the furnace, and a consequent dilution of the gases took place which, although it might have the effect of making a smokeless chimney, did not mean economy to the steam user. Then, in regard to insufficient boiler power,

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he supposed that very much more than one-half of the boilers in this country were now working above their economical rate. These boilers were being forced to give the supply of steam demanded from them, and forced firing was neither economical nor smokeless. Less would be said about the smoke nuisance if it were not that hundreds of chimneys attached to boilers were being overworked, which showed that to be the case by the volumes of smoke emitted. Improved appliances for firing and consuming fuel might help in such cases up to a certain point, but, so long as the present methods of firing boilers with coal were in vogue, the only true way of reducing the trouble was to increase the size or numbers of the boilers used, and work them at a slower rate. Mr Rowan referred to the estimation of smoke, but he had never been able to see much value in estimating the smoke by means of diagrams or scales or other contrivances to determine its density. A moment's consideration would show that a light grey smoke emitted for a long enough period would deposit just as much objectionable matter as a jet black smoke would do in a shorter period. Whether it was light grey or jet black, smoke was never anything else than a nuisance. Mr Rowan made a statement in regard to the energy required to produce the movement of the column of gases within a chimney, which seemed rather extraordinary to Mr Fyfe, as shown by his remarks upon it. Mr Rowan could easily explain it himself, but he might put the matter in another way, and say that from a furnace working with, say, 100 per cent. excess of air, and with a temperature of 500° F. in its escaping gases, about 19 per cent. of the calorific value of the coal was carried off in the products of combustion, and went to the production of draught in the chimney, all which, of course, was lost for the purposes of evaporation. In fact, a chimney was about the most extravagant apparatus possible for producing a draught, and a fan could be run for about one-tenth of the power represented by the waste heat required to create a good draught in the chimney. To come to the question of reducing smoke in

boiler furnaces, he agreed with Mr Rowan that the best method of using coal was to gasify it, and to burn the gas in the furnaces, but he did not well see how this could be universally applied with any of the present known arrangements. It seemed to him that this method could be more easily applied to large installations than to small ones, or to single boilers, and the latter were generally the worst offenders in making black smoke. It was likely that the single boiler and its steam engine would gradually disappear, and their places be taken by gas engines or electric motors. He thought it was more from a change like this that the first important reduction of smoke would be got, and not so much from a change in the method of utilising the fuel. However, he hoped Mr Rowan might have something to say on this point when he replied to the discussion.

Mr William Cuthill (Member) remarked that he certainly felt disappointed with Mr Rowan's paper. He did not know anyone who could have said more about the subject than Mr Rowan, who had made almost a life study of combustion in its various forms. Yet not one ray of hope had been given as to the practical means of keeping themselves clear of trouble with the smoke inspector. In reading the paper, the first clause led him to expect that the subject would chiefly be the economy of smoke prevention, but no proof whatever had been given in support of this. The second clause certainly began with the statement that "No one who knows anything about combustion can deny that smoke is so much coal wasted." This was no argument that to prevent it was economy. Everyone also knew that the extraction of the last residue of almost any substance employed in industries was of the most difficult and costly character, and yet such residue might be called "waste" and carbon was one. There would always be some carbon left in the ash, and some escape with the gases of combustion, just as in the case of many other industrial processes. Carbon, in finely divided condition, had a very blackening effect on gases, and it required an extremely small amount. One per cent. of the fuel burned made a dense black

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smoke, and it was difficult to see where the economy would come in, and not so difficult to understand why the author left it so severely alone. Under the heading of "Prevention of Smoke," Mr Rowan gave the views of various authorities on the subject, and finished with the statement, "to abolish smoke, can be done only by a system of gas firing"; but, as afterwards explained, this was not applicable to steam boilers. One would like to know something of the success and economy of the various systems of which Mr Rowan should be so able to speak. For example, in the country surrounding Glasgow, where only economy was studied, and little consideration given to the prevention of smoke, steam from and at 212° F. was raised at a cost for fuel and firing labour of 4d per 1,000 lbs. His experience was within the city boundary, under similar conditions to his competitors outside, and with only very partial success in smoke prevention. As Mr Fyfe knew, the cost was much higher—how much higher he hardly liked to say. It would have been interesting to learn from Mr Rowan what the cost was in the most successful cases of smoke prevention—for instance, in the Corporation electric stations, where steam raising was practised as a high art, with Babcock boilers, chain grates, over-grate brick arches, special fuel, pure water, &c. The lighting stations were worked under conditions not unlike the intermittent steam requirements existing in steel works, and any information regarding results in smoke prevention and cost of steam raising, he was sure, would be appreciated. Mr Fyfe had again brought forward his pet system of dual firing. It was first proposed for steel-heating furnaces, with the secondary furnace under the chimney or boiler at the opposite end of the primary furnace. Now the secondary furnace was placed at the bridge of a boiler furnace, where it would probably do more good. It was, however, a recommendation, with Scotch fuel, to be received with caution. Not long ago he was invited with Mr Fyfe to see an electric plant in the city where a CO_2 recorder was in use, and a beautiful instrument it was, one that would, in ordinary conditions, be of

valuable service when black smoke did not enter into consideration. Mr Fyfe strongly recommended him to get one, as a useful guide in the abatement of smoke. He did obtain one, and applied it to a range of boilers which the smoke inspectors frequently swore did not get a sufficient supply of air. The recorder indicated the CO_2 at about 5 per cent., showing a large excess of air. Dampers were lowered so as to reduce the draught of air at the furnaces, with the result that the CO_2 was raised to about 10 per cent., where at least it should be for economy, and the smoke made much more dense. While engaged with these CO_2 recorder experiments, the smoke inspectors came round one morning between six and seven o'clock, and the final result of the use of the recorder was a prosecution, conviction, and fine. It had not been in use since. He understood the Corporation inclined rather to teach by example than by punishment. Mr Fyfe preferred the latter, and would raise the fines. That was all very well for one accustomed to the police courts, with their association of thieves and felons. Most manufacturers thought such a position was ample punishment, letting alone any fine, in the enforcement of so impossible a task as the combustion of Scotch coal without visible smoke, and with the economy practised by their competitors outside the city boundaries. Mr Fyfe said the smoke inspectors were expert firemen, but he never heard of a case where they took a shovel in hand to show a fireman how to fire without wasting coal and making smoke. The Corporation, he thought, had ample opportunities to pose as exemplars in the combustion of local coal, not regardless of cost, but with the best economy and without smoke, and if the inspectors could not personally show how to do it, it should be their duty to refer cases to similar Corporation examples before they resorted to prosecution. If unable to do so, it was manifestly unjust to convict. The Act aimed at reduction of smoke, but it never intended waste of coal.

Mr James Neilson (Member) said it seemed to him a very dangerous thing to interfere by legislation in this question, because the majority of people had only house fires, and these were the

Mr James Neilson.

worst and most intolerant. He thought one thing, however, might be done and should be done; that the Act should not be confined to smoke from chimneys only, but should be made applicable to cases where an enormous quantity of smoke was emitted from a roof or any other place. The fact that it was not from a chimney ought not to be any barrier in the way of the authorities. It seemed to him that the worst smoke came from steel works and from gas producers, and not from chimneys at all. These steel works were sometimes blotted out by a sort of light-coloured gas or smoke, which appeared to be far worse than ordinary smoke, and he did not see how such cases should escape if it was a preventible thing. It was not so much legislation that was wanted; it was science, and in its present state all the legislation in the world could not prevent smoke. If science advanced, then legislation would follow. On page 10 Mr Rowan said —"Another consideration must be noted, and that is that the gases escaping from the chimney, cooled and diluted as they are, are to all intents practically incombustible, whatever may have been their condition in the immediate vicinity of the fire." And further on, page 15, he said no good results could be obtained by a secondary combustion of true smoke when once its formation was completed. A gentleman of his acquaintance in Aberdeen made an experiment on a Cornish boiler by putting pipes into the lower flue, and by means of a blast or steam jet forced a part of the coal gases through the furnaces again. If the results obtained were anything like what had been stated, he must say it was an eye-opener to him. He afterwards received word that this arrangement had been tried on a trawler at Aberdeen with great success. If the gases could in this way be burned over again at a profit, no doubt the system would become general before long. Mr Rowan said that a chimney required from 30 to 80 times the quantity of heat required by an engine and fan, but if he could state how to utilise the gases after they came to be no longer useful in the boiler, he would confer a favour on a great many people. Even if the fan were adopted, a chimney would still be required, as it would never do to discharge the products of combustion at or about the ground level. The point that he was most disappointed with was Mr Rowan's definition of smoke, which included only the carbon and ash, the black material that could be mechanically dealt with; but it seemed to him that that was the least harmful of all the products of combustion. With the exception of the mechanical effect of breathing, these products did not do people much harm, whereas the gases were much more dangerous, and, if smoke could be consumed entirely, it was very questionable whether, from a health point of view, people would be better than they were before. It seemed to him that before this question could be settled, not only would all the soot and dust which came from the chimney have to be dealt with, but also all the gaseous products of combustion, and that, he thought, was not an insoluble problem. He did not see why it should not be attacked in the same way as the owners of smelting works did. Long ago "Dixon's blazes" could be seen all over the country; now they were covered in, and Dixon's firm, and others in the same line of business, made a very good profit out of their residuals. In ordinary furnaces in the city of Glasgow he did not expect that much residue could be got, but he did not agree with Mr Rowan that this would be worthless. Although the tar products might not in any case be completely consumed, the ammonia gases would remain, and they would probably pay for extraction. If got by purification it might be possible to have a gas in the end which would burn, and if it could not burn to make any profit, it might at least burn and reduce the carbonic oxide or other deleterious gases. It seemed to him that the Corporation, which was so much concerned with the health of the people, ought to take a lead in this matter, and should be experimenting and finding out on its own boilers the best way to actually purify the atmosphere from a health point of view, and so confer a very great benefit on the citizens.

Mr S. Utting (Associate Member) believed that smoke could be prevented to such an extent that it would not be considered

Mr S. Utting.
injurious. In several parts of England an agreement was entered into between the employer and the stoker, making the latter responsible for the production of smoke and the payment of fines, and that had proved a satisfactory solution of the difficulty. Mr Rowan made a definite statement that gas firing was the only remedy for smoke prevention, while one of the speakers had said that in connection with boilers fired with gas from blast furnaces in steel works he had seen plenty of smoke, and he himself had seen as much smoke from the stalks of gas-fired furnaces as from those that were coal fired. He believed bituminous coal, such as was obtained in the Glasgow district, could be satisfactorily burned provided the circumstances of each case were investigated properly, but stoking was more laborious than with a Welsh coal, and it was difficult to get men to do such work conscientiously unless they were given encouragement and suitably paid. Although it was usually unskilled labour that was found in stokeholds, a man could be made, by training, to burn coal properly, and therefore economically. He had seen the coking method adopted in the Midlands with satisfactory results, when other methods in use were not successful in preventing smoke. There was an art in firing, although it was not necessary for a man to have a knowledge of the chemistry of fuel. Boiler owners too often overlooked that fact. In some places manufacturers paid their boiler attendants by results on a certain given percentage of CO_2, and if a man could not get that amount recorded he was put on a battery with men who could do so. He had ample opportunity of improving his methods, and if he then failed the manufacturer adopted the method which Mr Rowan had referred to on page 16. Mr Rowan suggested an Imperial enactment rather than a local one, but it was not quite clear what benefit could be got from such an arrangement. There might be a benefit in having a similar law for all parts of the country. In this connection he would point out that Mr Fyfe mentioned that chimneys other than steam boiler chimneys were not liable to a fine, but in the South of England that certainly was not the case.

Mr S. Utting.

In rotary kilns at certain cement works, where the smoke was frequently very black, it was quite a common thing to pay fines for smoke emission. So heavy were they in one case, that the section of the works responsible was shut down for long periods rather than face the repeated prosecution From statistics, about one-half of the coal burned ten years ago was used for steam generation, and out of that probably over 60 per cent. was consumed in Lancashire and Cornish boilers. Therefore, the Committees, referred to on page 16 of the paper, were well advised in directing special attention to that class of furnace. He did not think that there were so many boilers overworked as one of the previous speakers had led them to believe. Out of a very large number of tests in which he had been engaged, he found that it had been rather the reverse. The boilers were shown to be frequently working uneconomically. Consequently the furnaces during heavy loads were overworked, a condition which was always conducive to smoke production. He was pleased to hear the last speaker ask whether, after all, the sanitary point of view was really so important. In Cumberland, Sussex, Essex, and South Wales district, he had seen smoke as black as that represented by Fig. 9, and in the last-mentioned place the grass, which ought to have been green, was absolutely black. Vegetation, however, did not appear to suffer, and if the complexion of the inhabitants was an index to their constitutions, they did not appear to suffer either. An ordinary sized Lancashire boiler working economically would emit about 11,000 lbs. of gases per hour, and one working uneconomically (with, say, about 5 per cent. of CO_2, and about 14 per cent. of oxygen) would emit 20,000 lbs. of gases per hour, and that, it seemed to him, was far more objectionable. The majority of people did not realise that that was the case. He had analysed boiler flue gases collected when no smoke was visible, and found that the boiler was working at a very low efficiency—much lower than might obtain when smoke was emitted. He thought the æsthetic point of view, and the fact that there was an unnecessary drain on our limited coal supplies, more reasonable grounds for objection than one based on sanitary considerations.

Mr J. Millen Adam.

Mr J. Millen Adam (Member), like some of the other speakers, expected that Mr Rowan would have wound up his paper with a suggestion, but he supposed that Mr Rowan was much too old a parliamentarian to give himself away. He would refer to three points of interest as briefly as possible. He was very much interested in the explanation of the particles of smoke on page 8. Some years ago, when he had more to do with liquid fuel than at present, he found quite a similar phenomenon going to explain the oozy deposit that was caused round the burning of liquid fuel Precisely the same sort of vesicle as that described, but a heavy one, was formed by steam in attacking a cold particle of oil, condensing and escaping enveloped in a film of oil. Such a compound globule could not re-evaporate within the flame, and escaped to form the watery ooze so well known; in this respect the use of compressed air was preferable for pulverising the oil, to the use of steam, for that purpose. He agreed with Mr Rowan that the dust element was a very important one. Several years ago he had been asked by the Lord Dean of Guild and the Gas Commissioners of one of our eastern cities to report on the smoke that was caused by their stack of gas producers in the gas works, and he thought that some of the Members of the Institution who were interested in the development and design of such plants might give some little attention to this subject. The present arrangement made it most difficult, indeed, to get a ho d of the smoke—which rose in clouds when discharging the retorts—whatever one might be able to do with it after it was found; and certainly a municipal factory, which was generally situated on the lower levels of great cities, made more smoke than anything short of a steel works. Perhaps one or two passages from the report that he had given might be interesting in this connection as confirming some of the statements that had been made in the paper under review. In that report he said—"As requested, I have observed the emission of smoke from your retort sheds under several atmospheric conditions. It sometimes rises to the roof of the central bay, and diffuses in the atmosphere from the apex ventilators, but frequently, as on Saturday, 30th November, no smoke appears at this point. On that day a fog like a cloud, escaping from under the eaves of the eastern shed, lay close to the ground, and swept up the hill to the north-east among the terraces. A mechanical apparatus, with suitable receivers, could be designed to collect and discharge the bulk of the smoke in a concentrated form through a shaft or chimney, which, however, would be a 'smoky chimney' in the sense that the smoke would be very visible, and the only advantage gained would be its removal to the south end of the building. As you know, this smoke is a compound of several constituents. There are, firstly, colourless fumes (carbonic acid gas), which would readily diffuse; secondly, unconsumed hydrocarbons; thirdly, water vapour; and fourthly, dust. The most obnoxious to the housewife are, I presume, the second; which condenses as soot; and the fourth, dust, which is carried in large quantities. I have graded samples taken at various altitudes. These are aggravated by the presence of vapour, but were there no vapour given off, these elements (dust and soot) would rapidly absorb moisture from the atmosphere in muggy weather." The report went on to make recommendations as to cleansing the smoke from its solid constituents, which need not be recapitulated. The Commissioners did not adopt the chimney, perhaps for the reason that Mr Fyfe gave, that they themselves would be liable in an action. Undoubtedly the question of dust in smoke was a very serious one. Two or three years ago one of the large shipbuilding firms in the north-east of England, having been repeatedly summoned for the emission of smoke from a battery of several boilers, adopted an induced draught system, and associated with it dust separators, and that firm was now collecting tons of dust, which otherwise would be distributed over the surrounding town and country, and the smoke was no longer subject to complaint. There was no doubt that the facility offered for cleansing the smoke of its dust was one great prospective advantage of induced draught, but few engineers knew how to go about it. The third

Mr J. Millen Adam.

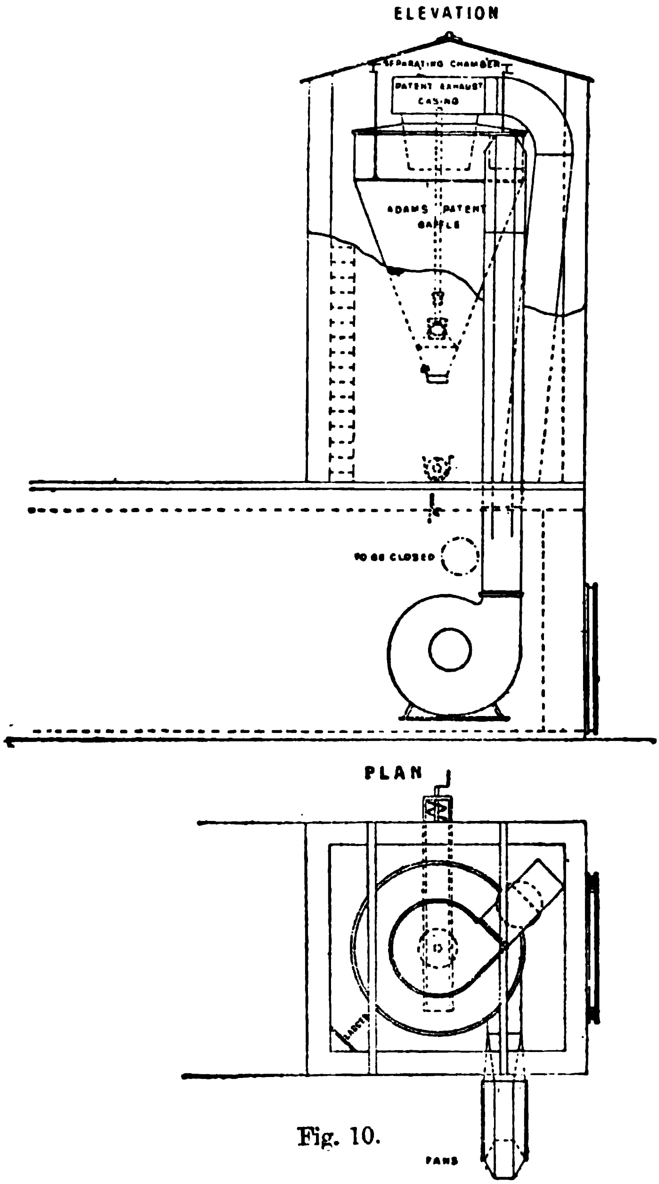

Fig. 10.

point that he wished to refer to was perhaps a little outside the subject, but was connected with it in respect that it showed that the dust under certain conditions might be utilised to advantage if it could afterwards be recovered. Some months ago his firm had been consulted by correspondents as to a proposal which involved the carrying of heated gases for a very long distance through a closed duct—he thought 200 or 300 feet in length—and the heat had afterwards to be applied to a drying process at that distance. The products of combustion were very heavily charged with dust, which was considered a serious impediment. Dust, however, was a much more efficient heat carrier than pure air or gas. A very powerful suction was arranged, which carried the impurified products of combustion away towards the drying chamber, where the hot dust was gently laid down on the roof of the chamber, while the air separated from the dust was delivered into the interior, Fig. 10. The report on the working of this apparatus stated that 85 per cent. of the dust had been recovered, and that, he thought, could be improved upon very materially, because the apparatus sent on had been fitted by people who had never seen anything of the kind before. He might add that under recent patents, it was possible to purify and partially cool the air or gas before passing it through fans. There were many purposes which might occur to Members—engineers and chemists—where it would be of the first importance to cleanse hot gases from contained dust, but he thought it was not generally recognised that, as a part solution of the smoke problem, the trapping of the dust constituents would often be worth while for its own sake. Even if it should not at first appear to pay—in the doing of it intelligently—other elements of economy might emerge, as in the illustration he had first given from his own practice.

Mr A. S. Biggart (Member) thought the statement made on page 19 of the paper that "Mechanical Stokers have the excellent feature of providing automatic regularity in the feeding of the coal, but they only reach the point of producing steadily the minimum flow of smoke; they cannot abolish it," a remarkable one

Mr A. S. Biggart

to make. His own experience ran entirely in the contrary direction. Ten or twelve years ago a mechanical stoker was fitted in one of the workshops of his firm, and it certainly ran and did still run for long periods at a time, without smoke being emitted from the chimney. Not only was that the case in the particular instance he referred to, but in many parts of Glasgow and elsewhere, where mechanical stokers were used, the chimneys were free from smoke for considerable periods, so far as could be judged by the eye, The instance that Mr Fyfe gave in connection with the St. Enoch Station Subway plant seemed to prove the contrary to what Mr Rowan had indicated in his paper. Perhaps Mr Rowan had some explanation to give, and he would be glad if Mr Rowan would refer to it in his reply. Although he had spoken about the matter to many of his friends, he had yet to find the user of stoking plant of this nature, that had found practically any economy from the use of it. In the case of his own firm no economy had been found, and the only gain seemed to be in having a purer atmosphere, and fewer calls from smoke inspectors. In the course of the discussion, a remark had been made by Mr Fyfe suspecting the leniency of the authorities in connection with the prosecution of parties whose chimneys were occasionally emitting more smoke than was allowable. Cases on the other side of the lenient line could be pointed out where the authorities tried to get convictions and failed. It had struck him that in some of these instances the authorities went about matters in what appeared a rather unfair way. No one had any idea when the inspectors were watching the chimneys or furnaces, consequently the evidence, as a rule, was onesided. If consumers wished to keep themselves in a position to give evidence at all, and such as might modify the opinion of the court with regard to the density of smoke, they would require to keep two men stationed all day watching every chimney. The inspectors not only watched chimneys without the user's knowledge, but they did so in strange ways at times. On one occasion his firm had been summoned in connection with some furnaces, and the authorities failed to obtain a conviction. In evidence it was brought out that some of the witnesses had viewed the situation from back windows near at hand. Speaking generally, he thought that in many cases the application of mechanical stokers would tend to increase the purity of the air of the City of Glasgow. The Corporation, however, might do a great deal more than it was doing, and until everything in its power was done, it certainly ought to be fair with other people. Until the Corporation did more than at present, in the way of giving cheaper gas for use in cooking and heating in houses, and in giving cheaper electricity for power and other applications to industrial progress, they would have failed at least in doing their share towards purifying the air of the City of Glasgow. The case against the Corporation in these matters was strengthened by the fact that it insisted on retaining the monoply of supply.

Mr James Andrews (Member) remarked that Mr Rowan had been particularly fortunate in bringing forward papers of great general interest to the Institution, and he thought this paper was one particularly adapted for discussion by engineers, because, although sanitary authorities and other societies had taken an interest in the question, it was essentially an engineer's problem. It was fruitless to grumble at quack doctors and quack remedies so long as the evil existed for them to practice on. Better have any kind of remedy than none at all. Nor did he think it was serving any good purpose to quarrel with local or sanitary authorities for "tackling" the question in sections and by the best means at their command, because, although it was not altogether fair to confine their vigilance to steam boilers, if engineers could overcome the difficulty in boiler furnaces the sanitary authorities would very soon turn their attention to some other kind of furnaces, otherwise, he supposed, their occupation would be gone. Now, while the difficulty of covering the whole ground on this subject in a single paper must be recognised, the general concensus of opinion, so far as the discussion had gone, was that Mr Rowan would have improved his paper considerably if he had omitted a great many of the complicated variety of furnaces, their purpose and con-

Mr James Andrews.
ditions of working, and given instead a lucid statement of his own remedy as applied to a definite case. Given a concrete example it was not so very difficult to apply the general principle in part, if not completely, to a great many furnaces, even when used for different purposes. Moreover, he thought that if a concrete example had been placed before them it would have broadened out the discussion considerably. They might have had the practical experience of a great many other members who had no doubt endeavoured to get over the same difficulty. The paper, circumscribed as it was, did not give the same opportunity of bringing forward actual cases that had come within their own experience. Considering the first principles of combustion, which Mr Rowan stated were so well known, he was not sure that they could all agree with him. No doubt there was a general agreement regarding the chemistry of the process, but when Mr Rowan went on to quote the practical conditions of good combustion, from various authorities, it was obvious that there was no general agreement between them. It was not even clear that Mr Rowan was altogether agreed with any of them. Most authorities differed in almost every respect except that there must be a sufficiency of air, and he (Mr Andrews) was not sure that any of them agreed as to where the air should be admitted. As a matter of fact that was the point that was known least about. The stoker, whose business it was to regulate the conditions of combustion, had no means of knowing what quantity of air was admitted to the furnace. He could not see it, nor could he measure it. He had no knowledge of its amount, relative to the amount of coal burned. He had no means of knowing whether it should be above or below the grate or at the back of the fire, and, as a rule, he could not even see the effect produced by varying the amount of air admitted at different parts of the furnace. He simply pitched into the furnace as much coal as he thought was required to maintain a given evaporation, and shut the door. How could any one expect to overcome the smoke nuisance or get anything but black smoke under such conditions. The stoker ought to be

Mr James Andrews.

placed in a much better position than he was. He ought to see what was going on in his furnace and be able to take an intelligent interest in what was happening during the process of combustion. There should be some means whereby he could know that when he charged his furnace the gases were being properly distilled and consumed before reaching the chimney, and that he was getting something more than black smoke. It was true that, in some cases, CO_2 recorders had been fitted. He (Mr Andrews) had used them, and he had recently seen a most interesting and delicate instrument of the kind, working in one of the largest electric stations in the city, to the evident satisfaction of the users. Now if there should happen to be a leakage of air at the wrong place, then what did a CO_2 recorder indicate? It was simply misleading and worse than no guide at all to the stoker. Such was, no doubt, the cause of a previous speaker's experience who applied a CO_2 recorder, and, who, when he discovered that he had got the proper percentage of CO_2 recorded (as he thought) found not only that he got black smoke, but that he was prosecuted for doing that which the recorder directed. There were, of course, other instruments which might be used—and were perhaps good in their way—as a guide to the stoker, such for example as the recording pyrometer. But, while it might indicate the highest temperature, under the given conditions, it did not follow that the maximum temperature would coincide with the minimum or even with a moderate degree of smoke. Now, it appeared to him that, the most important factor in the whole problem was the practical application of first principles, which was that furnaces ought to be properly constructed in the first instance, but by the present system of learning by experience how to build a furnace, one was generally well on in years and had made an endless number of blunders and experiments before he obtained a satisfactory furnace. The subject ought to be taught more generally in technical schools and colleges so that young men, coming into a drawing office from the college, would have some definite knowledge of the proper construction of furnaces, the areas over bridges, and through

Mr James Andrews.
passages, corresponding with the volume and temperature of the gases to be dealt with so that, when completed, furnaces would be capable of consuming their own smoke and be efficient, when in the hands of a stoker or attendant of average intelligence. Although he himself had had a great many young men passing through his hands, who had that work to do occasionally, he had never come across one who gave areas through a furnace and its passages or the volumes and temperatures of gases, any consideration. They simply copied one drawing from another, whether the furnace was required to burn 40 lbs. or 20 lbs. of coal per square foot of grate, areas over the bridge and at other parts were kept practically the same. He had known cases, where by simply dropping the bridge 5 or 6 inches, 30 or 40 per cent. was added to the power of the engine. In several cases where provision was made for the stoker seeing into the furnace and the back bridge, also into the combustion chamber, the stokers took a much deeper interest in attending to the fires and watching what was going on than they could otherwise have done. Provision was made for admitting air above and below the grate and also at the back bridge, gear being brought to the front of the boiler so that the stoker could regulate the admission of air to suit the rate of combustion required, and black smoke was never seen, indeed the smoke was so little that it was scarcely preceptible. Mr Rowan did not hold out very much hope for the abatement of smoke, but he (Mr Andrews) trusted that in his reply to the discussion he would be able to give some definite suggestions, something from his wide experience, which would be of service to the Members of the Institution and to a great many others who had not the opportunities of experimenting for themselves. The particular furnaces that he himself had been talking about were hand-fired, having more than one fire stoked alternately, but he had also seen mechanical stokers of the coking type working equally well with a chimney not more than 30 feet high, using induced draught, where seldom a particle of smoke could be seen issuing from the chimney. Much had been said about the

domestic fire being the greatest sinner amongst smoke producers. During the last eight years he had been using a fire in his dining-room, and during the whole of that time he had no recollection of having seen a particle of smoke coming out of the chimney, half-an-hour after the fire was lit. It was a closed fire or stove, having tall doors so that no one could see the process of combustion going on. The air could be regulated for admission either above or below the grate, the coal could be burned across the top or across the bottom as desired, and the rate of combustion was completely under command. It could be filled with coal to the top and completely burned out within an hour, or it could be adjusted to burn for nearly 24 hours. The fire could even be put out by simply shutting off the air supply, and all soot and dirt was collected within itself and cleaned out regularly. The temperature of the room could be varied at will up to 70° F. in the coldest possible weather, whereas in an adjoining room with an open fire place, it was difficult to reach a temperature of 42° F. during the recent cold weather. There was no dust or dirt about the closed fire referred to, the coals were completely burned to a brown ash and fell into a tray at the bottom. It was a great improvement on anything of the kind he had seen in this country. It was most commonly used, he believed, in Canada, but he had used it himself on the Continent where coal was much dearer than it was here, and where efforts were made to get as much heat out of the coal as possible.

Mr Andrew Gillespie (Member) supposed that in years gone by he had appeared in Court as often as his neighbours, but for some time past he had been giving his whole attention to another form of the smoke problem. In the very interesting paper which had been read, Mr Rowan seemed to come home to the facts of the case towards the end, where he referred specially to gas firing. He could not help thinking that in this discussion, and in their past experience of the smoke problem, they were, perhaps, going upon wrong lines. They should concern themselves less with smoke abolition and smoke prevention, and turn

Mr Andrew Gillespie.
their minds more in the direction of its utilisation. The condition of smoke he referred to was, of course, gas; and that had been utilised in connection with blast furnaces and coke ovens. Everyone was familiar with mechanical stokers and other forms of smoke consumers, but these cost money, and some of them failed to do what was expected of them. He did not despair of the time coming—and it might not be long in coming—when the smoke gases that came from the coal would be more fully utilised. It would be both possible and economical in an establishment where there were perhaps five or six steam boilers, to put down plant for the recovery of the tar and ammonia. That itself would very soon repay the outlay for the necessary plant. He did not think such a thing would pay a small concern with one or two boilers, but would it not be possible to establish districts in a city where a generating plant could be put down for recovering the bye-products, and supplying washed gas to power users, thus getting full value out of the coal? He also believed that the time would soon come when the domestic consumer would use such gas for cooking, heating, and other purposes. They were quite aware how the use of gas as a direct motive power was advancing, but along with this ought to be considered the recovery of valuable products, as well as getting clean gas for fuel or power, and the prevention of smoke. He knew one firm that had adopted a recovery plant in connection with its blast furnaces, and it had sometimes as much as £100 profit in one day.

Mr Alexander Wilson (Member) said there were two points which interested him, one in connection with the smaller users of power, and the other with domestic chimneys. Both were great sinners in smoke production. To hear Mr Gillespie one would hardly think there was such a thing as a gas works in Glasgow. Mr Gillespie advocated a supply of gas for power and heating purposes which had been purified from tar and ammonia. In gas works, coal was dealt with in the same manner as Mr Gillespie referred to, and clean gas was supplied which could be used for power and heating in exactly the way that Mr Gillespie wished. He thought the Welsbach incandescent mantle would be one of the factors in leading the way in the future to a gas of a much lower illuminating power than was at present supplied. When that day came, gas would be much cheaper than at the present rate. Even, however, at the present price gas could be supplied to modern gas engines at economical rates. Makers now guaranteed a consumption not exceeding 15 or 16 cubic feet per B.H.P., but even taking it at 20 feet, that meant less than ½d. per horse power per hour, and he did not think that a high rate for small users of power. Steam plants were often over driven, and by their use the formation of smoke could not be prevented, nor could coal be burned economically. The gas department of Glasgow had assisted to install a great many gas engines all over the city, in place of steam plants which caused so much smoke, and these gas engines gave very satisfactory results. Up to 80 or 100 H.P. a gas engine could compete very favourably with a steam engine, and save all the troubles that were entailed by the using of coal in small steam plants. While in London, a fortnight ago, he had the pleasure of seeing the gas exhibition there, but he did not know whether the gas fires shown could compete with that described by Mr Andrews, although they were made suitable for nearly all purposes. In rooms used intermittently, or for an evening, he did not think anything could beat a gas fire, which was very economical. There were no coals to carry, no ashes to clear away, and no smoke or dust, and the cost for gas was certainly not heavy. The same argument applied to cooking stoves and also to gas heated apparatus used for other purposes. Radiators were now made by means of which heating could be done very economically, and without trace of smoke, for use in places where it was not convenient to have fires.

Mr Andrew Sproul (Member) said he knew the gentleman in Aberdeen referred to by Mr Neilson as having made an experiment on a Cornish boiler. That gentleman was Mr Andrew Stewart, and he would just like to make a remark in regard to

Mr Andrew Sproul.
what had been said, as he had had an opportunity of seeing the boiler referred to in operation. The furnace was very much like a Meldrum forced draught furnace, but there were pipes in the under flue, from which gases came and these were passed into the furnace and burned over again. It was all very well to speak of economy in the use of a CO_2 recorder, and about gases being brought up to the proper standard, but he thought there were many things in the gases that could be consumed which the econometer told nothing about. In the instance referred to, it was a case of burning the gases over again with considerable advantage. He had seen the pyrometer put into the bottom of the chimney in this particular case, and he thought it indicated about 480° F. After the blast was put on, the temperature dropped to a good bit under 300° F. As a result of experiments made at Aberdeen, some people thought they could evaporate something like 18 lbs. of water per pound of coal. He did not believe that, but he believed that from 9 or 10, or perhaps from 12 to 13 lbs. might be evaporated. There was a possibility of gain by burning the gases over again. It took away the smoke for one thing. There was practically no smoke from Mr Stewart's chimney. The gases were simply burned and reburned until there was nothing at all to go up the chimney in the form of smoke. They had been told by some of the Members, and he thought Mr Rowan himself said, that a great deal of unconsumed carbon was driven up the chimney when forced draught was put on, but in this case it was arrested and returned to the flue, and sent back with a certain quantity of air to the furnace. Had he known sooner that the matter was to be of such interest, he might have brought certain data which he believed would have been very interesting.

Since making the above remarks, Mr Sproul obtained the following particulars from Mr Stewart:—The boiler plant consisted of two boilers, one 20 feet long by 6 feet diameter, with one furnace, the back end of the flue being fitted with a number of small tubes; the other was a Cornish boiler, 21 feet long by 5 feet diameter, with Galloway tubes in the flue, the fire grate being

Mr Andrew Sproul.

5 feet by 3 feet, giving 15 square feet of grate area. Before fitting the patent forced draught, both boilers were required to comfortably do the work with English dross, firing in the ordinary way. The smallest boiler was now fitted with the apparatus, which drew the hot gases from under the flue and delivered them under the fire bars. The front of the ash pit was closed up, but fitted with a small door for regulating a certain amount of air, as was found necessary. The working pressure of this boiler was 50 lbs. per square inch. The feed water was heated from the engine exhaust, and ranged from 150° F. to 170° F. when the boiler was forced to its utmost without the blower. The temperature of the flue gases at the back end of the boiler was 800°, F. and when the blower was put in operation the temperature at the same place fell to 350° F., and by forcing again by the blower the temperature could again be raised to 800° F. On a trial, extending over 30 consecutive days, no smoke ever appeared at the chimney. The boiler was under banked fires on Sundays, and the fuel used was Duff or slack from Durham. The fuel was weighed and the water measured, and the results were stated to be equal to evaporating 13 pounds of water per pound of fuel. The one boiler was now more than equal to all the regular requirements. With the high temperature of the furnace now obtained, the steam became dissociated, and the hydrogen and oxygen absorbed something like 6000 B.T.U. for each pound of steam used, which was given back again to the products of combustion in the back end of the flue, where the temperature was such as to allow them to reunite. At this point the greater part of the hot gases were abstracted by the blower and sent under the fire bars. In practice this seemed one way of getting rid of visible vapour, which appeared a popular solution of the smoke problem with some advantage to power users. Mr Rowan might have his own way in dealing with the merits of the device of Mr Stewart, who had given certain facts worthy of consideration, and it was with that object he put them on record.

Mr Rowan (in reply) thanked the Members for what Mr Biggart

Mr Rowan.
had aptly termed the hearty way in which they had received the paper and discussed it, and said his object in offering the paper was that there should be a discussion in which he hoped some part would be taken by some of the more active members of the Corporation. Those members of the Town Council who were specially interested in the smoke question might have given them the advantage of their ideas either by way of warning, or advice, or instruction. He had been disappointed in that respect. Mr Fyfe, however, had come and spoken very frankly on the subject, and deserved their thanks for so doing, but he must say that the general effect of Mr Fyfe's representation of the subject, to his mind at least, was to produce the impression that, as far as the magisterial or municipal mind was concerned, the smoke question was dealt with on a thoroughly irrational basis. They were told that smoke was a nuisance, and yet the authorities only dealt with one kind of furnace. Although it might have been quite right to begin with one kind, he could not see the consistency of remaining tied up to one kind of furnace only, when there was no proof that it was the greatest offender. They were also told that no matter how much smoke escaped from any building or works, there was no nuisance unless the smoke escaped by a chimney. The obvious rational conclusion, therefore, was, that it was the chimney that was the nuisance. Mr Fyfe would have them to believe, too, that there was no importance attached to the density or shade of the smoke, that the colour of the smoke escaping from a chimney had no part in deciding as to a manufacturer's liability to prosecution; but everything he himself had ever learned, read, or heard about municipal or magisterial practice was directly contrary to that, and he could scarcely think that Mr Fyfe genuinely wished them to believe it. His inspectors made reports and produced diagrams, which were used in evidence, and those diagrams and reports recorded the duration of the emission of smoke of the different degrees of density or shades of colour during the time of their observations. The same thing had happened when, in the old days, the police made these observa-

tions and reports, and he had never heard of a case in which any manufacturer was fined for anything else than for making *black* smoke for a certain time. In a very interesting paper of which Mr Fyfe, who was the author, had presented him with a copy, and which was entitled "The Sewage of the Air," the same distinction was made. Mr Fyfe spoke therein of "black smoke" repeatedly, and in one passage he referred to the magistrate's feelings "when rows of cases of *air pollution by black smoke* came before him," so that he did not see that he could very well affirm or maintain that black smoke had nothing to do with the question. Although the words of the Act did not make any distinction, but simply dealt with smoke, it seemed to him that if the common sense of the magistrates did not introduce some such standard as that by which to judge of the cases coming before them, the administration of the law would be even more irrational than they had imagined. The dilemma which Mr Cleghorn's artless question brought to light was enough to show the chaotic state of affairs; and it directly resulted from that, and from the discussion that had taken place, that what manufacturers had to do at present in order to escape prosecution for smoke, was to see that they had connected with their chimney serving the boilers some other kind of furnaces, and *to make sure that these furnaces were always making smoke!* In that case the boilers could not be successfully attacked. Mr Fyfe had attributed to him one or two remarks which he did not make; but he would pass these by, and take up two points which he thought called for notice. The first was as to mechanical *versus* chimney draught. It was not necessary amongst engineers at this date to go into figures showing the advantages of the one over the other. Many such calculations had been published. He himself had given some figures in a paper to the Institution in 1888, and he had since published others in a volume on "The Practical Physics of the Modern Steam Boiler." Mr Sinclair Couper had corroborated to some extent the view he expressed, and Mr Fyfe, as they saw, had himself unwittingly furnished them with very strong argument against chimneys! As

Mr Rowan.

to the system of boiler firing, to which Mr Fyfe had referred, he had obtained from Mr Fyfe and from the owners of the system some information about it. Mr Fyfe, in referring to his remarks about gas-firing, naturally limited them to boiler furnaces exclusively, but he (Mr Rowan) had really other furnaces more prominently in view when he made the remark. The system which Mr Fyfe referred to was called the Wilskemp system, and was a combination of gas firing and a coal-fired grate as applied to boilers. It was a compromise, and, like most compromises, was not entirely satisfactory. In fact, on going into the figures of a trial, which was carried out before the Glasgow deputation, of which Mr Fyfe formed one, he found that without the Wilskemp apparatus the boilers evaporated 6·28 lbs. of water per lb. of coal. With the apparatus attached they only evaporated 5·75 lbs. of water, so that the efficiency of the boilers fell off—that was to say, that the fuel was not used so economically. In 5 hours and 25 minutes, 2 tons 18 cwts. of Welsh coal were used in the first instance; and in 5 hours and 15 minutes, 3 tons 6¾ cwts. of Tamworth slack coal were used in the second. Some anthracite peas were also used in the producer, but the quantity of these or of the gas being made was not stated in the report. He did not think, therefore, that there was much benefit to be derived from that system, although as a smoke consumer or preventer, for which it was put forward, it was successful, and, notwithstanding Mr Fyfe's disclaimer, in order to be so it did necessitate the use of gas firing. He thought a better result could be obtained by an intelligent application of gas firing alone, without the additional coal firing. He fully admitted that given ample boiler power and no necessity for forcing the fires, it was quite possible to have boiler furnaces fired with coal by mechanical stokers, or even by hand with skilled labour, without the production of a large quantity of smoke. Mr Biggart had given some instances, but the fact of the matter was that these conditions, as some of the speakers had pointed out in the discussion, were very seldom obtained. They might be got on special occasions, like trials, and so on, but as a rule they were not obtained in regular practice. Moreover, in considering other furnaces—although he had been taken to task for introducing other furnaces than boiler furnaces—as he had said, a number of complex conditions cropped up, and it was particularly in view of the larger aspect of the subject that he had spoken of gas firing. Mr G. C. Thomson followed Mr Fyfe in the attempt to maintain that the colour or density of smoke had nothing to do with the case, but he thought, as he had already indicated, that was a very extraordinary position for an intelligent engineer to take up. Mr Thomson, however, was cautious enough to qualify his statement by saying that "it was only when smoke affected the health and happiness of the people by polluting the air they breathed and deprived them of the sunlight and its health-giving power, that it really became a question of importance." Now, apart from fogs, he thought that might be taken as a very clear indication that in Mr Thomson's mind, at any rate, the smoke must have been pretty black. Mr Thomson would not admit that smoke had anything to do with the formation of fogs, because he said that fogs had existed in a historic period very remote from this, when there was no such thing as coal used. He even went further, and maintained that dust played no important part in the formation of mist, because by the fogs that Mr Thomson spoke of in those days he supposed he meant mist. If Mr Thomson were to study carefully Mr Aitken's writings and conclusions as to the effect of dust in the formation of mist, cloud, and rain, he would alter his views. When Mr Thomson came to deal with the gas-fired furnaces, he, as well as Mr Utting, made some statements which either put too great a strain upon their powers of credence, or argued a very extraordinary experience on the part of those gentlemen. Mr Thomson was reported in his own remarks as saying that at the chimneys of some steel works smoke was conspicuous by its presence in first-rate quality. It was, however, well known that in the steel works in this district probably none of the steam boilers, of which there were numbers, were fired by gas. The gas-fired furnaces were confined to the

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steel melting and heating furnaces. If Mr Thomson was aware of this fact, that the boiler furnaces were coal fired in most of the steel works, then Mr Thomson had employed the device of making the coal-fired furnace speak for the gas-fired furnace, and that was not quite fair. Mr Utting had given a different complexion to Mr Thomson's remarks. Mr Utting's version was that he had said that, "in connection with boilers fired with gas from blast furnaces in steel works, he had seen plenty of smoke." If that had been said, nothing more was needed to show that the statement was an entirely unreliable one. The gas reaching steam boiler furnaces from blast furnaces consisted almost entirely of CO and N, the hydrocarbons having been washed out for the purpose to which Mr Gillespie had referred, and it was physically impossible to make smoke from carbon monoxide, which was the only combustible element in that gas. These facts did not induce him, at any rate, to attach much weight to Mr Thomson's further remark, that "he had never seen a gas-fired furnace that could not and did not fail to emit smoke just as well as its coal-fired brother"; or to Mr Utting's, "he had seen as much smoke from the stalks of gas-fired furnaces as from those that were coal fired." All he could say was that he challenged those gentlemen to give details of these furnaces, and of the circumstances of their examination of them, in order that they might be in a position to say whether there were actually any real gas furnaces amongst them, and whether the comparison was a fair one. In the absence of that information, no one who had had any experience of the combustion of producer gas in furnaces would be likely to readily accept their judgment. At the same time, he did not say that it was impossible, even with a perfect gas furnace, to produce some smoke, but it was impossible to produce black smoke, even although gross carelessness or incompetence were at work. In the other case—the case of coal-fired furnaces—it was only by the exercise of considerable skill and care that smoke could be prevented. Black smoke of anything like the quality or volume that was produced in coal furnaces could not be produced in gas

furnaces, because, for one reason, they never could be overloaded with fuel, as was the case where the furnaces were fed with solid fuel periodically, and the air supply was also quite differently arranged. Any appearance of smoke at the chimney of a properly constructed gas furnace could only be due to some unburned gas escaping, and a few turns of either the gas valve or the air admission valve would at once cure that. With the remarks of Mr Couper, he was happy to be in accord, but he could not say that he agreed with Mr Cuthill. Mr Cuthill's disappointment with the paper was, he thought, due to his idea that the subject of the paper was to have been the economy of smoke prevention, whereas what he (Mr Rowan) proposed to do was simply to survey the economics of the subject, which embraced more than the mere question of money saving. The money saving might be very small in certain cases, as he had indicated in the paper; it was pretty much in proportion to the temperature which was to be produced in the furnaces, but even as to that part, he did not think Mr Cuthill stated the case quite fairly. Mr Cuthill did not reject his remark that "smoke was so much coal wasted," but said that this was no argument that to prevent it was economy. He must ask Mr Cuthill to pardon his saying that he had always been led to believe that to "prevent waste" was the essence of "economy." If it were merely a question of preventing the escape of the 1 per cent. of carbon of which Mr Cuthill spoke, that would be a very small matter, but although it might be possible, as Mr Cuthill told them, to produce smoke which could issue in a pretty black state by an admixture of 1 per cent. of carbon, he thought Mr Cuthill would know very well that the smoke which actually escaped from industrial chimneys contained a great deal more than 1 per cent. Besides that, there were other economies which were attendant upon the introduction of a more perfect method of combustion. Regarding even boiler fires, he had some records of an instance of boilers fired with producer gas, the cost being ·007d per indicated horse power per hour, which he thought compared very favourably with Mr Cuthill's 4d per thousand pounds of water. That would

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work out at probably something between ·08d to ·2d per indicated horse power per hour, according to the class of engines employed. Mr Cuthill was mistaken in thinking that he (Mr Rowan) intended to exclude boiler firing when he had spoken about gas firing generally. His rising to correct Mr Fyfe was simply to prevent his excluding other furnaces when he spoke. He had no particulars at all of the work done at the Corporation electric supply stations, but he agreed with Mr Cuthill and other speakers that it would be of great advantage if the Corporation engineers would give some information on that subject. Mr Neilson's disappointment with the paper was due to his not distinguishing between smoke and the waste gases which were the ordinary and proper products of the combustion of coal. Of course, it was well known that the gases which were the proper products of combustion were carbonic acid, hydrogen, vapour of water, and small quantities of carbon monoxide and oxygen, and sulphur dioxide when sulphur was present in the coal. The only useful point about them, if the combustion was complete, would be the heat which they carried away, and that could be, and was in many cases, to some extent utilised in economisers and air heaters where there was no chimney draught. With chimney draught, a large proportion of that heat must go to waste, as it was necessary to produce the draught in the chimney caused by the hot gases ascending. Mr Neilson referred to the idea of extracting ammonia from the gases from furnaces. It was absolutely impossible to do that, because the gases did not contain ammonia. Gases that had passed through the fire of an ordinary furnace could not yield ammonia, no matter how much nitrogen the coal originally contained, and no matter although in the first reactions which took place in the fire, ammonia might to some extent be formed, that ammonia would be instantly destroyed by the temperature of the furnace. It was extremely difficult to retain ammonia when its formation was due to the combustion of coal, and one would require, as had been shown by Dr Mond in one way, and by Mr Duff and others before them, a very large

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quantity of steam, some four or five times the weight of coal, in the actual zone of combustion in order to preserve the ammonia, when it was formed from the nitrogen which was separated from the carbon during combustion. This led to Mr Gillespie's remarks, and it was extremely interesting to hear his advocacy of the use of fuel gas, with which he (Mr Rowan) was quite in accord, but he did not think that Mr Gillespie quite sufficiently distinguished between smoke and smoky gases, which he was careful to do in the paper. Smoke—that was to say the gases which had passed through a furnace—represented the ultimate results of what had taken place, and was not the same as combustible gas which was produced in blast furnaces or in a gas producer. Although that gas was smoky in appearance, it was not smoke, because it contained combustible hydrocarbons which formed a certain proportion of almost all coal, and was rendered combustible by the simple addition of air, while smoke was not. It was very certain, however, that these gases could not profitably be dealt with on the small scale referred to by Mr Gillespie. That was to say, Mr Gillespie imagined that in the case of a man using perhaps 30 or 40 tons of coal per week in firing boilers, the ammonia might profitably be extracted. To do that would require a considerable amount of space and a considerable amount of plant, and the small yield of ammonia from that quantity of coal he did not think would pay. It was generally accepted that on nothing less than 50 tons of coal would an ammonia recovery plant pay. As regarded the distribution of gas, he did not see at all why that should not be done, although the experience of the Mond Company in Staffordshire was not very encouraging. It was practically what Dr Mond got a Bill through Parliament for—to treat coal in a large central station in producers, extract the ammonia, and then distribute the gas, after having washed and purified it. Mr Wilson spoke of gas for engines at 2s per 1000 cubic feet. The production of gas in producers did not cost more than from 1d to 2d per 1000 cubic feet, but when it came to be distributed over a large area, the distribu-

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tion costs ran up the price until it was impossible that it could be distributed for anything less than 3d or 4d, or even more. When a manufacturer was asked to pay that price, he immediately started to consider whether it would not be cheaper to put down producers for himself, and get the gas at 1d per 1000 cubic feet, and a gas for furnaces which was rather better for his purpose than the washed and purified gas that was distributed. Even at the larger price, it was much cheaper for power than illuminating gas, but Mr Wilson was no doubt quite right in supposing that for small users of power in cities and towns the illuminating gas would be preferred. Mr Neilson had referred to a plan, which had also been alluded to by Mr Sproul, for using flue gases over and over again. It was perfectly plain to engineers that there was no such thing as perpetual motion, and to use the same gases over and over again in a furnace was absolutely impossible. A certain proportion of the gases might be withdrawn from the flue and passed a second time through the fire, but there was a very quick limit to such repetition, because as soon as there was more than a certain small percentage of carbonic acid mixed with them, when passing through the fire it would be precisely similar to, or rather worse than, putting a jet of water on the fire, and would make it black.

Mr Sproul—Perhaps there was more in Mr Stewart's apparatus than Mr Rowan thought of. He had seen the apparatus, and it certainly was a great success.

Mr Rowan—What proportion of gas was taken from the flue and passed through the fire?

Mr Sproul—He could not tell.

Mr Neilson—The boiler he saw had two pipes attached to it, each 9 inches in diameter. Nothing he had said justified the idea of perpetual motion. To him the difficulty about the matter was whether the proper gas could be got.

Mr Rowan—He was greatly interested in the dust catcher which Mr Millen Adam had described, and to some extent illustrated, in the proceedings; and he would gladly learn something more about it, because there was no doubt that it might be very useful in dealing with producer gas. The point raised by Mr Biggart as to mechanical stokers had been partly dealt with in replying to Mr Fyfe. Probably with every stoker there was a moderate rate of feed, bearing a certain proportion to chimney draught and boiler heating surface, which could be carried on with the minimum production of smoke, but as soon as that rate was exceeded—as at certain times, such as after cleaning fires, or when forcing the boiler, etc., it was sure to be—then combustion was not completed soon enough in the space, and smoke appeared. All the phenomena mentioned by Mr Biggart were easily understood on those grounds. He quite agreed with Mr Biggart that the procedure in smoke cases, as regarded the one-sided character of the evidence, demanded alteration and improvement. He did not think that by following Mr Andrews' advice, and restricting himself to "one concrete example of some special furnace," he would have added to the general interest of the paper, but rather the reverse, and he could not find any indication in the discussion—apart from Mr Andrews' remarks—that any one thought so. Possibly he might have been mistaken, but his idea had not been in any way to give a lecture on the construction and working of furnaces, which was practically what Mr Andrews would have preferred. Mr Andrews' description of the helplessness of stokers working hand-fed furnaces formed additional proof of the need of gas-fired furnaces which eliminated the uncertainties referred to. He did not agree with Mr Cuthill and other speakers that he had not held out a ray of hope to anybody as to escaping smoke prosecutions, or that he had not indicated the direction in which smoke prevention could be attained. He could only reiterate his conviction that engineering science was quite able to deal successfully with all the varied conditions of the employment of fuel, but no real diminution of smoke production could be arrived at apart from the general use of fuel gas. He did not say that other schemes should not be tried on certain occasions, but if they were to deal with the subject at all in a

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complete way, it could only be by the method of gasifying the fuel and dealing with the gas in furnaces. No doubt, as Mr Couper remarked, simultaneously with that would come the extension of the use of fuel gas for power in gas engines. That had been referred to, and he thought it extremely likely, though (as to this subject) it only affected the question of boiler furnaces. Outside of these, as they all knew, there was an enormous variety of furnaces which remained for individual treatment, but which the authorities so far practically confessed their inability to deal with, because they had not made them subject to prosecution. These were included in the whole subject, which required to be dealt with in an intelligent and comprehensive manner.

On the motion of the CHAIRMAN, Mr Rowan was awarded a vote of thanks for his paper.

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Mr JAMES LOWE (Associate Member) considered that the abolition of the smoke nuisance was well worthy the attention which it had received from the Members of the Institution. Mr Rowan's paper on the Smoke Problem brought to memory another very interesting paper by the same author on "Producer Gas, and its Use in Engineering and Shipbuilding," read during Session 1901-02. In that paper Mr Rowan showed the economy to be derived from the use of producer gas in all kinds of furnaces. There was no doubt that the prevention of smoke, so far as it came from industrial heating operations on a large scale, would be best effected by the use of gaseous fuel, and that it would pay to prevent smoke in this manner. There seemed to be a certain vagueness in the conception of what constituted smoke by some of the Members. Some appeared to consider smoke and the products of combustion to be one and the same thing. It was, of course, quite impossible not to have products of combustion, while it was quite possible to prevent smoke. Smoke resulted from incomplete combustion, and the best means of preventing it was to secure complete combustion. Products of combustion consisted principally of CO_2 and steam, and when dispersed in the atmosphere they were not injurious. The presence of unburned carbon as soot or carbon monoxide, or of hydrocarbon gases, was, on the other hand, both dirty and injurious to health. What was wanted was not smoke consumption as a second operation, but perfect combustion at first. The use of producer gas for heating steam boilers did not, as in the case of most furnaces, result in a great saving of fuel. It was possible that the equivalent evaporation might be slightly increased by this means, but a great saving was not possible if the boiler had previously been fairly efficient. There were, however, collateral advantages. The steaming power of the boiler might be very largely increased (he had been assured by as much as 50 per cent.), and certainly a great increase in boiler power seemed to be possible when one considered the greater temperature attained (nearly twice that possible with ordinary firing), and the fact that in, say, a Lancashire boiler, the flame might play round the whole circumference of the flue instead of only on the top. It seemed to him, however, that for small power installations, say up to 100 H.P., smoke might be prevented and power obtained more cheaply by the use of the gas engine with town gas than in any other way. For larger powers the day of gas engines with producer gas would certainly come. In the meantime, however, to prevent smoke the gaseous firing of steam boilers should be adopted. Of all the methods of using coal, those of direct firing in boilers, furnaces, and domestic fires were the most wasteful from the point of view of fuel economy, and produced most smoke, while the distillation of coal in gas works and coke ovens with recovery of bye-products, and the production of producer gas, also with recovery of bye-products, were the least wasteful. The abolition of smoke from domestic chimneys had been effected already to some extent by the adoption of gas cooking and heating appliances, and there was no doubt that the problem could, and would, be satisfactorily solved in this manner. Mr Rowan was to be congratulated on his prophetic

Mr James Lowe.

vision when he spoke of the desire to poke a fire being a happily lost relic of savage ancestry.

Mr WILLIAM KENT (Syracuse, N.Y.) observed that Mr Rowan said, under the head of "Prevention of Smoke," "Most of those who have made efforts in the past to arrive at the abatement of smoke seem to have chosen the wrong starting point. They assumed the accomplished formation of smoke, and started to destroy it in some way. This was a fundamental mistake." He also said—"In his book on 'Steam Boiler Economy,' Mr Wm. Kent endeavoured, by means of a partial and totally inadequate experiment, to prove that smoke could be profitably burned," and then quoted nine lines from his book describing the experiment with a Rochester kerosene lamp. This experiment was neither partial nor inadequate for the purpose for which it was made. Its purpose was clearly shown in the few lines in the book which preceded the account of the experiment. These lines were :—"All of the products of imperfect combustion, the carbon monoxide, the hydrocarbon gases distilled from the coal, and the soot or smoke may afterwards be burned if they are carried into a very hot chamber, where they are brought into contact with a sufficient supply of highly-heated air." This last statement is contrary to that made by Charles Wye Williams in his treatise "On the Combustion of Coal and Prevention of Smoke," first printed about 60 years ago, and copied extensively by later writers, viz., that "When smoke is once produced in a furnace or flue, it is as impossible to burn it or convert it to heating purposes as it would be to convert the smoke issuing from the flame of a candle to the purposes of heat or light." Mr Rowan further said—"Moreover, if the great heat and pure flame of a kerosene lamp were required to deal with the infinitesimal amount produced by a single candle wick or a small piece of paper, the smoke from a factory chimney would demand something like a steel-melting furnace for its similar treatment. A 'Treatise on the Theory and Practice of Fuel Economy in the Operation of Steam Boilers' would be more usefully occupied, as this one is in a later chapter, in showing the practical method of smoke prevention." Mr Rowan seemed to think that the smoke from a factory chimney would demand something like a steel-melting furnace for its similar treatment. Probably this would be true if attempts were made to burn smoke after it escaped from a factory chimney, but in order to burn it between the boiler fire-box and the chimney a comparatively small size combustion chamber was all that was necessary, and the temperature did not need to be any higher than that of a kerosene lamp, say about 2,000° F. To show that smoke produced in a steam boiler furnace could be burned, he might relate the details of an experiment he made in 1896, and repeated several times since, with a furnace of the wing-wall type, such as was shown in Fig. 18, on page 161 of his book on "Steam Boiler Economy." The boiler was being fired with Illinois slack coal, containing over 40 per cent. of volatile matter and about 14 per cent. of moisture. When there was upon the grate bars a bed of partially burned-out coke highly heated, four shovels full of coal, spread completely over the grate, would immediately cause dense clouds of black smoke to issue from the chimney; but if these four shovels full were placed upon one side of the grate only, not a particle of smoke would escape. The condition for the complete success of this experiment, which showed the production of smoke on the side of the furnace on which coal was thrown, and its complete burning in the chamber in the rear of the fire-box, was, that there should be a sufficient supply of air delivered through the other side of the grate, and the hot coke lying on it to consume completely all the tarry gases, soot, etc., that proceeded from the freshly-fired coal. That this smoke was at least in part "completely formed smoke," and not merely tarry gases. Mr Rowan would admit, since he said, in another part of the paper, "The high temperature in furnaces causes the decomposition of hydrocarbons, such as acetylene, into carbon and hydrocarbon, which would burn if the necessary temperature were continued along with the proper quantity of oxygen." In the experiment referred to he used a Uehling & Steinbart pyrometer to take the

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temperature of the fire-box. It was really over 2,000° F. when this moist bituminous coal was used, although 3,000° F. was frequently reached with a coal containing only 2 per cent. of moisture and not over 35 per cent. of volatile matter low in oxygen. In order to maintain the temperature of the fire-box or the combustion chamber above 2,000° F., it was necessary that one or the other, or both, should be roofed over with fire brick, and also that the combustion chamber should be of considerable size. These conditions it was almost impossible to obtain in a Lancashire or Scotch marine boiler. They could be obtained with water-tube boilers by building what was called a "Dutch" oven entirely in front of the boiler, as was shown on page 161 of his book on "Steam Boiler Economy." The wing-walls were necessary to make a complete mixture of the gases surcharged with smoke and the hot gases arising from the coke surcharged with air. With externally-fired horizontal tubular boilers, which were very common in the United States, but which, he believed, were rarely used in Great Britain, the furnace construction was still simpler. All that was necessary was to excavate a large combustion chamber in the rear of the bridge wall, arch it over, put wing-walls beneath it, and a baffle wall above it, so as to compel the gases to travel below the arch and become thoroughly mixed as they approached the wing-walls. In an earlier part of Mr Rowan's paper he stated that "A complete review of this part of the subject would most probably lead to the conclusion that the formation of a large proportion of the smoke is in most cases chargeable to the imperfect action of our present system of chimneys when combined with coal-fired furnaces." The formation of smoke took place before the furnace gases reached the chimney. The offices of the chimney were merely to remove such gases as were delivered to it, and to create a sufficient draught at the furnace to burn the required quantity of coal. If it removed the gases and produced the draught, that was all that any system of draught could do, and the chimney could not be charged with the duty of either preventing the formation of smoke or burning it after it was

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formed. If smoke was produced in the furnaces it should be burned in the combustion chamber before it entered the chimney, and could be burned if sufficient very hot air was provided, and thoroughly mixed with the smoky gases. He thought Mr Rowan did not give sufficient credit to mechanical stokers, when he said that "They only reach the point of producing steadily the minimum flow of smoke; they cannot abolish it. That can be done only by a system of gas firing." If he would build a "Dutch" oven in front of a boiler, and instal in it a chain grate stoker, and run the chain grate so that the rear portion of it had only coke upon it, the stoker and the "Dutch" oven combined then became a highly efficient gas producer, and also a gas burner if sufficient air passed through the coke on the rear portion of the grate to completely cousume the smoky gases arising from the front portion. Such a stoker might also be used for metallurgical purposes, such as the heating of iron and steel, but here the difficulty arose that a smokeless flame was apt to be an oxidizing flame, which was not desirable in heating iron and steel on account of the waste of iron which it entailed. The Siemens regenerative furnace, however, was capable of being so operated as to give a practically non-oxidizing flame with little or no smoke.

Mr George Craig considered this subject one of vital importance to shipbuilders and engineers, and as a case in point he might instance H.M.S. "Terrible," in which the coal consumption was now one-half what it had been before her recent overhaul. He made overtures to test and put the "Terrible's" combustion on a proper basis at her first steam trials, and his work would have cost a few pounds, but he could not put a figure on the cost of the Admiralty's experiment while this vessel was in commission. Mr Rowan, in his paper, mentioned five different classes of furnaces; the fifth being that in which a wide range of chemical operations were carried on. Now, one very seldom saw prosecutions for black smoke at chemical works; and of the chemical furnaces he quoted a black ash furnace might have a suggestive

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name, but it was generally smokeless, as was also a salt cake furnace, and a pyrites furnace by no possible manner of means could be made to smoke—as pyrites was the combustible, and there was no coal in or near it. Indeed, this class of furnace might almost be eliminated. It went without saying that gas firing would cure the existing evils, but until that took place he thought the sanitary authorities were quite correct to adopt nature's plan, and make the offenders learn through suffering —it was a department which had been neglected too much in the past. In the discussion Mr Fyfe and Mr Rowan were apparently antagonistic about the virtue, or rather about the smoke preventing powers, of mechanical stokers. As neither gentleman gave any data, he might say that both might be correct, and in this way. When working with a high efficiency of combustion, mechanical stokers might be said to reduce the smoke to a minimum; but even with extravagant or wasteful combustion there might not be a vestige of smoke. Mr Neilson referred to the performance of a boiler with an arrangement for using the waste gases over again, and as combustion was a combination of carbon and oxygen, while there was any oxygen in the waste gases there would be combustion. Coupling that principle with the fact that combustion was usually wasteful and extravagant at Aberdeen and elsewhere, the statement of an increased evaporation by this device became quite a good one. Sometimes he had got no more than 3 per cent. of CO_2 in the waste gases in the neighbourhood of Glasgow, and had often wished he could use that over again. For such gases at anything up to 500° F. were far superior to ordinary air as a supporter of combustion; and when the imperfect nature of boilers, settings, and even attendants were taken into account, the chances of obtaining better combustion were thereby greatly increased. Several speakers alluded to gas testing apparatus and CO_2 machines, generally condemning them. Having brought out a "combustion tester" himself, he might be biassed, but still he felt it was a great advantage when it enabled a man to see the truth in such a case as the Aberdeen boiler and to reconcile antagonistic views. In fact, until engineers had acquired the insight into combustion, gained only by acquaintance with some of these apparatus, they would be much at sea regarding combustion.

Mr James Whimster (Armagh) thought this a highly interesting paper, but one which had no apparent definite aim. It ought, however, to lead to a useful discussion, and the ventilation of the subject in such a centre as Glasgow, might be productive of much good. The solution of this great smoke problem was in his mind, to be found in one word—Gas. Gas power and gaseous firing would be found to be the true remedy for this most expensive nuisance. Gas engines had already gone a long way in mitigating the evil with small firms at least. They had displaced many small steam engines whose boilers were great offenders in this matter, and they had been installed in many instances, where, but for them, steam would have been used, and consequently more smoke poured into the atmosphere. If the vast number of gas engines in use all over the country were considered and one imagined their places taken by steam engines with smoke-producing boilers, it would be then understood what an improvement they were responsible for. Their still extending use, in both large and small sizes, whether supplied by town gas or producer gas, would before very long result in a very marked improvement in the purity of the atmosphere of all but our very largest towns, and such districts as Coatbridge. As for furnaces other than those of steam boilers, the author admitted that the necessary conditions could be attained by gaseous firing ; and there was no doubt they could in this way be better attained than by direct coal firing, for the heat could be better regulated and a uniform temperature maintained. The question of first cost ought to be no obstacle, as the economy and higher efficiency would certainly more than compensate for the extra cost. Gaseous firing had been so successful in gas works that direct-fired retort settings were now quite antiquated. It undoubtedly paid gas manufacturers to pull down even good direct-fired settings and replace them with

Mr James Whimster.
regenerative furnaces; and he imagined that the same would hold good in other industries where high heats were necessary, and it would certainly be for the benefit of the community at large.

In reply to the written communications Mr ROWAN remarked that Mr Lowe had very neatly epitomised the view which he (Mr Rowan) took of the whole subject, and he complimented Mr Lowe on giving such an intelligent account of it in so few sentences. Although Mr Kent seemed to object to his saying that the experiments referred to were inadequate, yet he on the other hand seemed to corroborate that opinion by giving the results of an additional experiment, which, however, only illustrated the system of alternate firing often adopted in the case of steam boilers in order to keep down the production of smoke. He (Mr Rowan) had no doubt that a large portion of the gases given off from most coal fires could he ignited if, before they were cooled, they were mixed with air and exposed to the requisite temperature, but this, instead of arguing that a secondary furnace was wanted, only showed that the combustion in the coal-fired furnace was incomplete, and it was the primary combustion which should be perfected. Under the circumstances which Mr Kent described relating to the experiment with the wing-wall furnace, Mr Rowan could not admit that the gases formed on one side of a fire place such as that described could be accurately termed completely formed smoke. He had more than once emphasized the fact that "cooling" was necessary to the "complete formation" of smoke. Mr Kent again seemed to differ from him as to mechanical stokers and their action, but really supported him when describing an ideal stoker by saying that "the stoker and the Dutch oven combined then became a highly efficient gas producer and also a gas burner if sufficient air passed through the coke," etc. Although he might differ from Mr Kent as to the efficiency of the arrangement yet he cordially agreed with him as to the principle of the action described. Mr Craig had apparently failed to learn from the chief of the Sanitary Department of Glasgow the reason why "one very seldom sees prosecutions for black smoke at chemical works," seeing that Mr Fyfe distinctly announced that no furnaces

Mr Rowan.

except those of steam boilers were at present *liable* to prosecution. That fact, therefore, was no foundation for an assumption that chemical works furnaces were smokeless. Regarding the special furnaces mentioned, if black ash and decomposing or salt-cake furnaces were in practice "generally smokeless," it was not because they could not be otherwise when coal fired, but that in some chemical works the conditions of proper combustion were attended to. Chemists have frequently recognised imperfections in these furnaces, and that was evidenced by the numerous attempts made to introduce improved forms of them. Moreover, smoke might be a nuisance inside the works as well as to the public outside, and in the cases in which the products of combustion were allowed to mingle with the hydrochloric acid from the decompositions, a very much smaller quantity of smoke than would be liable to prosecution (if the Act were applied to such furnaces) was objectionable, and might even be fatal to the working of the acid towers. Regarding pyrites furnaces, he must remind Mr Craig that there were furnaces in use for roasting copper pyrites in the manufacture of copper in which coal was used, as well as those for the burning of pyrites in the manufacture of sulphuric acid, in which only the sulphur was burned. Mr Craig's criticism was, therefore, beside the mark. Mr Whimster would find, if he read the paper carefully, that in as far as the author had to indicate a method of smoke prevention which was capable of universal application, his aim was as definite as that expressed by Mr Whimster himself when he said that "gas power and gaseous firing would be found to be the true remedy for this most expensive nuisance." He (Mr Rowan) had also another point before him, and that was the importance of the authorities recognising the fact that the subject of smoke prevention should not be dealt with in an arbitrary or a fragmentary way. Merely local restrictions in the hands of administrators not fully competent, or applied by methods that were onesided and crude, were mischievous. There was no good reason why the whole matter should not be dealt with in a comprehensive and equitable manner.

THE BREAKAGE AND RENEWAL OF A LARGE CYLINDER.

By Mr Hector MacColl (Member).

SEE PLATE III.

Held as Read 25th October, 1904.

Some years since a fast passenger steamer returned to port with damaged machinery. She had a single screw turned by three-crank compound engines, the H.P. cylinder, working with steam of 95 lbs. pressure, being in the middle, exhausting into a low pressure cylinder forward and into another aft.

History.

On the morning of the second day of the voyage loud pounding was heard in the H.P. cylinder, the engines were stopped, and it was found that the cylinder was damaged beyond repair. The H.P. engine was disconnected, piston valves drawn, their packing rings taken off, holes drilled in them, and the rings pinned over the ports so as to shut off the broken cylinder. Steam at 20 lbs. pressure was then admitted to the two L.P. engines, and the vessel returned to port. Probably there was nothing heroic in the performance of these operations, but, with a ship rolling, as this one could roll, drilling, tapping, and jointing in heated chambers 25 inches in diameter was a more painful and exhausting job than this description might indicate, and the performers deserve credit for the speed and efficiency with which the work was done.

As soon as possible after the vessel's return, a contract was entered into for the renewal of the H.P. piston rod, piston and cylinder, with other work in connection therewith, the price being about £1,600, and the work guaranteed to be completed in eight weeks under a heavy penalty, with corresponding premium for earlier completion. It was arranged that the new piston should be finished one inch smaller in diameter than before, but the cylinder liner to be made of the original external diameter, and thus finished half an inch thicker, so as to admit of reboring to the original size, should that ever be required. The broken cylinder with double piston-valve casings had been cast in one, but, as the relative positions of the various parts permitted, it was considered better to cast the new cylinder and casings separately, bolting them together as shown in Figs. 1, 2, and 3.

On the second day the cylinder was disconnected and removed from the ship. On the third day the cylinder liner, weighing 5·05 tons, was cast. On the thirteenth day the cylinder, weighing 8·6 tons, was cast. On the eighteenth day the valve casing, weighing 8·5 tons. was cast. On the morning of the forty-seventh day the whole work was sent out of the shop complete. During the day the new cylinder was lifted into its place, and all the joints carefully tested and found to fit accurately. It was then lifted out for the application of jointing material, and finally bolted in place that day. On the fifty-sixth day from date of contract all the work was completed. The total weight of castings amounted to 25·5 tons, and the detail of these weights, as well as the dates just given, are more clearly seen in tabular form :—

Current Days from Date of Order.	2	Cylinder out of ship.			
	3	Liner cast,	weight	5·05	tons.
	13	Cylinder cast,	,,	8·6	,,
	18	Casings cast,	,,	8·5	,,
		Other castings,	,,	3·35	,,
		Total,	,,	25·50	,,
	47	Work sent out of shop.			
	56	Work completed.			

As it may appear strange that the contract was finished exactly to time, it should be explained that as soon as it was evident that the work could be completed inside of that time, a strong hint was given that payment of a premium was to be, as the Board of

Trade instructions say, "discouraged." It was then evident that, to parody a well-known newspaper phrase, a premium had been embodied in the contract, "not necessarily for payment, nor as a guarantee of good faith," but solely to legalise the penalty. For the owners, it is only just to say that, having fixed and advertised a sailing date, there was no advantage in spending extra money to have the ship ready earlier than was necessary. It is generally well to make a virtue of necessity, and to bow before the inevitable; therefore, as the shipowner is always necessary, he must be virtuous, and as his decisions are inevitable, they must be bowed to, so overtime was eased off, and the work finished comfortably at the contract date.

CAUSE.

It was found on examination that two pieces were broken off the lower flange of H.P. piston on the sides opposite the steam port, as shown on Fig. 4. After a thorough investigation of all the facts, it was concluded that parts of the packing rings, which had worn thin, or of their tongue pieces, had broken, and as the ship was rolling heavily, these parts, slipping into the clearance bore at the bottom of the cylinder, had, at the turn of the stroke, broken a piece or pieces off the piston flange, so that the piston on its down strokes had pounded out the bottom of the cylinder.

LESSONS.

One of the obvious lessons learned from the occurrence is to arrange the relative positions of counter bore and piston packing rings, so that the latter do not overrun the former at either end of the stroke. This was done by making the new H.P. piston as shown in Fig. 5; while the two L.P. pistons were altered, as shown in Fig. 6, to effect the same purpose. But, as the practice is now general, nothing more need be said on the subject.

A more important lesson, both to engineers and to shipowners, is the advantage of subdividing large cylinder castings. It has been too long the custom in this district to look upon the cylinder as a thing of which one cannot have too much in a single casting. Large and complicated cylinders have not only valve cases cast on, but sometimes small fittings, causing the iron founder to run unnecessary risks, and involving the engine builder in extra expense machining small parts on large and costly machines, with consequent delay in completing the various operations. Probably one reason for this practice is that on the upper reaches of the river the foundry is almost entirely dissociated, both financially and geographically, from the engine works. The engineer too often looks upon the foundry as a dirty, smoky place, to be avoided as much as possible, whereas it is a department of his business in which an intelligent interest will be well repaid. The ironfounder with some pride in his art will do his best to cast structures of which his experience disapproves, but it would be to the advantage of both if his brother the engineer regularly conferred with him. Subdivision would benefit the shipowner by reduced cost of renewals, and much more by reduced time in effecting these. In the present instance the renewal might have been done in half the time had the cylinder body, bottom, and valve casing been cast separately, and, while four weeks would have been of enormous value to the owners, the suggested method of construction need not have increased the original cost.

Discussion.

Mr D. C. Hamilton (Member of Council) observed that he had been in Liverpool at the time that this renewal was carried out, and had seen the original cylinder, and also the cylinder that was proposed to be put in. The original cylinder was certainly a very complex casting, and he had no doubt that had it originally been designed as Mr MacColl planned the new one, it would have saved the shipowner a considerable amount of money and a great deal of time. It was not advisable to make such complex castings, especially when they were so heavy. Cases of the same description had happened, not very often, fortunately, as more

Mr D. C. Hamilton.
modern designed engines were less complicated, but at the period that this steamer was built it was the custom of a great many Clyde engineers to have the casings and other details cast on the cylinders. From what he had seen in recent years, the custom had altered considerably, and, he thought, to the shipowner's advantage.

Mr E. Hall-Brown (Vice-President) said it seemed to him that sometimes the designer of engines got very scant credit for his work. For instance Mr Scott Younger considered that it would be a distinct advantage to the shipowner and probably to the underwriters if pumps were cast in several pieces, and if even the valve chests of circulating pumps were cast separately; but he did not say where he would find the shipowner willing to pay for that. It so happened that most people nowadays had to face very keen competition, and as a rule the cheapest engines were bought; that being so it was very seldom that they could be subdivided so that each piece would have a minimum value. That remark, although due more to Mr Scott Younger's communication than to anything that appeared in the paper, was also suggested by what Mr MacColl had said. Mr MacColl pointed out that if the cylinder had been subdivided it would have been a very much simpler casting for the moulder and the loss when the cylinder was broken would have been very much reduced. That was very true, but he was not sure that even Mr MacColl, if he were asked, would say that he considered a live steam joint right through the flange which was bolted to the column head, to be a joint in its proper place. There were quite a number of people who would hold, with a certain amount of reason on their side, that possibly it was better to risk a fairly large casting in the hands of a competent moulder than a live steam joint right through the cylinder foot. It was always easier, he thought, to criticise a breakdown than to design a cylinder in the first instance, and probably the designer of this cylinder followed what he considered the best practice; and he (Mr Hall-Brown) believed that he had done what most engineers on the Clyde would still do with a cylinder of the same size. He

Mr E. Hall-Brown.

did not know that it was now the common practice to cast large casings independently from their cylinders. That he thought obtained very many years ago. He remembered one of the first things he did as an apprentice was to rub a piece of sandstone over a very old cylinder that lay outside the shop at Fairfield. It had been cast long before his day, possibly more than 30 years ago. That cylinder was subdivided to an extent which he had not seen approached since. If he remembered rightly the liner was one piece, the cylinder body another, and the top and bottom ends (apart from the cover) were other parts. In all, he thought that cylinder was in four pieces. The invariable practice later on, at Fairfield, was to cast the cylinders and casings in one piece, and he did not know that even the underwriters would have been very much benefited had these cylinders been in two pieces. Another thing that Mr MacColl called attention to was that the work should have been exactly done in the contract time—eight weeks. He could not imagine how that was arranged so exactly, unless the cylinder lay more or less finished in the works; and even if it were so he did not know that he admired the risk that was run in testing it at the last minute. Even although the ship was not wanted to sail until a fixed date, it seemed to him that the safest course—so far as the owners were concerned—would have been to have a "turn" as early as possible. Repair work was not work in which he had had any considerable experience and he highly appreciated the paper which Mr MacColl had placed before the Institution. At the same time it was well to note that none of the points which were altered in the new cylinder were those which caused the breakdown. That was due to defective piston design rather than to defective cylinder design. The cutting of the cylinder into two, although a convenience in manufacture, did not rectify any defect which caused the accident. Although he was no believer in big castings he thought it was sometimes advisable and even necessary to use castings that were bigger than one would otherwise care to have, rather than have a joint in what might be considered a doubtful place.

Mr MacColl.

Mr MacColl, in reply, said he was glad to learn that Mr D. C. Hamilton believed such cylinders as described were not now made on the Clyde. Referring to Mr Hall-Brown's remarks, he would repeat that he believed large cylinders subdivided, as suggested, would not cost more than if cast in one piece. As the founders' risk would be minimised, the rate per ton would be reduced; and the production of a cylinder in less time, and on less expensive machines, would meet the cost of machining and jointing. The table on page 79 showed that the cylinder was cast on the 13th day and the casings on the 18th, so that if the cylinder and casings had been cast together they could not have been cast in less than 18 days, and thus the machining of the cylinder would have been delayed at least 5 days, and the whole work delayed much longer. The question of cost need not, however, be a matter of opinion, as it could be got out accurately from working drawings of the two designs. With regard to the steam joint in the connection to column head, he did not hesitate to say that, although such an arrangement should be avoided if possible, it was undoubtedly preferable to casting the casings on the cylinder. The joint was not one about which there need be any doubt, and in the present case the lower inaccessible flanges were double bolted, with a rust groove between. The risk of having to remake this joint was not so great as that in the valve-casing joint connecting two cylinders, and many engineers adhered to the latter plan, although rejointing involved the removal of a cylinder. While it was true that it was easy to be wise after the event, no great originality was required in designing a subdivided cylinder, although it was no doubt still easier to follow what had been done before, as Mr Hall-Brown suggested. He thought the paper fully explained why the work was not completed in less than the contract time, but probably Mr Hall-Brown's misapprehension was due to his admitted inexperience in repair work. Those who had this experience knew that all contracts for such repairs provided for the work to be tested under steam, and Mr Hall-Brown might be sure that no unnecessary risk was run. The conclusions arrived at in the paper were in total disagreement with Mr Hall-Brown's last sentence; and he could only add what he thought was obvious, that the cylinder, as remade, only represented such improvements as the time and circumstances permitted, not such a cylinder as a new design would call for.

On the motion of the CHAIRMAN, Mr MacColl was awarded a vote of thanks for his paper.

Correspondence.

Mr JAMES MOLLISON (Member of Council) was afraid that the ingenuity and skill displayed by engineers in effecting temporary repairs at sea, to enable the vessel to be brought safely to port did not always receive the credit they deserved. In the present case, from the description at page 79 of the paper, the cylinder appeared to have been one of those (perhaps too common at one time) cast all in one piece, with double piston-valve casings and other connections, intended to save machining and jointing. This was very doubtful economy, as the risk of some defect in the casting was much greater than if subdivided into various portions, not to speak of the facility by which repairs when necessary could be effected. In this case, Mr MacColl mentioned that the renewal of the cylinder took exactly eight weeks, whereas by a subdivision of the casting the work might have been done in four weeks. This appeared to be a very liberal estimate of the time, because if the casting had been subdivided very likely only one portion might have been damaged. The renewal, however, of such a large cylinder, with its attachments, in eight weeks, was a piece of very good work, and Mr MacColl, in bringing the matter before the Institution, had given the Members an opportunity of knowing what could now be done by taking advantage of the improved facilities at command in our principal ports. In reading the paper, a very recent case of a broken cylinder came to his mind. A vessel belonging to Glasgow, while casting anchor at the port of Gabes, where she had gone to load, had the whole side or casing of one of the cylinders blown out with such force as to go through

Mr James Mollison.

the bunker plating. Being so disabled the owners sent out their superintendent engineer, and also an engineer from one of the repairing firms on the river, to arrange for a new cylinder. Luckily, the barrel of the cylinder, with the valve faces on either side of it, were intact, and it was decided to have the vessel towed to Malta for temporary repairs, and there the engines were put into such an efficient condition by the closing in of the broken casing with ½-inch boiler plating, and by the introduction of a 7-inch copper pipe to carry the steam from one cylinder to the other, Fig. 7, that the vessel was enabled to return to Gabes, where her cargo was loaded and conveyed to Glasgow. The new cylinder was prepared and ready for fitting on board on her

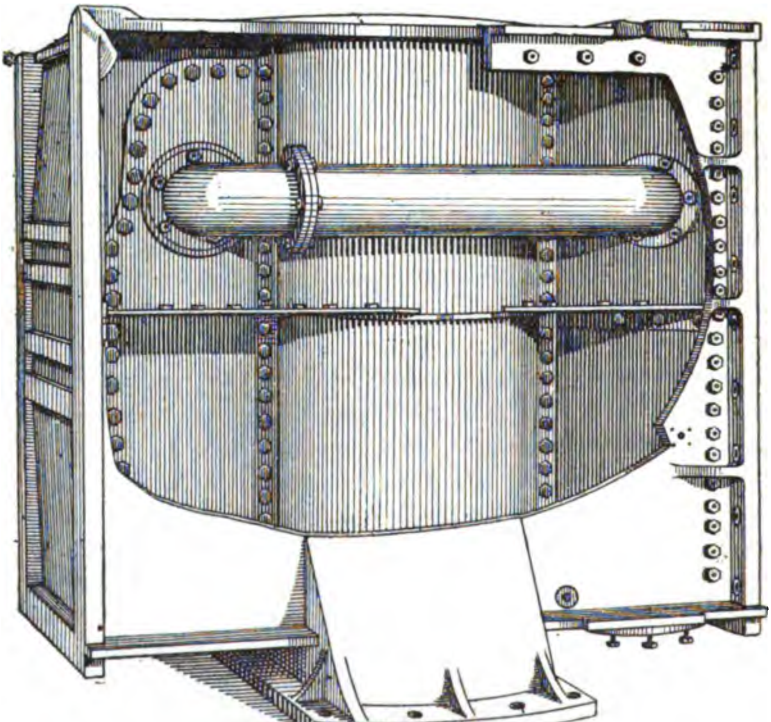

Fig. 7.

arrival. He was very much struck by the skilful way in which the repairs had been carried out, whereby, no doubt, both owners and underwriters were saved a considerable sum of money. Many clever and skilful repairs were devised and carried out by sea-going engineers, often in very adverse and trying circumstances, and he was sure that it would be a great benefit to the Institution if such men became corresponding Members, and thereby be induced to put on record, through the sanction of their employers, the results of their experience and endeavours.

Mr A. Scott Younger, B.Sc. (Member) considered that Mr MacColl had told his experience in a plain, straightforward way; and most practical engineers would be prepared te accept his theory of the accident, and the lessons to be drawn from it. There was not much to be said by way of criticism, at least adverse criticism, but there were one or two points which might be referred to. With respect to the cause of the accident, one felt inclined to ask why the packing ring was allowed to remain working in the cylinder when worn so thin? In a ship of this class it was likely that the working parts would be frequently and carefully examined, so, unless one supposed there was some undue wear, the condition of the rings must have been known to the engineer. The method adopted to prevent such an accident in the future would, no doubt, be quite effective though liable to lead to the formation of a ridge at the bottom of the cylinder band, which might give trouble later on. The adoption of a much thicker section of ring, like Buckley's or M'Lean's, would also have answered the purpose, and been free from this objection. The most important lesson was one that was very properly emphasised by Mr MacColl, viz., the advantage of subdividing large cylinder castings. Mr MacColl might have gone much further, and extended his suggestion to include other large engine castings as well as the cylinders. At the present time it was the practice of many engine builders to cast large box condensers all in one piece, which were liable to fracture under the stresses arising from the differences of temperature to which they were subjected. These, Mr A. Scott Younger.

he thought, should be subdivided, or made of circular section, and kept apart from the main framing of the engine. This, of course, was frequently done, but the practice was not so general as it should be. Another common practice was to cast the air and circulating pumps together, which was done to save labour in the fitting shop, and though there was no sacrifice of efficiency so far as the engine was concerned, there was an almost certain increase in the cost of renewals to be paid sooner or later by the shipowner. It was well known that the circulating pump was subjected to severe stresses arising from the racing of the engines, and was more liable to break down than the air pump; it was also much more subject to the wasting away of the metal forming the valve seats. while the air pump was free from this action. Therefore, it happened that the circulating pump was perhaps completely done, while the air pump was as good as new, so that, being cast together, the renewal of one meant renewal of both, with a large increase of cost and sacrifice of time to the shipowner. One well-known east coast firm not only cast the pumps separate, but the valve boxes of the circulating pump were apart from the body of the casting. In this way the cost of renewals was kept down, and no doubt the high estimation enjoyed by the firm referred to was due to the low cost of upkeep and repairs. During the last eight years he had had five new circulating pumps through his hands, the cost of fitting which would have have been considerably reduced had the castings been of simpler design.

Mr MacColl, in reply to the correspondence, said that Mr Mollison's description of a cylinder repair was most interesting, and he cordially agreed with his suggestion that the Institution would benefit by having such cases described and recorded in its transactions, by the men who carried out the work. Mr Scott Younger would readily see that the question he asked, and the further subdivision of castings he suggested did not come within the scope of the paper. The latter might well form the subject of a paper from Mr Younger himself, and, as an inducement, he

Mr MacColl.

promised him some discussion on his five burst circulating pumps, of which he knew nothing, but imagined a good deal. He quite agreed that the condenser should not form part of the framing; and that the air, circulating, feed, and bilge pumps should be separate castings. Some would remember the time when they were all cast on the condenser.

THE TRANSMISSION OF POWER BY ROPES.

By Mr Edwin Kenyon

SEE PLATES IV. AND V.

Read 22nd November, 1904.

Second only in importance to initial energy is the transmission of that energy or power to the productive machinery, without which it would prove merely a demonstration in applied mechanics as impotent as Hero's steam globe or Branca's turbine.

Boulton and Watt's Engine.

As the twin terms "power" and "transmission" are inseparable in actual practice, it might be pardonable if, on the threshold of this subject, a lantern slide be introduced showing one of the best specimens extant of Messrs Boulton & Watt's engine, erected by that enterprising firm for the Birmingham Canal navigations in the year 1777, and only recently removed from its original bed after 120 years of almost incessant working; and an illustration of

Newcomen's Engine,

a fine relic of Thomas Newcomen's effort to improve upon the work of his immediate predecessors, the famous Rutherglen engine at Farme Colliery, working since 1809.

Comparative Efficiency.

Without some such exhibition it would be difficult to conceive the enormous progress which has been made in the construction of the steam engine before it became possible to produce the marvellous machine shown on the screen. Briefly described, this is an inverted vertical triple-exansion rope-driven engine of 1,150 H.P., working under a steam pressure of 180 lbs. per square inch, and is guaranteed not to consume more than 1¼ lbs. of coal per I.H.P., as against about 7 lbs. for the Boulton & Watt engine.

Truly, a state of efficiency has been reached in the manipulation of steam as a motive power, beyond which it appears almost impossible to advance.

Skilfully devised contrivances, designed to enthral every atom of the force-giving element, are in evidence throughout the entire system. Huge steel boilers constructed to resist enormous pressures, mechanical stokers to apply and regulate the fuel, steam blasts to assist combustion, arrangements for arresting the escaping furnace gases (and with them almost vapourising the incoming water), insulating appliances to check thermal radiation, methods for superheating the steam on its way to the cylinders, sensitive actions to cut off and admit at the precise moment, and so on, until activity fails from sheer exhaustion. Even then means are taken to condense the almost lifeless vapour to its primary condition for the purpose of creating a vacuum, so that there may be attraction where propulsion is no longer possible.

Not content with such efficiency, however, demands are now made upon the engineer amounting almost to the total abolition of all waste. Every ounce of coal should produce its full equivalent in steam, every fugitive thermal unit should be captured, and there should not be the slightest particle of frictional loss either in the engine itself or the power-transmitting medium. When the battle with natural force results in such a consummation, then may the engineer rest from his labours and enjoy the millennium.

Electrical Transmission.

Giving priority to electrical transmission, controlled by that still incomprehensible medium, of the capabilities of which we are even now but imperfectly informed, it may be taken for granted that where units of power require to be distributed over large areas rom a central installation, there is no other known method comparable with that of transmitting electric motive force through wires from dynamo to motors, either attached to line shafts or to the machinery itself. Or where prolific water supplies may be pressed into the service for the turning of turbines, this system may be profitably applied to the working of more compact factories.

But when such conditions do not obtain, and when the driving may be effected by other means, the comparative cost and maintenance of electrical transmission is declared by some engineers to reach a point bordering on extravagance. One electrician who was entrusted with the lighting of a large factory, when requested to estimate for the driving of heavy machinery, advised not to attach a motor wherever it was possible to apply a belt or rope.

Notwithstanding many improvements in the direct coupling of engine with dynamo, which electricians throughout the country have not been slow to adopt, it is still a debatable point as to whether on the whole equal efficiency with greater general economy may not be secured by the employment of a more elastic medium. At a large work where electricity is the chief agency in the production of alkali, and where ropes are employed to drive the dynamos, the maintained efficiency from cylinder to switchboard is declared to be not less than 86 per cent. On the other hand, breakdowns at large power stations, involving considerable losses from prolonged stoppages, and the premature renewal of expensive parts, have led engineers to seriously reconsider their former verdict in favour of direct-coupled plants, particularly where floor space limitations are not a considered item in the estimate. Fig. 1 illustrates the method for driving dynamos by means of ropes.

Spur Gearing.

Of all the systems of power transmission yet devised, spur gearing appears to have dominated the rest, and to have been reverenced beyond measure by its devotees as the standard *par excellence* by which all other methods must be gauged, not because of its higher capabilities in a general way, but because it is said to register the smallest amount of loss from friction. Needless to say, the proving of this is fraught with considerable difficulty. In the first place, as every mechanical investigator knows, it is impossible to bring into complete agreement repeated tests made upon the same set of wheels; and again, the experiments which resulted in the acceptance of this dogma were conducted during the raw youth of rope driving, in what may be termed the Manilla period.

The introduction of cotton into the manufacture of driving ropes, and better mechanical arrangements, have gone far towards the establishment of a theory, which, if it does not actually reverse the former judgment, at least declares the difference between the two methods in the before mentioned respect, to be infinitesimal.

Breakdowns.

Therefore, we are disposed to treat this supposed detriment as a negligible quantity in the equation, and turn to a more practical issue, that of liability to break down.

Summarising his most interesting report on stationary engine breakdowns, published a few years ago, Mr Michael Longridge declares that while 124 breakdowns were due to spur gear, only three could be traced to the failure of belts or ropes. Further, the grinding noises attendant upon spur gearing are most effectually silenced when rope driving is introduced. This may not advance the production of material, but it certainly conduces to the comfort of the workers,

The Transmission of Power by Belts and Ropes.

Here the issues are so intricate as to lead expert thinkers towards conclusions totally at variance with the teachings of actual practice. The dominant factors governing the transmitting power of both belts and ropes are circumferential friction and velocity. But the most superficial observer will not fail to notice that entirely different means are employed to obtain this necessary friction, and that, while belts depend upon contact with flat surfaces, ropes are impacted into a series of grooves provided for their reception.

Herein lies the crux of the much-debated question as to whether centrifugal force exercises the same retarding influence upon rope as upon belt driving. This query can be answered in the negative. Tables have been issued purporting to make allowances for centrifugal detractions, which indicate a steadily increasing power in the ratio of speed up to a certain velocity, when the power as rapidly decreases. But the compilers of these tables have evidently overlooked the fact that when ropes are set in motion two conflicting forces spring into activity, the tendency of each being to nullify the effect of the other.

There is the force compelling rotation, the tendency of which is to fling the ropes away from the pulleys on the one hand, and on the other hand the wedging force or "stiction" in the grooves having decidedly contrary tendencies. Whether this antagonism of force goes to the extent of establishing complete equilibrium it would be difficult to say. One thing is certain, that the very high peripheral speed of 7,040 feet per minute, from a driving pulley 30 feet in diameter, shows a considerable accession to the estimated *pro rata* power without any apparent detriment to the ropes themselves. This point will be referred to more definitely later on.

Dr Stroud conducted a most interesting experiment in the physics laboratory of the Yorkshire College, demonstrating the effect of centrifugal tension upon an india rubber belt, driving from comparatively large on to a small pulley. One view shows the pulleys at rest, while the other is photographed with the pulleys running at a velocity sufficient to drive the belt right away from the bottom one, Figs. 2 and 3. This demonstration, of course, is given with a view to exaggerating what actually takes place in high speed belt driving. A similar, though not readily photographed effect, may often be perceived on the driven pulley of a small high speed fan. When velocity has reached its highest point, and before seizure again takes place, a thin line of light is distinctly discernable between the belt and the rim of the pulley.

In belt driving there is always a certain amount of creep or slip which must be considered in estimating for speeds. But when ropes are employed as the medium of transmission, the motion conveyed by them may be regarded as positive as that of spur gearing, unless they are overburdened, or reach the bottom of the grooves. As the slightest slipping induces frictional heat upon the pulley rim, any diminution of speed without this effect may be attributed to miscalculation.

Another item of comparison which may well claim attention, is that of first cost. But as parallel specifications dealing with both classes of driving are not always obtainable, it is difficult to arrive at definite conclusions upon the question of average values. A few years ago counter tenders were invited to identical specifications for power, speeds, sizes of pulleys, and centre distances, by a firm in the Midlands, with a view to settling in their own minds the question of general economy affecting belts and ropes, the results of which they were good enough to submit through their consulting engineer at the conclusion of the transaction.

The quotation for a best double leather belt 21½ inches wide amounted to the sum of £51, while the cost of ropes, including fixing, which meant sending an expert splicer a distance of 83 miles, totalled up to only £21.

The purchasing value of ropes to drive an equal power may be generally set down at about one quarter that of belts, if splicing is not included. Add to this, say, 15 per cent. upon the cost of belt pulleys for extra work in grooving, etc., and one has a fair estimate of the difference in first cost between the two systems.

This item should not be passed over without some reference to another compensating clause. Soliciting opinions on probable durability elicited the information that, if periodically well cleaned and lubricated, the belt might be expected to last at least 5 years, while the life of the ropes, under the well-appointed conditions suggested, was computed at from 12 to 15 years.

Without further labouring the question of comparison, it may be just as well to presume upon the conclusiveness of the evidence so far adduced, and, for the time being, declare the case proven in favour of rope driving, leaving the cudgels of rebutting argument to those who may best handle them in the after-discussion, compared with which, as a rule, the reading of a paper is merely an indefinite prelude.

There are few, if any, industries through the whole range of manufacturing enterprises requiring rotary motion, where rope driving may not be applied with most beneficial results. Of these, from the very nature of its application to all other industries, the iron trade ranks foremost, and therefore demands first attention. Few indeed are the processes where driving ropes have not been applied in the treatment of iron and steel, from the moment it leaves the furnace in molten masses, through the varied processes of forge and workshop, until it emerges a huge monument of mechanical skill, or is, perchance, incorporated into that delicate piece of mechanism we carry in our waistcoat pockets.

Iron Rolling Mills.

But what may probably prove of more interest to the Members of this Institution is the application of rope driving to iron rolling mills. The ultimate power necessary to carry the great masses of heated metal through the rolls until they are reduced to the required shape and dimensions, and how to provide against breakdowns due to excessive vibrations from shocks and stresses, are issues with which only those who have given special attention to this class of work are competent to deal.

An old engineer, who was largely engaged upon the construction of cogging mills, was wont to direct his chief draughtsman to ascertain the power required at full load, make liberal provisions for this, and then double the strength of the machinery. A rough and ready way out of the difficulty truly, but one which must commend itself on the ground of safety.

It is to be regretted that a better view could not be obtained of the rolling mill shown upon the screen, because of an interesting experiment with which it was connected. The power was originally transmitted from the engine to the rolls by means of a treble leather belt 19 inches wide, which, however, proved a source of annoyance, from considerable stretching and frequent renewals, until it was ultimately discarded, to be replaced with 7 cotton ropes 1¾ of an inch in diameter, at a cost, including splicing, of only one-third that of the belt; one year's outlay in renewals amounting to more than the price of pulleys and ropes combined. This experiment led to the application of rope driving to many other rolling mills.

Messrs Jonah Davies & Sons, of Wolverhampton, who are well-known consultants for iron works' plant, have planned and put down some 6 or 7 rope drives at works in their district, principally for hoop and strip mills (iron and steel), with a great saving in friction and power as compared with the old spur wheel system, giving a better output per turn, and the hoops, strips, rods, etc., a better finish with less waste. Messrs Davies & Sons state that the usual speed for hoop mills is 140 revolutions, small guide mills for rods from 240 to 260 revolutions, bar mills 1 inch to 2½ inches, square or round, from 60 to 80 revolutions, and large strip mills 120 revolutions per minute.

An engine at Stalybridge, which, unfortunately, is in too dark and cramped a position to be successfully photographed, is driving three sets of rolling mills; one called a 14-inch mill, direct from the crank shaft, which is making 120 revolutions; a "faggot" mill on the opposite side geared down to 38 revolutions per minute; and another for thin strips, by means of 8 cotton ropes 1½ inch in diameter from a fly-wheel 14 feet in diameter on to a pulley 6 feet in diameter, making a peripheral speed of 5,275 feet per minute, the direction of rotation bringing the tension side of the ropes over the top of the pulleys, a most desirable direction considering the erratic character of the driving. The important question of "trailing span" will come in for notice later on.

It may be stated that in Sheffield and in the Yorkshire district generally, most of the sheet steel and other rolling mills are fitted with driving ropes

Ropes Applied to Colliery Fans, Cranes, Etc.

Since the abolition of the old furnace draught, rope driving has played a most important part in ventilating the workings of coal mines, by transmitting power to the fans now employed for the purpose. At the Wigan Junction colliery, there is a compound 450 H.P. engine driving a fan installed for a duty of 300,000 cubic feet of air per minute, and has a 5-inch water gauge with a good reserve of power behind this to provide against emergencies. Judging from the enormous quantity of rope supplied for this purpose it may be surmised that other methods are at a discount.

Driving ropes are very much in evidence for the working of cranes used in engine works, moulding shops, and the like.

The various purposes to which ropes are applied in the manufacture of textile fabrics, from the raw material right on to the finished article, whether it be composed of linen, silk, wool, or cotton, are too well known to require more than passing mention. The action created by the transmission of power being generally speaking of an unvaried rotary character, it may be desirable to leave out almost all reference to duties imposed and consider under what conditions rope driving may be expected to best fulfil its mission.

Rope Driving Divided into Two Systems.

Rope driving may be divided into two leading branches known as the American or continuous system, and the English or individual rope system ; and the relative value of each in its effect upon the general principle involved should be carefully examined, not simply by theoretical deduction but by practical investigation.

First, then, dealing with the American or continuous system,

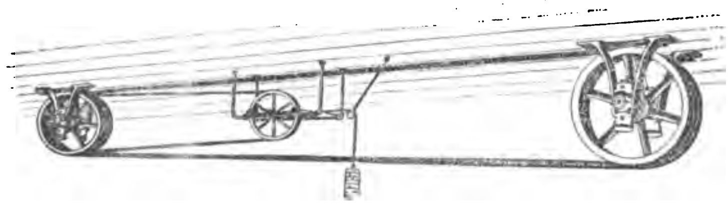

Fig. 4.

Fig. 4, that of winding a long rope round and round the pulleys and then carrying it from side to side as it completes the circuit, by means of a jockey pulley fixed at the required angle, it will be observed that this system necessitates a series of deflections from the straight driving path, causing the rope to assume the form of an elongated spiral and setting up a one-sided pressure in the grooves until the rope passes on to the arcs of contact on both the pulleys.

If the weight upon the jockey pulley is so arranged as to merely take up the slack and balance the driving tension of that part of the rope which it controls, then the frictional loss due to carrying the rope across the pulleys is not a very damaging factor, but when it is overloaded with a view to levelling up the entire drive, the strain, as may be imagined, is very materially increased without accomplishing its object. In order to better understand this method of driving, take, what was up to a short time ago, one of the best examples on this side of the Atlantic, but which is now transformed to the single rope system.

In a case of grain elevator driving, the full load was transmitted from the engine to the main shaft by separate cotton driving ropes, and then conveyed to grain elevators by means of Manilla ropes fitted up on the American system by the firm supplying the machinery. When in full action this continuous drive displayed a most interesting phenomenon which offered rebutting evidence to the much vaunted tension equality theory. Looking direct down the driving line a distinct deviation from the presumed horizontal plane was observable along the whole width of the drive. At the commencement of its circuit the rope was seen to reach its highest tension, from which it gradually declined at regular intervals, marked by its passagefrom groove to groove, reaching its lowest point at the last lap, to renew and repeat the operation so long as it continued to work.

When it is considered that the grooves form a part of the driving pulley itself, and are not loose sheaves like those in a pair of blocks, it will be readily understood that the wedging action prevents any interference with the original tension at which the rope is fixed, save by the strain on the working side, unless the rope stretches unduly or is made to slip, and that such a process is fraught with loss of power. Doubtless the greatest hindrance to the general adoption of the American system for all purposes, is the fact that dependence has to be placed upon one rope and should that fail the driving must stop until it is replaced, Whereas, with the separate rope system, an excess of the actual power required being usually provided, the replacement of a rope may await a convenient season, and that without detriment. A wholesale condemnation of this system is not proposed as there are circumstances where continuous rope driving may be adopted with advantage over other methods. For instance, in its application to paper-making machinery and under other awkward conditions. An advocate of continuous driving recommends pulleys of not less than sixty times the diameter of the ropes.

This leads up to other considerations bearing upon the relationship of ropes with pulleys under the conditions governed by the individual system. The absolute point of detraction in power from the employment of relatively small pulleys cannot of course be determined with mathematical accuracy, by reason of the elastic medium which has to be dealt with, and elasticity varies with almost every make of rope. One must therefore be content to declare a position between the extreme limit where the bending faculty of a rope ceases to exert its influence, and the diameter controlling the highest capability with which he is acquainted.

Size of Pulleys in Relation to Diameter of Ropes.

By reason of the great disparity in elasticity between cotton and Manilla, what is known as "permanent set" (i.e., where elasticity altogether ceases) being reached at a very much earlier stage in the tension of the last mentioned, it has been found necessary to fix the smallest pulley diameter at 50 per cent. greater than that of a cotton rope. It has been discovered that to attain efficient transmission of power the smallest pulley used with cotton ropes should not be less than 30 diameters, therefore with Manilla ropes

45 diameters should be taken as the minimum, unless extra rope power is added to make up for loss of grip.

The diagram, Fig. 5, will serve to illustrate the detrimental effect upon a rope by bending round abnormally small pulleys, better than any amount of verbal argument. For the purpose of emphasising this point, the circle round which this rope is fixed is only 14 diameters. By taking an angle of 45 degrees to represent the chord of the ogee arcs forming the interstices of the strands at the horizontal portion of the rope, and carrying this angle through at its junction with the vertical centre line, the diameter is found of the small circle to which tangent lines are drawn from the bent portion, which graphically displays the extension of the outer periphery at the expense of the inner pinch of the rope. It will thus readily be seen how the circle could be so reduced that the rope would refuse to bend round it.

The question now arises whether the amount of rope in direct contact with the pulleys influences in any way the power transmitted? And without hesitation it might be answered in the affirmative, all experience pointing to the fact that a reduced holding surface, from whatever cause, is accompanied with a corresponding loss of power. Although this implied detraction may not prove a realisable quantity in a drive where the factor of safety is recognised, it is always as well to make some allowance if only for the benefit of the rope.

Ignoring for the moment the curve represented by the "trailing span" and allowing straight lines to stand for the rope, it will be seen that, while the total contact upon the two pulleys always remains the same, the respective arcs are governed by the relative distances between the two pulleys. Thus with the circles at close quarters, as in Fig. 6, the arc of contact is represented as 135 degrees upon the small pulley. But as the distance between the pulleys is increased, the arc contact also increases until the position represented by Fig. 7 brings it to 157 degrees, or a difference of 32 degrees between the two.

From the foregoing it will be surmised, and rightly so, that the

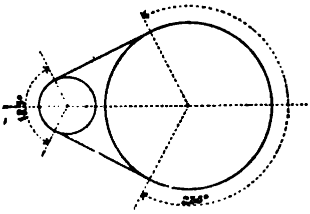

Fig. 6.

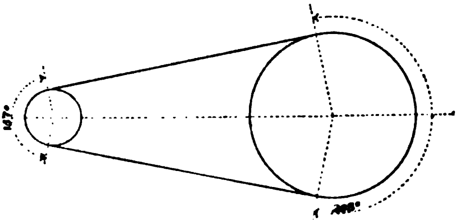

Fig. 7.

mallest pulley whether it be driver or driven, must be the, foundation on which to build any calculations. This understood there is also another influence which may either advance or impede efficiency, that is the position of the "trailing span" or idle side of the rope hanging between the two pulleys. Although there is a distinct increase in the arc of contact when the tight or working side of the rope is below the pulleys as shewn in the diagram, Fig. 8, this position is not always attainable, or even desir-

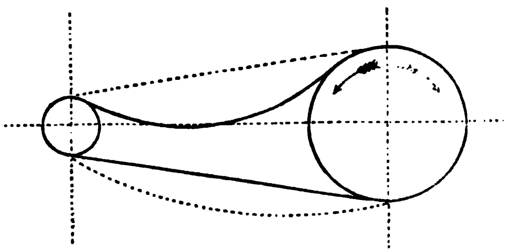

Fig. 8.

able. For instance, in cases where an erratic delivery of power is required, such as the driving of iron rolling mills, the shock is taken up by the ropes which display every irregularity by a series of wave like oscillations, and should these by any chance synchronise with the length of tension on the ropes, they may be induced to travel across the grooves or swing entirely off.

Now if the direction of rotation be reversed, the working strain being uppermost prevents the ropes wandering from their appointed track, while the slack, still feeling the impulses, falls naturally away by its own weight. It is often found advisable to adopt this direction of driving when applied to gas power by reason of irregular impulses. In down driving, i.e., where the driven pulley is lower than the line of the driving pulley, the trailing span may also with advantage be allowed to fall below. Generally speaking, an addition of 10 per cent in the ropes is sufficient to make up for any difference so caused in the arc of contact. With oblique driving the case is of course different because of the check administered by its upward tendency.

Long Centres.

The preceding question brings another of equal importance in its train; that of distance limitation. With the aid of guide pulleys, rope transmission may be carried forward to enormous distances. But how far centres may be placed from each other without intermediate support, is largely a matter of pulley dimensions and driving directions. Naturally with large pulleys the under and over travelling portions of the rope are kept well apart, and again there is always an amount of sag on the working side of a long distance drive which helps to prevent contact even with the slack above the pulleys. We are acquainted with several cases where centres for unsupported drives are fixed at from 70 to over 100 feet with the slack below the pulleys.

Short Centres.

A swing of the metaphorical pendulum brings one to the opposite extreme, and suggests continuity. The transformation of a spur gear drive to ropes at a Belfast Factory brought the pulleys into such close proximity, that it was deemed necessary to attach a tension pulley and drive on the continuous system. This, and the fact that Manilla ropes were used, proved so troublesome that both tension pulley and ropes were discarded, the latter being replaced with cotton on the individual system, much to the satisfaction of the firm. In this case the pulleys are both 8 feet in diameter, with centres 9 feet apart, allowing a clearance of 12 inches between the rims.

An engine house in Dundee, contains, if it might be so expressed, the concentrated essence of rope transmission. Within the limited space once occupied by a spur gear engine, has been compressed a series of drives, comprehending vertical, horizontal, oblique (both up and down), counter drives, and long and short centres varying from 43 feet to 16 feet, the latter only allowing a clearance of 1 foot 7 inches between the pulley rims, the fly-wheel being 22 feet in diameter.

Another rope drive represented by Fig. 9, also in Dundee, permits a clearance of only 8 inches, and is transmitting 380 H.P. with sixteen cotton ropes 1⅝ of an inch in diameter, from a main pulley 14 feet in diameter making 62 revolutions per minute.

Awkward Conditions.

There is no system of power transmission which lends itself so well to what may be considered awkward conditions as rope driving. It is so flexible that with the aid of guide pulleys, any angle may be negotiated or corner turned. But as it is impossible to cover all the variable conditions which present themselves, a few leading suggestions may show the way towards the solution of other problems of a like nature.

Perhaps there is not a case where the difficulties arising out of awkward conditions have been more successfully tackled than at a large timber work in Dundee, where 225 H.P. is transmitted from an engine above ground through a subterranean tunnel to a distant shaft by means of 8 cotton driving ropes, 1¾ inches in diameter.

The fly-wheel is 13 feet 6 inches in diameter, and makes 83 revolutions per minute, while the jockey pulley, which deflects the ropes into the mouth of the tunnel, is 4 feet 4 inches in diameter. Beyond the jockey pulley, the ropes are sustained with two pairs of pulleys, each 2 feet in diameter, and fixed at unequal distances. The centres from the fly-wheel to the jockey pulley, thence to the first and second guides, and forward to the driven pulley (5 feet 6 inches in diameter), read as follows :—

16 feet, 15 feet 6 inches, 29 feet, and 22 feet respectively.

This unequal distribution of centres along the driving track has the advantage of breaking up the measure and destroying the unison in any oscillations which may be set up in the ropes. Strong wave-like vibrations are sometimes observable between the engine and the jockey pulley when the load is suddenly removed or when starting the engines, which, as they cannot synchronize along the entire length, quickly diminish to mere rippling disturbances.

An interesting combination of rope drives is also to be seen at a bleach work in Ireland, where the power is transmitted from a water turbine to the main shaft over the top of the driving pulley with 4 crossed ropes, and again round guide pulleys to a shaft fixed at right angles, with 2 ropes.

Shafts fixed at right angles may be successfully driven by the aid of guide pulleys, as shown in Fig. 10. It will be seen that the pulling side of the rope is deflected by the guider resting at the necessary angle, while the "idle" side is directed by the pulley having the horizontal axis. The transmitting and receiving pulleys need not necessarily rest upon the same plane, nor at any particular angle; so also may the position of the guiders be altered to suit any set of circumstances, *e g.*, they may be placed either above or below the driving line, see Fig. 11. Another example shows a right-angled drive with the two shafts resting upon the same plane, running one below the other, and the guide pulleys at some distance above them.

Right-angled driving may also be accomplished by the introduction of guide pulleys running freely (in opposite directions, of course) upon a vertical shaft. Deep grooves require to be cut into the guiders, and it is necessary for the ropes to be kept moderately tight. In another drive sustaining pulleys are introduced to prevent the ropes falling away from the guiders.

GUIDE PULLEYS GENERALLY TOO SMALL.

In the majority of cases guide pulleys are made sadly too small, and on this account the ropes are worn out much sooner than they would be if a similar rule to that which governs the relative diameter of ropes and pulleys in ordinary driving were adopted. True, the arc of contact is less, but this is no relief to the bending strain put upon a rope in passing a sharp curve.

When shafts are only slightly out of parallel, ropes will direct themselves without the help of guiders. The limit of deflection at which this may be accomplished, governed as it is by centre distance, cannot be definitely fixed to meet all cases, and it is better to rely upon experiments in each particular drive than upon any data suggested by past experience. For this purpose long key-ways should be cut in both shafts, so that the pulleys may be moved to the best working position in actual practice, giving the lead to the idle side of the rope. Deep, well-polished grooves (which polishing should be extended to the mid-feathers, maintaining the same angle throughout), are undoubtedly the best for this class of driving.

In some cases a tilted groove, after the fashion illustrated in Fig. 12, is brought into requisition, which, it will be seen, gives

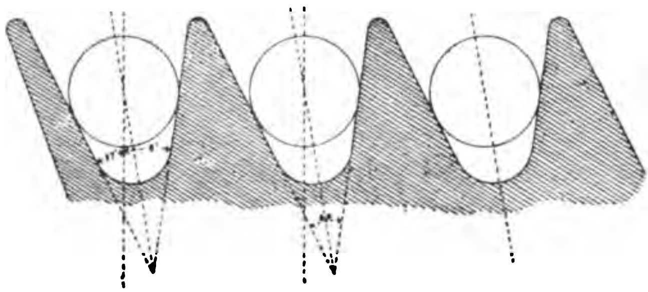

Fig. 12.

more slope to one side than the other, with the intention of allowing the ropes to roll with greater ease into their driving positions. A little contemplation of Fig. 13, which gives a somewhat exaggerated definition, will reveal the fact that immediately the rope attains its proper position in the groove the pressure exerted is at right angles with the face of the pulley, and is therefore equal on both sides, whereas, in the tilted groove the pressure is greater on one side than the other. In a particular case, where

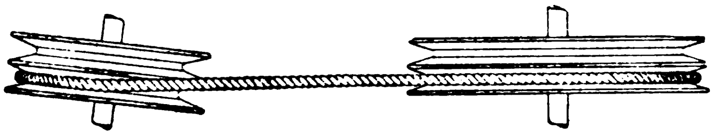

Fig. 13.

the centres were at a considerable distance from each other, and the angle rather wide, the difficulty was successfully overcome by the introduction of two intermediate shafts, and by dividing the angle between them.

The drive represented by Fig. 14 was one in which the driving

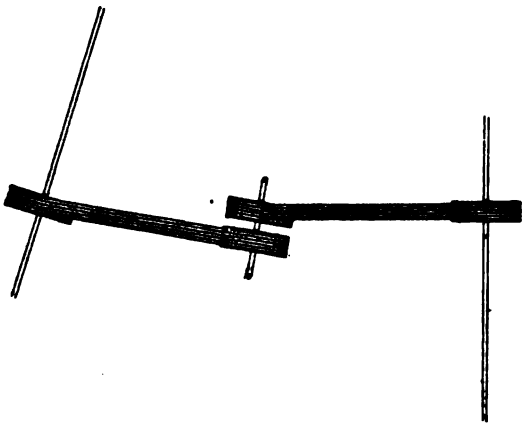

Fig. 14.

and driven shafts were 20 degrees out of parallel. But the power is now successfully transmitted by fixing intermediate driving pulleys in such a position as to equally divide the angle. The grooves for all these pulleys were made to an angle of 50 degrees, and of sufficient depth to completely bury the ropes, which were 6 in number, and 1¼ inches in diameter.

Cross Driving.

Cross driving is most readily effected with ropes, and although there must of necessity be a greater amount of friction upon them than when driving under ordinary conditions, the wear and tear at the crossing point is not as terrific in actual practice as might naturally be expected. Because the strain upon the driving portion permits the slack to pass by without exerting much

Fig. 16.

pressure, and if the crossing is alternated, the tight and slack sides run in couplets, thus further reducing the friction.

Numerous cases could be mentioned of cross driving where considerable powers are transmitted, but as these are mostly boxed off or in cramped up places where the camera may not take in the full view, it is difficult to obtain good working examples, and the one shown in Fig. 15, is of small calibre.

Fig. 16 illustrates the application of ropes to right-angled, or half-crossed drives from vertical shafts. The method is practically the same as that adopted for belt driving, as to the direction of the leading side allowing the driving portion to be pulled away in an angular direction, so that if the rotation were reversed the ropes would roll off the pulleys. The previous remarks *re* long key-ways and well-polished grooves also apply to this style of driving.

Vertical Driving.

Power may be just as successfully transmitted to shafts fixed

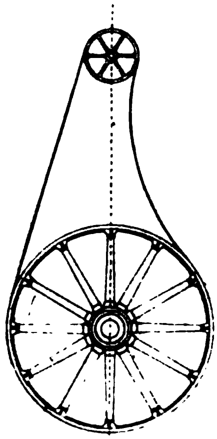

Fig. 17.

upon the same vertical lines as in any other direction. Much experience in this class of driving leads one to the conclusion that, grooves of not more than 30 degrees, a little extra driving force, backed up with the resilience of good cotton ropes, are the best influences to counteract the retarding effect of gravitation. When the drive of which Fig. 17 is an illustration, was first constructed, it was deemed necessary to transmit the power obliquely to and from an intermediate pulley, but gaining nothing beyond extra friction, it was removed and cotton ropes attached direct from driving to driven pulley, with most beneficial results.

A large flax spinning mill had adopted vertical driving, which in the first instance was fitted up on the continuous system with a tension pulley midway, but this proving a constant source of expense and annoyance, was transformed to individual cotton ropes and is now working most satisfactorily with centres at about 42 feet, and pulleys 12 feet and 4 feet in diameter respectively.

Fast and Loose Rope Pulleys.

Previous remarks have dealt with Rope Transmission in its relation to main and counter driving. Advancing a step further, its application to the driving of machinery when the motion is not constant may be demonstrated. By a simple combination of fast and loose sheaves this is most effectively carried into practice at several large cotton mills in the Lancashire district. Fig. 18 shows this system in full operation. The power is carried from line shafts to the numerous ring frames with ropes, in this and other rooms engaged in spinning 90's yarn at a spindles peed of 9,000 revolutions per minute. Fig. 19 presents a nearer view of the same method of driving but at a different mill; and well displays the means adopted for guiding the ropes from the shafting to the fast and loose pulleys within the guard boxes.

To what extent the weight upon the shafting is relieved by the substitution of ropes, will be appreciated when it is stated that $3\frac{1}{2}$-inch belts are usually employed for ring frames which means a pulley surface of about $4\frac{1}{2}$ inches in width; while the ropes are only $\frac{11}{16}$ of an inch in diameter, and the grooves occupy a space of about 1 inch including flanges, *i.e.*, upon the driving shaft. Nor is lightness the only favourable condition. Ropes are declared to be safer and better for the operative. There is no fear of being carried round the shafting by catching upon the clothing. Distressing electrical disturbances due to slip (which often prevent the fibres lying close while spinning), are never present and no time is lost in putting the machinery in motion, a decided advantage where a quick start and knock off are required. On the other hand when a slow start is desirable, the introduction of an intermediate shallow groove renders the action most sensitive and gradual. From the section Fig. 20, it will be seen how this contrivance is fitted up. The fast

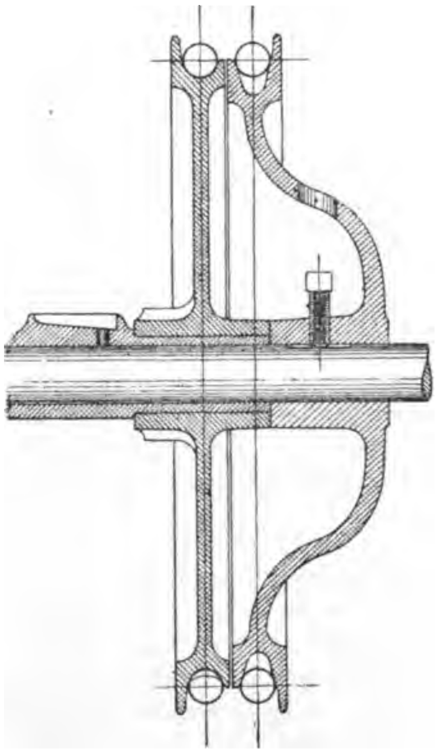

Fig. 20.

pulley is keyed on to the shaft, while a sleeve is fitted for the loose one to run upon. The rim section, Fig. 21, shows the shallow intermediate groove mentioned, and also the clearance allowed between the prongs of the fork which passes the rope in and out of gear with the greatest ease. The fork usually takes the curve of the pulley allowing just sufficient room to clear the rims in passing.

Fast and loose rope pulleys are also attached to the overhead gearing of lathes, to mortar mills, to milling, and to numerous other classes of machinery.

In Fig. 22 a radius fork operates the rope which is worked by a rod running the whole length of the frame. Although the principle

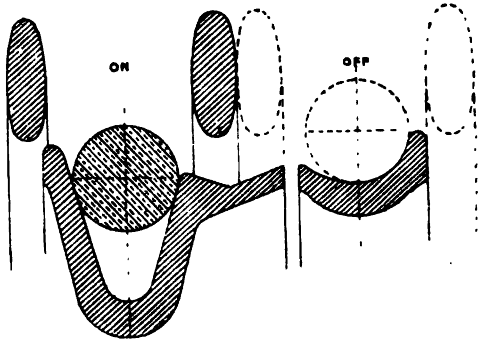

Fig. 21.

is the same, the conditions are so varied that almost every case requires different handling. The ring frames previously shown are worked by small levers attached to the guard boxes.

GROOVES.

One of the most important items in the whole economy of rope transmission, at least so far as mechanical arrangements are concerned, is the construction of the grooves. Many and varied are the shapes and angles which have at different periods been submitted or adopted, as may be inferred from the wonderful exhibition of templets, Fig. 23. The difficulty of selecting a suitable rope is not by any means lessened when the manufacturer is expected to provide one that will work equally in "A" and "B" grooves, which are supposed to represent both driving and driven pulleys. The only course left open in such cases is to ascertain as near as possible the happy mean, and even then the result is anything but creditable

When templets of existing grooves require to be taken the most correct, as well as the easiest method, is to obtain a plaster cast, which, when trimmed off gives an exact impression. Before making the mould it is advisable to grease the grooves.

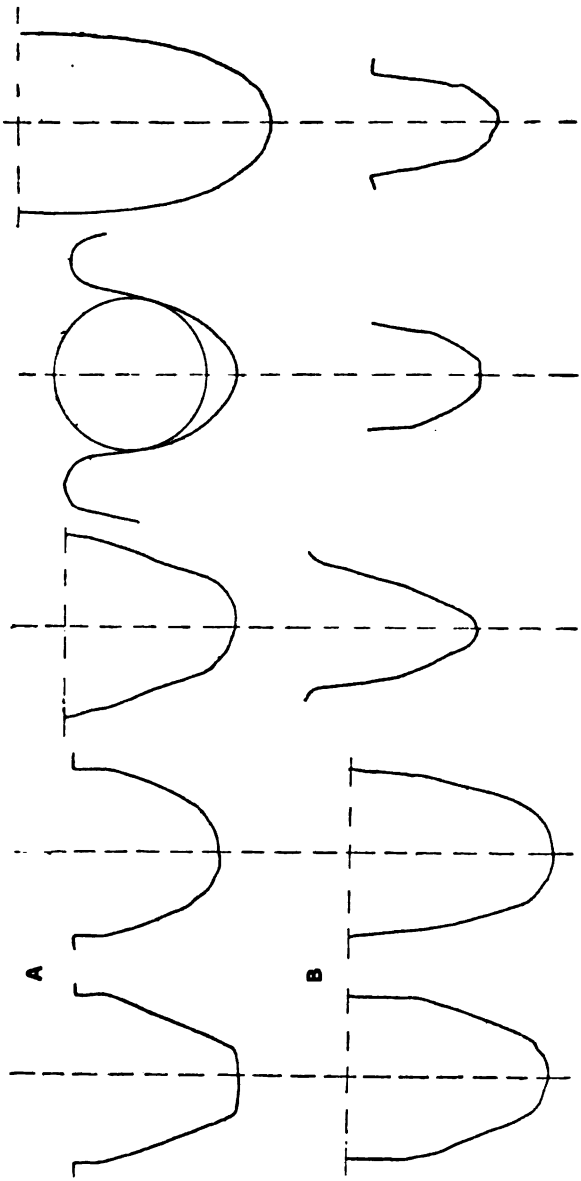

Fig. 23.

At one time it was an accepted theory with many engineers that grooves should bear some resemblance to the rope itself, and therefore curved sides were introduced in the belief that they afforded a necessary easement to the rope when leaving the grooves, Fig. 24. When grooves of this description are employed it is generally found necessary to increase the diameter of the rope to the utmost limit, not only to make up for the loss of power but to prevent as far as possible, the rolling action often induced thereby.

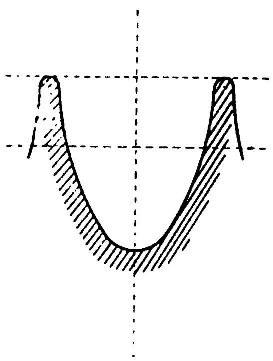

Fig. 24.

ROLLING ACTION.

This action, though suggesting an equal all-round wear from the smoothness of the rope so treated, has a most detrimental effect upon its life, besides encouraging impeditive driving force. Revolving ropes are readily distinguished from the fixed ones by their glossy appearance. The curve disallowed, there can only be one logical corollary to the previous proposition, viz., the angular. groove. This accepted, it is desirable to ascertain which of the many angles used has proved the most beneficial. Before attempting to decide this question it will be just as well to brush away whatever theoretical cobwebs may still linger *anent* the force required to extract a rope from its groove after completing the circuit of the pulley.

The point of centrifugal tension has already been argued, and, if the deductions are sound, then "stiction" must offer an opposing influence thereto, and *vice versa*. Beyond all this there is the resilience of the rope to be accounted for. Time and again an endeavour has been made to so press a cotton rope into an acute groove that it will retain its position during one slow revolution of the pulley, but immediately the ends are released it unbends and falls away.

The angle at which driving grooves are constructed vary as much as from 54 degrees to 15 degrees, the latter being applied to the driving of cotton machinery with small bands, and from the results obtained it would appear that every diameter of rope has its most appropriate angle. While this need not be carried to the extent of providing a range of templets to cover all sizes, some line of demarkation between the acute and obtuse is advisable. One firm of engineers works to four different angles, beginning with 30 degrees for small ropes from $\frac{5}{8}$ of an inch to $\frac{7}{8}$ of an inch in diameter, 36 degrees from 1 inch to $1\frac{1}{4}$ inch, 40 degrees from $1\frac{3}{8}$ inch to $1\frac{5}{8}$ inch, and 45 degrees from $1\frac{3}{4}$ inch to 2 inches What I would advocate is 30 degrees for all driving ropes under 1 inch in diameter, and 40 degrees for all above that size, including the 2-inch diameter. Indeed, from what I know of the working of $1\frac{1}{2}$-inch ropes in angles of 29 degrees, I have no hesitation in declaring my belief in the keener angle for all diameters, excepting the small machine bands. Acute grooves afford a check against revolving action. In setting out a groove it should always be borne in mind that a rope is at its best when it assumes the cuneiform, something like the old sample and section here submitted, which well exhibits the effect of compression.

Method of Setting Out Grooves.

Therefore, instead of commencing with a circle to which the groove sides are merely tangent, it is always as well to presuppose the wedge shape, and build up the grooves with a view to preventing the rope reaching the bottom, or any part of the curve with which it terminates. Credit is due to Mr William Kenyon for discovering a method of setting out a groove, which is simplicity itself, and withall possesses the virtue of complete accuracy.

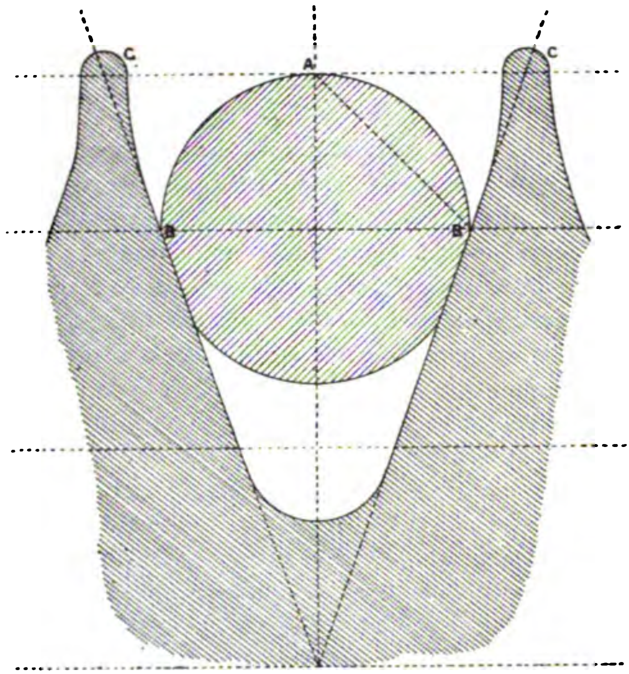

Fig. 25.

Referring to Fig. 25, it will be seen for a 40-degree groove that, the first process is to draw a circle representing the diameter of the rope through which the vertical and horizontal centre lines are projected. Afterwards the chord of the arc " A B " is marked off. This becomes the standard of future measurement, and points the centre of the curve terminating the groove from the centre of the circle, and, when repeated downwards, fixes the apex of the angle, which always comes out just under 40 degrees whatever the size of the rope may be. Extend the lines of the angle through the point "B B," cutting off segments of the circle on the way, until they intersect the upper horizontal line at "C C," which points fix the radius of the flanges from "B," and also ascertain the thickness of the metal. If the angles were carried out to the full extent, and the terminals simply rounded off, the power could be nearly doubled if required by the introduction of thicker ropes. The flanges (which are merely introduced to save pulley space), however, block the way to such extension, and are entirely discarded by some engineers.

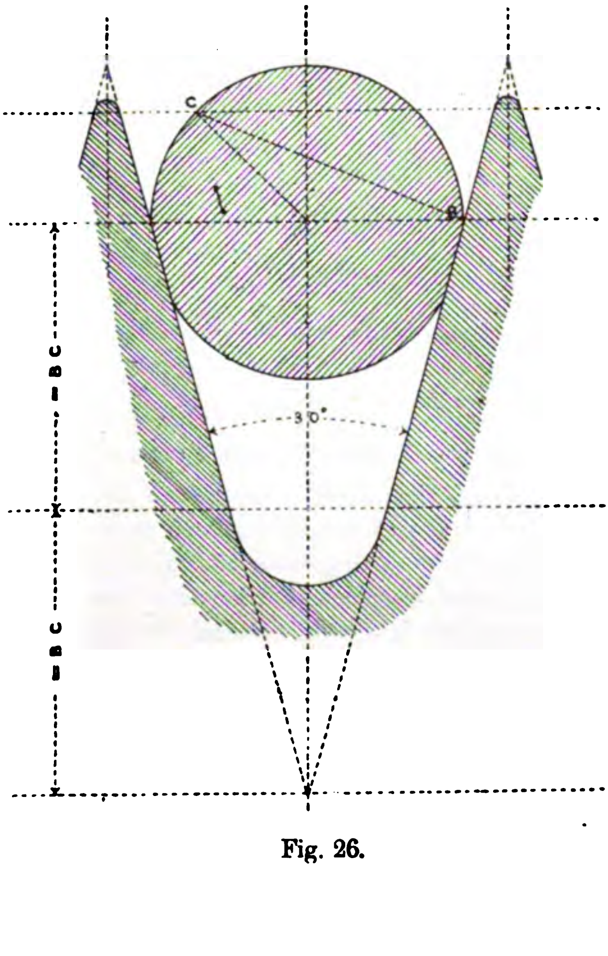

Fig. 26.

The same formula may also be applied in the construction of a 30-degree groove down to the formation of the bottom curve, Fig. 26. But for the more acute angle a longer measuring staff is required, and this is indicated by a 45-degree set square, making the chord of the arc "B C," doubling which fixes the apex of the angle.

Grooves having no power to transmit, but which are simply used as carriers, should be so arranged that the rope will fall well into the bottom; a little more easement should, however, be allowed than is shown in Fig. 27. The pitch of carrier grooves

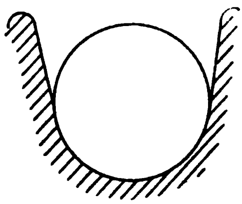

Fig. 27.

should also correspond with that of the grooves to which they are tributary. Grooves for cross-driven ropes should be either spaced or (which is to be preferred) used alternately.

Patent Expanding Rope Pulleys.

Messrs Bertrams, Ltd., of Edinburgh, have favoured me with a photograph of a "Patent Expanding Rope Pulley," which well deserves attention before the question of grooves and their construction is dismissed, inasmuch as it provides a means of dealing with small alterations in speeds, such as are required for paper making and other machines, Fig. 28. Without elaborating upon the specification, the chief advantages of this unique contrivance may thus be briefly summarised :—By separating or closing up the two halves of the pulleys, the diameter may be altered to a fraction, giving an ample range for the purpose of 3 inches, with a rope 1½ inch in diameter. Alterations may be effected while the machinery is in motion by means of a brake wheel and brake strap operated by a foot-lever. One half of the pulley is keyed to the shaft, and is made with a boss, over which the boss of the other half slides, a feather being fitted to ensure united rotation.

Eleven of these pulleys, which required to work in perfect unison with each other, are applied with great success to large paper making machines. For this purpose a continuous rope, 1,100 feet long, is employed, the slack being regulated by a weighted tension pulley, thus dispensing with the belts, cones, and belt shifters hitherto employed in this class of driving. The utmost variation attainable depends upon the diameter of both pulleys and ropes, the dimensions of which may be altered to suit conditions, and also by the angle of the groove, which in this instance is 40 degrees.

Driving Ropes.

Beyond an occasional acknowledgement of its existence, we have scarcely referred to the transmitting medium, having decided to relegate a brief study of the material and workmanship employed in the making of driving ropes to this stage of the paper, not because the rope is deemed subservient in importance to the purely mechanical side of the question, but more, it must be confessed, from a desire to emphasise final impressions. Few, indeed, are the fibres capable of manipulation which have not been pressed into the service of the ropemaker. First, there is the coarse-grained Manilla; second, a fine-dressed quality of hemp; third, Ramie fibre; and last, cotton spun into suitable yarns. The firm with which I am connected once made up a rope from silk waste, which, however, proved anything but durable, and also experimented upon ropes made from paper strips rolled up in the form of threads, but these were run to death in a few hours.

Taken merely upon the basis of resistance to tensile strains, Manilla undoubtedly holds the field against all comers, but the fibres are of so harsh and wiry a nature that they do not take kindly to the successive twisting operations to which a rope is subjected, nor do they cling to the pulleys with the tenacity of softer materials. Having no resilience, the strands scrub one upon the other, setting up internal abrasion, which not only proves an inconsistent quantity, but invariably leads to undue stretch and repeated tightening.

Cotton v. Manilla.

The fact of rope driving having first been introduced to any great extent in what may be designated the home of the Manilla trade, this material quite naturally claimed the earliest attention and for a time gained precedence over all others, until the system was taken up by the cotton manufacturers of the Lancashire district, who argued, and not without reason, that as nothing in the nature of hemp would successfully transmit power to the various motions of a spinning mule, the peculiar ramifications of which demanded a material possessing the greatest resilience coupled with wearing capabilities of the highest order, it was merely a matter of applying cotton to larger powers. Evidences of the progress of cotton in the manufacture of driving ropes are so far reaching that, its superiority may be considered as much an accepted principle in rope transmission, as the law of gravitation is in science.

The great stumbling block to its acceptance in some quarters is the price, and truly the divergence is wide enough when that fickle institution known as the cotton market declares for the high points, but for all that its enhanced power transmitting value, its immunity from frequent attention in the matter of tightening, its safety and comparative longevity, more than out-balance first cost considerations. The higher capabilities of cotton over Manilla were most strikingly exemplified a short time ago in the case of a large linen mill where, owing to some miscalculations, Manilla ropes proved totally inadequate to drive the power and were almost constantly slipping. These were replaced with the same number of cotton ropes, which are now comfortably driving the added load of a dynamo for electric lighting.

At another flax mill in the same district, Manilla ropes were employed to drive what is known as a 108-inch mangle. These could never be relied upon, and proving a constant source of annoyance from slipping, were replaced with the same number and diameter of cotton ropes, which appear to be capable of transmitting a much greater power. Still another example which gives a more definite comparison. In this case eight Manilla ropes 2 inches in diameter, upon one drive, and ten ropes 1¼ inch in diameter upon another, have been replaced with six and eight cotton ropes respectively, and the driving is declared to be more satisfactory in every respect. The modulous of elasticity in a well made cotton rope is such that the "permanent set," may not be reached until it falls to pieces from absolute wear after years of successful running.

As to the longevity of cotton ropes, the illustration shown upon the screen is a reproduction of an engine from which 24 cotton ropes 1¾ inch in diameter are transmitting 820 H.P. at a peripheral speed of 4,396 feet per minute, from a driving pulley 28 feet in diameter. All the card room ropes in this drive have been running since 1878, a period of 26 years, without any attention whatever. The conditions are certainly all that could be desired.

The lives of numerous other cotton ropes similarly circumstanced have extended over periods little short of this, while others fixed from 10 to 15 years ago are still working almost night and day. Take for instance the case of the Clyde Paper Co., at Rutherglen, within whose works cotton ropes have been running almost night and day for 14 years without attention. It would appear therefore that fatigue of material due to constant activity, does not manifest itself in ropes of this description.

Having fixed upon cotton as yielding the best results, the question of selection still remains, that is to decide between two leading classes known as Egyptian and American. Theoretically, Egyptian with its tough silky staple appeals more forcefully to the manufacturer than its coarser American rival, and if judged by the standard of market values only, would certainly hold the premier position, seeing that under normal conditions the purchasing price of Egyptian is from 25 to 30 per cent above American, if reckoned on the basis of best qualities. This argument does not apply to those minor productions which are little better than waste spinnings passed off as good Egyptian, at a price which should servé no other purpose than that of exciting suspicion in the mind of the intending purchaser.

A Practical Experiment.

Such inferences however, without an appeal to actual practice, too often prove futile methods of reasoning. The main difficulty in dealing with questions of durability is the time exhausted in conducting reliable experiments, which according to previous shewing, under good conditions, would extend over a considerable period of years. For this purpose two ropes running side by side at a terrific velocity, on one drive, were tested. One rope was made from ordinary American yarn, while the other was of a superior quality of Egytian cotton, spun down to the same counts from a higher mixing. Both ropes were accordingly made to the same specification, fixed upon the pulleys at the same time and allowed to run for a period of three years, when they were removed and carefully dissected, with the result that the American proved to be in at least 10 per cent better condition than the Egyptian.

Construction of Ropes.

The mere selection of material would prove of little value were the construction of the rope itself omitted. Although familiarity with this article may go to the extent of reaching the borderland of contempt, there is more connected with the manufacture of a rope than meets the eye of the casual observer. It will be noted, however, that a rope generally consists of strands, few or many, and that these are held together by a succession of twisting operations, from the fibres to the yarns and from these to the strands which in turn are locked together by the same agency. The sections illustrated by Figs. 29 to 32, show a few varieties of ropes which to a greater or less degree are employed in the transmission of power. There are the three-strand, the four-strand (with the centre core), the seven-strand, (or six-strand and core), and the "lapped" rope, which it will be seen consists of three strands with the interstices filled up with cords, while a thicker cord so envelops the rope that the strands disappear altogether. There is also a plaited rope bearing some resemblance to the old fashioned gaskin formerly used as engine packing, which is used mostly in Germany.

Three- and Four-Strand Ropes.

Compared with the contest between three- and four-strand ropes, the other sections have scarcely had a look in. It may therefore, be appropriate to devote a few words to determining if possible which of these possesses the highest capabilities. The strands of a rope may be regarded as elastic cylinders until they are compressed by the final twisting into as many wedge shape spirals. Therefore if circles be substituted for strand sections the necessity for a core in a four-strand rope will be readily perceived, because the parallelogram of forces prevent the building up of an even contour without such support.

In a four-strand rope from which two of the strands have been extracted in order the more readily to exhibit this inner core, it will be seen that as the driving strain is exerted in a longitudinal direction the core is most affected thereby, and being only about one-fortieth part of the whole bulk, it must ultimately yield to the superior extending force of the main body, Fig. 33. And this is what actually takes place. When occasion arises to examine or tighten four-strand ropes, the core is generally found so broken up that the strands, having lost their internal support and in their struggle to fill up the vacancy, override each other and produce distortions.

It may also be stated that any increase in the number of strands retards the bending faculty and also militates against driving force. To such an extent was this manifested in one case that replacement became absolutely necessary after not more than tw years running. It was found undesirable to impose a load greater than 110 H.P. with four-strand ropes; whereas, now 170 H.P. can be used under precisely the same conditions, and with the same number and diameter of three-strand ropes. In another case of replacement, four three-strand ropes were discovered to be equal in power to six of four-strand running on small pulleys with short centres.

A three-strand rope furnishes one of the best examples of what is known as the triangulation of strains which enter so largely into the study of applied mechanics, whether our object be the building of a girder bridge or the construction of a bicycle. The diagram, Fig. 34, formed of a rope section, three pins, and a piece of black cotton, demonstrates far better than any amount of verbal description, the origin of that trinity of equal forces which compels so complete a union. So also may the removal of a strand prove the best explanation for superior resilience, as showing the undisturbed spiral deflections of the entire rope. Fig. 35 illustrates a three-strand cotton rope, which has had an average running of 20 hours per day for a period of 15 years. Though presenting such a ragged appearance, it is anything but done, and is now wearing out its life on a shorter drive, having been removed from its original position on account of structural alterations. This exterior abrasion which so alarms some users is no indication of immediate collapse, but is simply the ruffling up of the outer fibres which fill the interstices of the strands, and act like a cushion against the side of the grooves.

Allowing the claims put forward in favour of a three-strand driving rope, without further advocacy of the principle involved, it may be contended that if such a rope possesses a constant equality throughout, if the yarns are equal in counts, number, strength, and tension, each from the centre to the circumference following its appointed track without deviation, and if all are of the best quality attainable, then has been a point arrived at bordering upon perfection in the making of driving ropes.

Table of Powers.

Having surveyed the general conditions governing efficiency in rope driving, it may be advisable now to submit a reliable table of powers which good three-strand cotton ropes may be expected to transmit at 1000 feet per minute, when running over pulleys not less than 30 times the diameter of the rope employed, and in angular grooves not exceeding 45 degrees :—

1″	diameter rope	will transmit	3	H.P.
1⅛″	,,	,,	4	,,
1¼″	,,	,,	5	,,
1⅜″	,,	,,	6	,,
1½″	,,	,,	7·3	,,
1⅝″	,,	,,	8·6	,,
1¾″	,,	,,	10	,,
1⅞″	,,	,,	11·5	,,
2″	,,	,,	13	,,

These figures ignore any supposed detriment from centrifugal tension. They are based upon the many times proved hypothesis that a rope 1¾ inch in diameter will transmit 10 H.P. per 1,000 feet of speed, and that this power is a constantly increasing quantity in the ratio of speed. This at once launches us into the metric system so far as velocity is concerned (would that this system prevailed throughout, and that British prejudice did not compel circumlocutory calculation, the sole object of which appears to be that of complication). Thus, by lopping off these wonderful terminal cyphers, speed is at once reduced to power—1,000 feet 10 H.P., 1100 feet 11 H.P., and so on to the limit of mechanical capacity. The powers of the remaining sizes are calculated upon the relative sectional areas, the 1¼-inch diameter being fixed at over half that of the 1¾ inch. This gives a little benefit in driving force to the smaller rope.

The publication of tables purporting to make allowances for the detrimental effects of centrifugal tension has already been mentioned. One table begins with a speed of 2,000 feet per minute at which it declares a rope 1¾ inch in diameter to be capable of transmitting 28 H.P. (8 H.P. more than I should care to advise without encroaching upon the margin of safety), and this is a steadily increasing quantity until it attains 4,800 feet, when the power gradually declines to 29·5 H.P. for 7,000 feet, or a gain of merely 1½ H.P., instead of 50 in 5,000 feet! Fortunately for this argument, one of the finest examples of high-speed rope driving in the country might be cited, possibly the only case where a rope velocity of 7,040 feet per minute is attained direct from a fly-wheel 28 feet in diameter. Fig. 36. The power is taken direct from the fly-wheel to the shafts driving the machinery of the five spinning rooms each with two ropes 1¾ inch in diameter, which are transmitting no less than 93 H.P. per rope (or 186 H.P. per pair).

The fact before mentioned, that ropes 1¾ inch in diameter, running at a speed of 4,396 feet per minute, have lasted 26 years, also appears to contradict the supposition that high speeds interfere with the longevity of ropes.

PATENT INTER-STRANDED COTTON DRIVING ROPES.

What is now most favourably known as the Patent Inter-stranded Cotton Driving Rope, answers the foregoing requirements to the letter, and is certainly a unique production which has never yet been successfully imitated. Each of the three strands is made up of a succession of sheaths, or layers of yarns, which may be peeled off until the last thread is reached. The constantly increasing bulk due to these concentric rings, has the natural effect of lengthening the yarns in corresponding gradations.

The superlative advantages of this inter-stranding process demands but little explanation if the even lay so faithfully depicted in Fig. 37, is compared with the crinkled effect shown on Fig. 38, to be found more or less in all ropes made upon the ordinary method—which is roughly that of taking bundles of yarn about equal in length and twisting them together in a haphazard manner, so that the inner yarns must of necessity crumple up to accommodate themselves to the undue strain upon the outer ones, which in time give way to the encouragement of repeated tightening operations and premature collapse.

How little an inter-stranded rope is affected by external abrasion, is manifested to a remarkable degree, in the unrolling of the strand, as shown in Fig. 39, which it will be acknowledged, presents a completely worn out appearance. The first layer of yarns is scarcely penetrated, while the second remains altogether untouched. For purposes other than rope driving, such as haulage, where safety is one of the first considerations, inter-stranded ropes are invaluable, as any damage, which always takes place on the surface, may be readily assessed and the rope worked upon that assessment.

There is practically no limit to the length of a Patent Inter-stranded Driving Rope. Every piece made is one continuous length of the particular size upon which the machine may be engaged.

Two ropes 1¾ inch in diameter, and in continuous lengths of 8,115 and 8,208 feet respectively, without splicing or any other attachment, were recently consigned to India through a firm of shippers in this city.

Splicing of Driving Ropes.

The importance of good splicing in relation to rope driving can scarcely be overestimated, and although the initial bill may suffer somewhat from the engagement of a thoroughly competent man, the true economy of such a proceeding is thoroughly realised later on. For if the ropes are properly fixed at the outset, it is rarely that they require attention afterwards. So much is this understood in large undertakings that, men from Dukinfield are almost constantly engaged in different parts of the Continent, and they have been sent eastward as far as Russia, and westward as far as Brazil.

Short of ocular demonstration it is most difficult to explain or even illustrate the process of splicing a driving rope. The following illustration, Fig. 40, may, however, give some idea of the splicer's work:—

No. 1 shows the ends whipped together to the required length, and it will be seen that a strand from each side has been cut away.

No. 2 shows how to untwist the strand from one side and reinsert

it from the other. It will be seen that two strands are still held together in order to preserve the spiral form.

In No. 3 the strands are thinned down by stripping the outer thread ready for working in with the marline spike.

No. 4 requires the projecting ends to be cut off to complete the splice, as shown in No. 5.

The length allowed for a driving rope splicing should not be less than, say 80 times the diameter of the rope.

METAL FASTENINGS.

Much time and money has been expended in endeavouring to do away with splicing altogether by the introduction of metal couplings, but without adequate results. The hook and eye coupling, Fig. 41, is doubtless the best of this order. The method of attachment is to twist the ends of the rope into screws made in the couplings, and then drive a pin right through. Should the rope slacken down, it is unhooked, twisted up to the right tension, and rehooked. The main difficulty in such couplings is that they cannot possibly take the same position as the rope in the groove, and that the metal strikes against metal in passing over the pulleys.

BLOCKING ROPES.

Difficulties are sometimes experienced in the shape of heated journals, when ropes have been fixed for a little time before the engine is put in constant work, through the shrinkage against the pulleys. In such cases it is always advisable to insert a block of wood (or several blocks according to the size of the pulley) between the ropes and pulley, as shown in Fig. 42, against which they tighten. When it is removed the tension is, of course, somewhat relieved.

It might be advisable to point out that painted grooves drag at the fibres of the rope, and therefore it is always advisable to have them well greased for a start, which also applies to the side of the rim to prevent chafing as the rope is being passed into its place.

Discussion.

Mr A. S. Biggart (Member) said his experience in connection with rope driving had extended over twenty-five years, and when reading Mr Kenyon's paper it gave him pleasure to see that in many of the statements made he was at one with the writer. One thing he had specially noticed, and that was the class of rope that Mr Kenyon had found best to adopt in connection with this system of driving. After trying many of the various classes of rope, in connection with the driving of drilling machines particularly, and for other power drives in the workshops at the Forth Bridge, it was found that the best was that which Mr Kenyon had found to be the best, namely, the cotton rope. Further, it had been found that there was one particular class of cotton better and more suitable than any other. Mr Kenyon had stated that he had found a water twist cotton to be the best, and in this he entirely concurred. Some of their ropes were passed round the fly-wheel and then over a series of pulleys. Particularly was this the case in connection with the drilling of the great tubes of the Forth Bridge The pulleys had to be smaller than desirable, and trouble lay in finding a rope that was suitable for this severe driving. If large enough pulleys were used, almost any kind of rope would do fairly well. If comparatively small pulleys were used, only a very high-class quality of rope would stand. He remembered trying a raw hide rope. Great things were expected of it, but in a few days it was done. The paper, of course, required to be limited to some extent, but he felt a little disappointed when he found that no reference had been made to driving with wire ropes for power purposes, such, for instance, as could be seen on the Glasgow Subway, the Edinburgh Cable Tramways, and in many places, especially on the Continent, where water power was used. Twenty years ago, when the introduction of wire ropes for lifting and other purposes was in its infancy, they were largely used at the Forth and Tay Bridges. At that time he instituted a series of experiments, the results of which, by the way, could be found in a paper in the Minutes of the Institution of Civil

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Mr A. S. Biggart.

Engineers. Some of the results were remarkable. The gist of the whole thing came to this, that provided one used a pulley large enough, and that that pulley was of the proper form, it was difficult to put a limit to the life of a wire rope for lifting or driving purposes. It was exceedingly interesting to read what was said regarding the length of life of cotton ropes, and many Members would no doubt be surprised at the number of years that these would run without giving the slightest trouble. He was sure that in many cases there were to be found great advantages in the use of ropes, even in competition with the modern electric drives of to-day.

Mr Sinclair Couper (Member) said that Mr Kenyon was a recognised authority in rope driving, and the Institution was indebted to him for bringing before it this subject; especially at a time when attention was being given to electrical driving, and when older methods, some of which were fairly economical, were apt to be lost sight of. He would just like to say a word or two about ropes made of another material than that which Mr Kenyon recommended. He had had experience of rope driving extending over many years, and he had used many Manilla ropes and had found them in some cases to have a longer life than cotton ropes. In the West of Scotland and in the North of Ireland, Manilla or hemp ropes were very easily procured, and they were generally adopted for the driving of cranes, and the driving of parallel lines of shafting. He had used Manilla ropes, generally 3½ inches in circumference, for these purposes and they had given entire satisfaction. He had also found that the point in rope driving was to give attention to the pulleys, both driving and guiding pulleys. In the driving pulleys the chief feature was to have the proper form of groove in which the rope lay, and in the guiding pulleys as well as the driving pulleys, the diameter had to be carefully considered. It would be seen, if a rope were frequently bent many times in a minute over a small arc of a circle, that its fibres broke up, and he had found in ropes running over pulleys of too small a diameter that the fibres were ground to small dust in the centre of the rope, and when the strands were unwound, the heart of the rope would be in a condition like flour. The pressure exerted on the fibres of the rope by the tension and the acute bending combined, had broken and ground the particles down till the heart of the rope was destroyed and its strength very much reduced. He found that the best diameter for pulleys was from 35 to 36 times the diameter of the rope; that was to say that a rope one-inch in diameter should run over pulleys from 35 to 36 inches in diameter. These figures might seem large, but it paid in the long run to have large pulleys, and although with ordinary crane driving the same length of life in hemp ropes was not to be had as with cotton ropes running over large driving fly-wheels and on large pulleys, still the life which did obtain was fairly satisfactory. He thought, as Mr Biggart had remarked in his criticism of the paper, that in many cases it was quite certain that considerable economy was to be had from rope driving, and that there were many situations where it could still be used successfully as a means of transmitting power.

Mr L. Broekman (Member) remarked that in the preface to his paper Mr Kenyon alluded to the wonderful progress which had been made in the construction of the modern steam engine, and went on to point out that notwithstanding the very high efficiencies already obtained in the production and transmission of power, engineers were more intent now than ever to prevent any semblance of waste throughout the entire system. Proceeding, he gave priority to electrical transmission, of which he had evidently a good opinion, qualified in some respects, it was true, and although he absolutely traversed Mr Kenyon's statement as to the alleged extravagant first cost and upkeep of electrical apparatus, a debate on that point would be outside the scope of the present paper, and would carry him beyond the point to which he wished to confine himself. By Mr Kenyon's own showing, on page 102, mechanical transmission was at a serious disadvantage, in cases where an erratic delivery of power was required, such as for the driving of iron rolling mills, the vibrations from shocks and stresses causing the ropes to display "every

Mr L. Broekman.

irregularity by a serious of wave-like oscillations, and should these by any chance synchronise with the length of tension on the ropes, they may be induced to travel across the grooves or swing entirely off," giving rise to a general breakdown. He accepted it on Mr Kenyon's authority that ropes acted more effectively than belts for such a purpose, that they lent themselves far better to awkward conditions, and that by unequal distribution of centres along the driving track these oscillations were neutralised to a very large extent. Still, after all, by doctoring a drive in that way ingenuity was applied to the surface only, to the mere manifestations of the stresses and strains going on inside the machinery, by reason of the sudden and severe fluctuations, which were responsible for loss of power and for excessive wear and tear. Surely, therefore, it would be sounder engineering and better business to go to the root of the trouble, and to equalise the evil effects of the fluctuations on the machinery, enabling boilers and engines to work constantly at their most efficient output, no matter how erratic the working load might be. In mechanical transmission there was no elastic medium, cushion, or buffer capable of absorbing the excess of power produced during periods of light loads, and retaining the same so as to assist or supplement the boilers and engines when sudden heavy demands exceeded their over-load capacity. Consequently, the engines would be pulled up, and tend to race alternately in quick succession, and even with sensitive governing the speed would vary within wide limits. If, to prevent this, sufficient boilers and engines were always operated to meet the maximum demand, it followed clearly that, for the greater part of time, these would be worked under a miserable load factor—hence uneconomically. By adopting electrical transmission in conjunction with an automatic power-reserve, under these conditions generating plant need be operated equal only to the mean power demand, the automatic reserve taking care of the fluctuations, so that stresses and strains were equalised, and space could be economised safely by direct coupling prime movers to dynamos. The advantages and saving in running the smallest number of units at the same high load factor were obvious, and, moreover, the uniformity of pressure guaranteed would ensure the maximum output and best quality of work from the machines and tools driven, even if the load fluctuated from almost zero momentarily to two or three times the value of the mean load the next instant. Constant pressure was a very important point in connection with textile manufacture. The conditions of the drive approached the ideal under this system, which had been in use for years in connection with electrical tramways and railways and power work of different descriptions on a large scale, and was applicable both to the operation with continuous and alternating currents. There were numerous other benefits relating to overtime work and week-end repairs without running any generating plant at all, and its action as an unfailing standby in case of temporary interruptions. Apart from the smooth drive and consequent lower depreciation rate of the plant, an automatic power reserve plant joined to any direct operated electrical installation would effect a saving of from one-fifth to one-third in the coal bill alone, according to the magnitude of the fluctuations; the wider their range, the greater the saving, and it could generally be relied upon to redeem its cost entirely in less than five years, so that this solution of the problem would compare favourably with any other means which might be adopted to overcome the difficulty in question.

Mr R. T. Napier (Member) remarked that he had to do with the fitting up of rope gearing about 25 years ago. All the information then available was hunted up and acted upon, and he was pleased to see that later experience had confirmed the practice of that date. The angle of pulley grooves was then about 40°, and 36-inch pulleys were used for ropes of 4 inches in circumference, being practically the 30-inch diameter rule now enforced. "Fast and loose" rope pulleys were enquired about, but pronounced impossible then. He was very pleased to know that they had been made a success. Anyone thinking of adopting rope gearing had to bear in mind that while only intelligent mechanics could learn to lace a leather

Mr R. T. Napier.
belt, the making of a proper "long splice" on a rope required a special training, and few, save riggers to trade, could be trusted with the job. Without proper splicing, ropes gave small satisfaction. In using steel wire rope there must be a limit, and that was soon reached, in the matter of size of rope. The ropes on the Glasgow Subway were popularly supposed to last a little over twelve months, while those on the Cowlairs incline, which worked intermittently, lasted a little over two years.

Mr J. Millen Adam (Member) said that he had read the paper on rope driving with great interest, but he could not agree with every proposition therein stated. Referring to an observation that the author made with regard to the manufacture of ropes, he was glad to know that cotton ropes were now being made on an intelligent plan. The astonishing thing was that rope makers ever departed from the old method of making hempen ropes and tried to make cotton ropes by taking a warp of thread—in the weaver's sense—a quantity of thread in a bunch and twisting it together as described at the foot of page 126, where the author said "The superlative advantages of this inter-stranding process demands but little explanation if the even lay so faithfully depicted in Fig. 37, is compared with the crinkled effect shown on Fig. 38, to be found more or less in all ropes made upon the ordinary method—which is roughly that of taking bundles of yarn about equal in length and twisting them together in a haphazard manner, so that the inner yarns must of necessity crumple up to accommodate themselves to the undue strain upon the outer ones." That of course was done only in cotton ropes, because he supposed rope makers got very easily bundles of yarn in that form, and it showed their ignorance of the first principles of the art. The old method of buying Manilla and other hemp ropes was very different, each thread was drawn separately through a perforated plate and let into the strand with about equal strain upon it. That just gave practically the same distribution of the fibre as was illustrated in Fig. 39. In the paragraph headed "Construction of Ropes"—page 122, the author showed due appreciation of his subject: a three-strand rope was really one of the most remarkable of structures, because it was spiral throughout. Microscopically the fibre itself was frequently of a spiral form; the thread took another spiral and again a spiral was formed in the strand; and fourthly by the strand in the rope itself; so that the dominating features of a rope were its pliability and its elasticity. In view of that it was rather astonishing to find that on page 95 the author said that, "the motion conveyed by ropes might be regarded as positive as that of spur gearing, unless they were overburdened, or reached the bottom of the grooves." If by being overburdened meant that the rope took any stretch at all, that might be true, not otherwise, because the moment it began to stretch there was of necessity a creep over the drum. He had tried about a year ago at a meeting of the Institution, and perhaps unsuccessfully, to enunciate the same principle with reference to the *necessary* slip in a marine propeller measured by the angle of incidence. These things which seemed so very unlike had this in common, that they both were characterised by an apparent loss which was alike necessary and incidental to the transmission of power through an elastic medium, and which was very different from slip in the sense of leakage or a refusal to do the work. The other was incidental to the doing. To return to practical matters, he had been present officially a year or two ago at a starting trial of a very large engine. He thought there were about 30 ropes on the main drum, each of about two inches in diameter, and some time before the start the painters had been at work whitewashing the walls with a lime squirt, so that where the drive came through a brick arch a very clearly defined white bar was left on the belt of ropes, if the expression might be used. The engine was started, and before it had made half-a-dozen revolutions it was apparent that the bar of white had got into a reedy formation and presently the whitewash was distributed in about equal streaks over the whole drive. It was very apparent that there was an irregular creep going on over the whole drum. He believed, however, in rope driving, and he thought it had a muc bigger future before it than possibly was imagined, due perhaps to the

Mr J. Millen Adam.

fact that cotton ropes had been so badly made that they had not up till now had the vogue which they might have had. He thought with Mr Sinclair Couper that the Manilla rope had been unduly condemned. He had a recollection, a very long time ago, of a Manilla drive which seemed to go on, until the outer skin was worn into a brush which filled up the interstices, with the whole fibres shining like silver spirals between. Those were the days, however, when Manilla was Manilla, not Sisal or Aloe or New Zealand fibre; the Americans now take care of the real article. With regard to the form of the groove he supposed he would be going against all orthodoxy in the matter in saying that he did not agree with the V-groove at all. He thought it had been adopted to suit the very hard Manilla rope, and it would be very much better done away with in the cotton rope. In the manufacture of the Manilla rope, also as still obtained in the preparation of jute, it was almost saturated with oil in the dressing, and it was in order to meet the tendency of the rope to slip under these conditions that the V-groove was originally adopted. It would be very much better to coil the rope one-and-a-half times round a smooth drum. Once bent round the first quadrant there would be no further stress to the rope; it would indeed be a momentary rest. Moreover, when it had to pass over guide pulleys that tended to give it a different sectional shape than on the V-groove, the wear on a rope was much increased. As to the size of the pulleys he did not know that his experience was very great, but about 18 months ago he had had occasion to send away a number of exhaust fans that were to be driven by ropes $\frac{3}{4}$ of an inch in diameter —about 18 of them altogether,—and it was impossible to get more than a 10-inch pulley. All the fans were driven by 30-inch pulleys from a motor having 550 revolutions, on to a 10-inch pulley which of course had to run to 1650 revolutions, and in view of the fact that each of these fans absorbed about five horse power, he adopted double grooves meaning to drive them with two ropes. Recently on making inquiry of the engineers who had erected the plant, they informed him that these fans were running with only one rope—a cotton rope—so that it was doing remarkably well under conditions much more severe than the author of the paper allowed.

Mr E. HALL-BROWN (Vice-President) said electrical driving in various forms and electrical transmission would seem, in some cases, to be considered a cure for all the ills that any industrial establishment was ever afflicted with—so much so that he had seen in an engineering works not very far from where he stood, an engine coupled direct to a dynamo and that dynamo transmitting current to a motor within 10 feet of itself, the motor in turn transmitting power by means of a belt to an overhead shaft not 20 feet away—an engine, a dynamo, a motor, and a belt for one line of shafting which could easily have been driven by means of a belt direct from the engine. He hoped that within a very few years such would be seen nowhere else, it was the acme of delusion with regard to electrical driving. It was worth considering what the loss must have been between the engine and the shaft overhead as compared with any other drive—let it be a belt or a rope drive—in addition to the first cost of the dynamo and motor. He did not wish to disparage electrical driving. There were large fields where it was the most economical method of transmitting power from one place to another, but he was afraid that a great many people had considered that electrical driving was a source of additional power or that in some way there was a gain between the dynamo and the motor. That, of course, was utterly absurd, but nevertheless it would be found that that fallacy lay at the bottom of a great many ideas. In designing any system of power transmission the utmost that could be attained was the adoption of the system which would transmit the power with the minimum loss; and it would be well to remember that, as the writer of the paper had shown, the loss with a well-designed rope drive seemed to be a very small one. Almost the only point in which he differed from Mr Kenyon was with regard to the creep of the ropes, and upon that subject he entirely agreed with what had been said by Mr Millen Adam. When a rope was transmitting any force at all there must be a certain

Mr E. Hall-Brown.
amount of creep, due to the elasticity of the rope, and the drive could not be a positive drive such as spur gearing. It involved a certain minute loss which was included in the general loss due to rope driving, and was really a very small matter, for the efficiency of a well-designed rope drive was very high. Up to the present time British engineers had favoured direct dynamos, and doubtless with good reason. It might, however, be worth while to consider whether some of the slow speed engines which had been installed in Glasgow for the purpose of driving dynamos direct, might not have formed a cheaper installation had they driven higher speed dynamos by means of ropes, rather than the enormous machines to which they were coupled. He was rather interested in Mr Broekman's remarks, but he must confess that he felt rather mystified, probably because he was not an electrical engineer; and he would be glad if Mr Broekman would explain what the "automatic power reserve" was. Whatever it was it could not affect the fluctuation of power at the motor. It might prevent the fluctuation from reaching the dynamo, but the fluctuation must always reach the motor, and he questioned whether it was worse for a motor or for a rope drive to be coupled to an exceedingly fluctuating load. Electricians had the advantage that when a motor failed to work satisfactorily upon a variable load they could state that the wrong kind of motor had been installed. No matter whether the machine was of one kind or another; when it was unsatisfactory it was always of the wrong kind. It did not seem to him that a motor worked any better with a fluctuating load than an ordinary rope drive did; and consequently as regards this point, raised by Mr Broekman, he did not think that electrical transmission had any advantage on that score over a belt or rope drive. In many cases both systems were required, and he cordially welcomed the paper for the information it contained.

Mr A. Sproul (Member) agreed with Mr Kenyon that up to a velocity of 7000 feet per minute there would be a proportional increase in transmission of power by ropes. Taking a rope of 1¾ inches diameter, running at 5000 feet per minute, it would

Mr A. Sproul.

safely carry 50 horse power. That was a cotton rope, with proper diameter of pulleys, and grooves of suitable shape, such as was referred to on page 116. He had a good deal to do with rope driving, and in practice never troubled about the effects of centrifugal force, it being a small element in the practical use of rope transmission. A cotton rope of $1\frac{3}{4}$ inch diameter would safely and economically stand a working strain of 330 pounds, and this, at 5000 feet per minute, equalled 50 horse power, or 70 horse power when the speed was 7000 feet per minute, which agreed with Mr Kenyon's table on page 125, where a $1\frac{3}{4}$-inch rope at 1000 feet, carried 10 horse power, or 10 horse power for every 1000 feet velocity per minute. The weight of a good cotton rope of $1\frac{3}{4}$ inch diameter was 79 pounds per foot length, and the centrifugal force at 4800 feet per minute, which was said to be the best velocity to run ropes to prevent loss from centrifugal action, equalled 13 pounds, and at 7000 feet 18 pounds. On a working strain of 330 pounds only 5·45 per cent. acted in redncing the pressure of rope in the groove, and was of value in overcoming the "stiction" when the ropes were leaving the grooves on the slack side. The usual tables for rope drives gave, for a $1\frac{3}{4}$-inch rope, 28 horse power at a velocity of 2000 feet per minute, while at the speed assumed for best practice, namely, 4800 feet, the horse power was 47·3, and with increasing velocities a gradual reduction in horse power was made till at 7000 feet it was only 29·5. The reduction being due to centrifugal action while the rope was wedginn and binding itself round the pulley. Such tables might be discarded in practice. It was interesting to find a man in Mr Kenyon's position as a ropemaker discrediting them, even against the value of his sales, as it was really advocating smaller ropes and higher velocities; and this should not be lost sight of by the engineer when designing rope drives. Referring to carrier pulleys, he did not quite agree with the easement to the ropes in cases of surging. When any sudden change was made on the power, a wearing action took place. Then the side swing entering and leaving such easy grooves caused the ropes to chafe. If

Mr A. Sproul.

carrier pulleys were used, then V-grooves were better; but from some rather interesting experiences he had had of a long stretch of about 800 feet, with frames fitted with double carrier pulleys to take both upper and lower ropes, he found that from want of oil at times, the pulleys made much noise, soon got slack on the pins, and caused much annoyance and expense to keep them in order. To stop the rattling noise, men working near wedged the pulleys in the frames, so that they could not revolve. The repairs to pulleys then stopped, and the life of the ropes was lengthened, as the gliding action over the polished surface seemed to do very little harm, and he would have no hesitation in future in dispensing with carrier pulleys, and in their place have well-rounded, polished slippers of iron or lignum-vitæ or other hard wood. Not only were ropes very much cheaper than belts, but they took up much less room. A 1¾-inch rope would transmit, at the same velocity and diameter of pulleys, a power equal to a leather belt 7½ inches in width. Referring to Mr Adam's suggestion to use flat drums in preference to V-grooves, and to make one-and-a-half turns of the rope round them, not only would this take up much room, but the grip the ropes would have would be far more than they could stand if any excessive strain was put on them. Instead of a slip to save the rope, the result might be a rupture of the rope. V-grooves would transmit the safe power of the rope without the ropes being very tight, while if a load more than a safe working one was put on, slip would occur, and save perhaps a complete stoppage of a machine.

Mr L. Broekman (Member) said that in reference to Mr Hall-Brown's remarks at the last meeting, he had not personally come across an instance of that trust amongst Northern Engineers in any shadowy benefits from electricity to which he had alluded. On the contrary, the most searching questions were invariably put to him, and chapter and verse demanded for every single statement. To put forward electrification as a universal balsam for all conditions of power production and transmission was a mistake which no man with any experience would commit. Where the

Mr L. Broekman.

total costs per I.H.P. hour worked out at one-third of a penny, with steam power and mechanical transmission, conversion manifestly could not be recommended on the score of further material economy, although that was not the only consideration by any means, and increased output from the mills or works by reason of the higher average speed which could be obtaïned with electric motors might, by itself, warrant the expense of changing over to electricity. An automatic power reserve, such as he had advocated for severely fluctuating loads, consisted essentially of two parts—one, the battery that stored whenever the load was light, and supplemented the generating plant whenever the demand was heavy, and might therefore be called the flexible link. The other, a combination of motor and dynamo, technically known as a reversible booster, that kept the line pressure constant no matter how wildly the load might vary within a given limit. Assuming that in any yard or mill the power demand fluctuated suddenly and frequently between 1000 and 200 horse power, it was not necessary to provide generating plant for the maximum demand, but for the mean load only, which, in that case, might be taken as 600 horse power—a saving of 400 horse power right away in first cost and running charges. This 600 horse-power plant was run throughout at its full output and best efficiency. All dips below 600 horse power went into the battery by way of charge, and the power for peaks above 600 horse power was furnished from the battery, so that it was either receiving or giving out alternately in quick succession. The entire action was automatic, instantaneous, and at uniform pressure. It did not interfere with, or tend to limit in the slightest degree the free operation of any individual motor installed. That would be detrimental, and would hinder instead of help. The power that every motor demanded must be given without restriction. So long as a motor was correctly designed for the maximum work it had to do, there was no need to trouble at all about the load on it falling off periodically. The motor would then simply take less current for the time being, and there should be no difficulty about

Mr L. Broekman.
sparking, especially if the pressure remained uniform. Sparking troubles generally arose from faulty adjustment of the brushes, either too loose, or bearing too hard on the commutator, or from being wrongly set. But whether the load varied on any individual motor, or whether the number of motors running at the same time changed rapidly and within a wide range, to ensure thoroughly satisfactory efficient working it was essential to prevent these fluctuations from reacting on the dynamos, engines, and boilers, also from affecting the line pressure, and these conditions were fulfilled by the use of an automatic power reserve.

The CHAIRMAN asked whether Mr Broekman would recommend such an apparatus as he described as an automatic power reserve, supposing he wished to drive a planing machine where fluctuations obtained from nothing up to the maximum once or twice a minute.

Mr BROEKMAN—Yes; it was specially suited for fluctuating and intermittent loads.

Reply to Discussion.

Mr KENYON, in reply, said Mr Biggart had contributed most valuable testimony to the advantages of cotton over Manilla, hemp, and hide ropes, and his views on the subject not only drove home, but clinched the arguments set forth in the paper. He regretted he was not sufficiently acquainted with wire ropes to furnish reliable data upon which to build any hypothesis as to their relative value for power-transmitting purposes, and his inquiries for definite information both from manufacturers and users had hitherto proved barren and unfruitful. Wire ropes did not enter very largely into British practice save for haulage, under which category cable tramways might well be placed. A few Continental cases had come to his notice through the French works of his firm, but the information was too vague to be of much importance. One of these cases was the replacement with cotton of a wire rope transmitting power from the mainland to a small island in Holland. The users had volunteered the statement that the cotton rope transmitted the power more successfully, besides having a much longer life than the wire rope. Mr Couper dissented from the superior position given to cotton above other materials, particularly for the driving of cranes and similar machinery. Judging from the amount of cotton crane ropes supplied to the Government, to the leading railway companies, and to engineering firms generally, it would appear that Manilla ropes were fast becoming obsolete for this special purpose. Belfast was acknowledged to be a strong Manilla centre; yet even there one firm alone had fitted up over seventy mills and factories with cotton ropes, in addition to those supplied by other makers, and the majority of these were to supplant the Manilla formerly employed. The jute districts of Scotland were also large users, nor was Glasgow by any means the smallest consumer of cotton driving ropes. He would not attempt to pit an inferior cotton against the finest Manilla, and he had himself more than once met with firms who had expressed their dissatisfaction with cotton, and had turned again to Manilla. He had, however, generally found that the fault rested either with the quality—often waste yarns passed off as good Egyptian cotton—the make, or it might be because the splicer was not accustomed to the manipulation of the more pliable material. The four-strand rope, as illustrated by Figs. 30 and 33, was probably the greatest offender in the matter of malconstruction; and again, ropes made on the principle of Fig. 58 were responsible for much trouble through undue stretching. Whatever the material, comparatively large pulleys were certainly a gain both in driving force and longevity. By reason of its suppleness a good three-strand cotton rope might, however, be successfully run upon considerably smaller pulleys than were absolutely necessary for one made from the harsher fibre. That internal grinding process which reduced the heart of a Manilla rope to "a condition like flour" was seldom if ever perceived inside a well made cotton rope however long it might have worked. Invariably the abrasion took place upon the outer surface. He

Mr Kenyon.

had opened ropes with well-worn exteriors which had been working for periods of say 12 or 15 years, but had perceived no evidences of interior granulation. Mr Broekman would readily perceive that he did not claim to be an electrician, but based his remarks upon the information derived from practical engineers. In the instance of the alkali works mentioned, it might have been stated that this firm had had considerable experience of both direct coupled and rope driven dynamos, and the manager of the works unhesitatingly expressed a decided preference for ropes, and had gone so far as to arrange a new dynamo house with a view to further extensions in that direction. Nor was this by any means an isolated instance. For erratic driving, such as that of iron rolling mills, Mr Davies most emphatically declared that for this class of work he found no other method to equal rope driving, particularly if the inertia of a fly-wheel was added to that of a heavy driven pulley. With regard to the application of electricity as an antidote "for all the ills that any industrial establishment was ever afflicted with," to borrow a fitting phrase from Mr E. Hall-Brown's criticism, he could not do better than leave the admirable reasoning of the aforesaid gentleman (Mr Hall-Brown) to work out his own corollary. Mr Napier's experience of 25 years ago in relation to angles of grooves and relative sizes of pulleys agreed with what his firm advocated for a longer period. The matter of groove angles had a more important bearing on the general economy of rope driving than some engineers were prepared to admit. Since reading the paper he had been called in to inspect a number of drives owned by a large cotton firm, some of which were constructed before rope driving had emerged from its early tentative stage. In one of these, where 1⅜-inch ropes were transmitting 1300 H.P. from a driving pulley 26 feet in diameter, the grooves were made to an angle of 68 degrees. To this obtuseness was attributed the destruction of the ropes long before those at other mills owned by the same firm, which were operating in grooves of about 45 degrees, although a larger number of ropes were employed (*i.e.*, in the grooves of 68 degrees) than would be necessary under normal conditions. The outcome of such tests as these might, of course, only be ascertained after many years. He would emphasise the fact already stated in the paper, that an angle of 40 degrees had proved hitherto to give the best results, particularly as a preventative of the rolling action so much to be avoided. Fast and loose rope pulleys were becoming more and more used in driving the machinery of Lancashire cotton mills, and they needed but introduction to the linen, jute, and similar textile trades to prove their value as a power-transmitting agent for all classes of machinery, where inconstant rotory motion was required. Proper splicing was certainly an important factor in rope driving, and although the illustration submitted in Fig. 40 might not prove very instructive to the entirely uninitiated, it would serve to put even an indifferent splicer upon the right track. Mr Adam had evidently had some experience of rope making; it might, however, be suggested that whatever the method adopted in the manufacture of Manilla ropes, the crinkled effect reproduced in Fig. 33 was only realisable in the softer materials. The system referred to of drawing each thread through a perforated plate was, as Mr Adam declared, a very old one, and had been applied to cotton; but until the introduction of the inter-stranding process the equality of tension and concentric lay of the yarns, as displayed in Fig. 37, was not procurable. As to the positive motion produced by driving ropes, although "creep" was suggested as the only alternative in recovering from the working strain, seeing that the pulling side of a cotton rope was thinner than the trailing span or "idle" side, thus indicating its resilience, such "creep" was never allowed to enter into the equation when calculating for speeds, and, if it existed at all, it was always regarded as a negligible quantity. Even the rolling action, to which reference had been made, did not travel the whole circuit of the pulleys, but the rope might be said to worm its way to the point where actual seizure took place, when the periphery in contact at the moment was carried forward until it was relieved from the bite of the groove. This alternate revolving and fixing often had the effect of flattening the sides of

Mr Kenyon.

the rope until the section assumed the shape of an irregular polygon. The best service and longest life might be expected from a rope when it was compressed to the shape of the groove, and maintained that position notwithstanding the breaking up of the outer fibres, as shown in Fig. 35. Mr Adam recalled the time when Manilla was not the commercial substitute they now had sent to them, and reminded them that their friends on the other side of the Atlantic retained the best for home consumption. While admitting this deterioration, evidence galore might be produced both from personal experiences in the United States, and also of the Manilla ropes supplied and fixed by American firms in this country, which went to give the highest place to cotton. With regard to the V-shaped groove, unfortunately the fallacy was still abroad that a curved-sided groove was better, and gave more easement to the rope when leaving it. When his firm were called upon to supply ropes for such templets, permission was always asked to make them at least $\frac{1}{8}$ of an inch thicker than specified (*i.e.*, for the larger sizes), knowing full well that if this was not done, and if the grooves were not filled to their utmost capacity, the result would be a shortage of power upon the usual calculation. It was most gratifying to have Mr Adam testifying to the fact that the paper had underestimated the driving force of ropes. If they would do well under the severe conditions mentioned, might not greater general economy be expected under the comparatively luxuriant circumstances which existed in well-appointed drives? Mr Hall-Brown entered into a most interesting and instructive discussion upon the application of electricity to the transmission of power, which he gratefully accepted as a rebutting argument to those who would electrify almost everything to the exclusion of other methods. A short time ago he visited a works in the north, one part of which was driven by electro-motors, the other by belts and ropes. When appealed to for his opinion upon the relative economy of each style of driving, the manager most emphatically declared in favour of the belt and rope driven plant. Mr Sproul, by giving his reasons for discarding the centrifugal tension theory, and for admitting the only tenable conclusion that the power of a rope was a constantly increasing quantity in the ratio of speed, had conferred a greater favour upon him than he probably imagined. It scarcely appeared credible, but it was nevertheless a fact, that the struggle to materialise these visionary detractions still went on in some quarters, despite the palpable evidences of their non-existence. With respect to the substitution of hard-wood or iron slippers for carrier pulleys, he believed that some such arrangement had been tried in the Birmingham district, but with what success he had not been able to ascertain. If the same rule which applied to the diameter of driving pulleys was also applied to their tributaries, the trouble so often experienced in long drives would be materially lessened, if it did not disappear altogether. The method (previously mentioned by Mr Adam) of wrapping ropes three or four times round flat pulleys was working very satisfactorily for light machinery, but the width taken up by them almost, if not entirely, equalled that of the belt they were designed to replace, whereas a single rope only ¾ of an inch in diameter, operating in a suitable groove, was driving the same class of machinery with equal success, and was doing the work of a belt 3½ inches wide. He was not aware of any instance where the flat pulley method had been applied to larger powers. He desired to thank the gentlemen who had contributed to the interesting discussion, which materially enhanced whatever of value the paper contained.

On the motion of the Chairman, Mr Kenyon was awarded a vote of thanks for his paper.

Correspondence.

Mr R. B. Hodgson, Birmingham, expressed a desire to add his testimony to the usefulness of the paper, and the valuable information therein contained clearly indicated that the author was eminently qualified to deal with the subject. In the transmission of power, there were frequently many matters which cropped up that had to be duly considered before the problem was

Mr R. B. Hodgson.

settled as to whether gearing, ropes, or belts were most suitable for a particular and special purpose. At the same time, in the face of the evidence available for engineers' use, it was not at all difficult to make out a good case for the cotton rope system. With regard to breakdowns, as mentioned on page 93, the evidence of Mr Michael Longridge was very important and far-reaching, as every engineer knew the authority of that gentleman in deciding such questions. It was also interesting to see that his own views were confirmed by his esteemed friend, Mr Jonah Davies, as certainly there was no one in the Midlands who had either a greater or larger experience than he had had in relation to iron works' plant. Many times it had been observed that marks occurred on bright rolled strips, as a result of vibrations of spur gearing, which disappeared after rope driving had taken the place of the gearing. In the matter of belts *v.* ropes, mentioned on page 95, he could thoroughly support the author. In 1896, he had occasion to plan some works, which gave him an opportunity of putting the rope to the test. Previous to this he had known a 12-inch leather belt to be completely used up as a result of three years work, so in this new scheme he recommended the adoption of a 3-strand cotton rope on a compound engine as a trial, the drive consisting of a 12-feet driver connected to a 6-feet drum by means of 16 ropes, each of 1½ inch diameter. He had some difficulty in convincing his friends as to the advisability of adopting ropes, because their experience at another mill with four-strand ropes had been very disappointing and disastrous. For reasons which the author explained on pages 123 and 124, the new drive, however, turned out to be very satisfactory, and subsequently the four-strand ropes at the old mill were replaced with three-strand ropes of Kenyon's make, and the trouble previously experienced disappeared. The cost of ropes, as compared with belts, was much in favour of the former, particularly in instances where any heavy work had to be performed. It seemed unfortunate that Mr Kenyon had not included in the paper some information on the subject of arc-of-contact in the working of pulleys. It was a fact that any pulley arrangement with either ropes or belts would give better results with an arc-of-contact of say 190 degrees, than could possibly be expected from an arc-of-contact of say 160 degrees. It was equally certain that any given arc-of-contact would give a certain definite result independent of the pulley diameter, and this point could not be emphasised too clearly, since so many engineers persisted in misconstruing the *arc*-of-contact with the *area*-of-contact. The following three statements would always hold good for belt or rope driving:—1. The adhesion of the belt to the pulley was the same (the arc or number of degrees of contact, aggregate tension, or weight being the same), without reference to width of belt or diameter of pulley. 2. A belt would slip just as readily on a pulley four feet in diameter as on a pulley two feet in diameter, provided the conditions of the faces of the pulleys, the arc-of-contact, the tension, and the number of feet the belt travelled per minute were the same in both cases. 3. A belt of a given width, and travelling any given number of feet per minute, would transmit as much power running on pulleys two feet in diameter, as it would on pulleys four feet in diameter, provided the arc-of-contact, tension, and conditions of pulley faces were the same in both cases. When an engineer found his pulleys would not drive his shafting, he generally decided to employ pulleys of larger diameter, and when this was done the trouble usually disappeared; but not by reason of greater *grip* or *friction*—the extra power was gained by increased velocity of belt.

Reply to Correspondence.

Mr KENYON considered the letter contributed by Mr Hodgson a commentary in itself, adding to the discussion an instructive treatise upon several important issues, and was well worthy of consideration if only for the remarks upon the arc-of-contract, and its effect upon either rope or belt driving.

MULTIPLE STEAM TURBINES.

By Mr ALEXANDER MELENCOVICH (Associate Member).

SEE PLATE VI.

Read 24th January, 1905.

PAPERS have been read before this Institution by Mr Konrad Andersson and by Professor W. H. Watkinson, in which reference was made to the high rate of revolutions peculiar to steam turbines.

The best method of reducing excessively high revolutions and circumferential volocities of steam turbines is to allow the steam to pass through a number of turbine wheels arranged in series, in order that the pressure and kinetic energy may be absorbed gradually. Such multiple turbines may work with different grades* of reaction from about one-half, as in the Parsons' turbine, down to pure action, as in the Rateau type. The later turbines, as a rule, require fewer rows of vanes for the same circumferential velocity than reaction turbines; the steam speeds are, however, considerably higher. The general law of mechanics, upon which the flow of steam through such multiple turbines is based, can be stated as follows:—The energy made available by the expansion of steam, from the working to the back pressure, must be equal to the sum of energies absorbed in each of the consecutive rows of vanes, plus the different losses per lb. of steam. Under certain circumstances the steam does not expand down to the condenser

* Suppose Δp_1 and Δp_2 to indicate the drop in pressure in the guiding and moving vanes; then $\Delta p_1 + \Delta p_2 = \Delta p$ will be the drop in pressure in one pair of vanes. If now k_1, k_2, and k are the energies made available by the drop in pressure, Δp_1, Δp_2, and Δp, then $\frac{k_2}{k}$ is called the reaction grade.

or receiver pressure, but may leave the last row of vanes with a certain higher pressure. Suppose, now, the working pressure of a turbine to be p_1, and that the steam leaving the turbine exhausts into a condenser in which the pressure is p_2; then, if a greater amount of steam passes the turbine with a back pressure raised to p_3, the steam will leave the last row of vanes at the higher pressure, p_3, and suddenly drop in pressure after leaving the turbine to p_2. Mathematically speaking, the back pressure will have adjusted itself to the maximum of the passing fluid. Under normal conditions, the above-mentioned phenomenon will not occur; but when working astern turbines, in which the steam speeds grow very high (as will be seen later on), this case is quite probable.

For the sake of simplicity in dealing with the multiple turbine problem, it will be assumed that equal energies are absorbed by each pair of rows of vanes: for similar blading, this implies uniform speeds. The elastic fluid will also be assumed to follow the equation $p.v$ = constant, and to be frictionless. With these assumptions the following equations can be easily integrated, and it is comparatively easy to follow the behaviour of the elastic fluid passing through a given turbine when either revolutions or pressure is varied. From this simple case deductions may be made which will be approximately correct if the law $p.v$ = constant is more or less departed from.

The expression giving the pressure p along the turbine may be derived by integrating the equation $-v\Delta p = \Delta zk$, *i.e.*, the amount of energy $-v\Delta p$ made available by the drop of pressure $-\Delta p$ in each one of the rows Δz, must be constant. The above equation, if combined with the equation $p.v=$ constant, and if differentials are taken instead of differences, is transformed into $-\frac{dp}{p} = dzk_1$, which, after being integrated, and the proper constants introduced, becomes—

$$\log_e p = \frac{z}{z_a}(\log_e p_2 - \log_e p_1) + \log_e p_1 \quad - \; - \; - \; - \quad (1),$$

This equation enables the pressure p to be calculated at any of the rows z if the total number of rows z_n and the working and back pressures p_1 and p_2 are known.

If the diameter of the turbine is great in comparison to the length of blade, and the fluid is admitted over the whole annulus area, then the length of blade must vary inversely as the pressure, on account of the equal speeds. The bending moment at the root of the blade increases in proportion to the length of the blade, therefore the width of blading must increase with the length.

If equation (1) is transformed to $\frac{z}{z_n} \log_e \frac{p_2}{p_1} = \log_e \frac{p}{p_1}$, it will be observed that the curve of pressures and the length of blades along the turbines depend only upon the ratio of pressures $\frac{p_2}{p_1}$; in other words, if the working and back pressures are altered (with constant revolutions) in the same ratio, the speeds and absorbed energy remain uniformly distributed, and also constant, because the available energy per lb. of fluid depends only upon the ratio of expansion. The I.H.P. of the turbine will then vary as the density of the fluid. To take a practical example:—Suppose a turbo-dynamo to work with constant revolutions at a pressure of 100 lbs. absolute, and a condenser pressure of 2 lbs. If the working pressure be reduced to 50 lbs., and the condenser pressure to 1 lb., then the steam speeds and absorbed energies in each of the rows of vanes per lb. of steam will remain approximately the same as before; the curve of pressures along the rows will be similar, but the I.H.P. will be reduced to ½. These theoretical considerations are fully borne out by the complete experiments made at Elberfeld.

Attention may be drawn to the fact that if the back pressure is not reduced in the same proportion as the working pressure, but is greater in proportion, then the back pressure will be reached before the last row, and the steam will pass the remainder of the rows of vanes with constant pressure and gradually reducing speed. This case will happen in a turbo-dynamo when the governor throttles the working pressure, owing to part of the load being taken off, and the air pump is unable to produce a better vacuum.

As is well known from the water turbine theory, the energy absorbed in one pair of wheels for reaction grade one-half equals

$$\frac{1}{g}(-u^2 + 2uc_1 . \cos a) = k \quad - - - - - - - \quad (2),$$

where c_1 = the speed of fluid leaving the guiding vanes,
u = circumferential velocity of vanes, and
a = the angle of vanes as indicated in Figs. 1 and 2. If u is altered by altering the revolutions without changing the pressures p_1 and p_2 (p_1 must be taken here, not as the working pressure of the turbine, but the pressure after the first guiding vanes, when the steam has acquired speed) k remains constant, and c will vary till equation (2) is satisfied. Considering c_1 as a function of u in equation (2), a hyperbola, as shown in Fig. 3, is obtained, which shows that with diminishing revolutions more fluid is passing the turbine. This well-known peculiarity of turbines is most undesirable for marine work, where the power, and therefore, the amount of passing fluid, should vary approximately as the cube of the revolutions. This inconvenience is remedied by reducing the working pressure, when for equal speeds less fluid passes through the turbine.

The amount of energy made available per lb. of steam by the drop of pressure can easily be determined by using the entropy diagram and the pressures at the end of the H.P. turbine—the receiver—when the work is equally distributed between H.P. and L.P. turbines, or, as is most often the case, when $\frac{1}{3}$ of the energy is absorbed in the H.P. turbine and $\frac{2}{3}$ in the L.P. Further, this diagram is very useful for investigating the expansion and flow of steam, when, owing to frictional resistance, part of the kinetic energy of the steam is transformed back into heat. The expansion line in the entropy diagram appears, therefore, not to be vertical, but inclined and slightly curved, as shown in Fig.4 : the ratio of the areas $\frac{B}{A}$ is the proportion of loss due to friction. It is interesting to notice that an increase in vacuum in a turbine of the Parsons' type causes an increase in efficiency greater than what would be expected theoretically with the adiabatic expansion. This very curious feature is explained by the distortion of the entropy diagram, Fig. 4, which causes the lower part of it to gain in importance in comparison with the higher. The expansion curve, with 20 per cent. frictional loss, is approximately given by the equation $p.v^{1.1}=$ constant, and the curve of the pressure along the turbine for equal energy absorbed by each row is given by the equation

$$\sqrt[10]{p}=\frac{z}{z_n}\left(\sqrt[10]{p_2}-\sqrt[10]{p_1}\right)+\sqrt[10]{p_1} \quad - - - - - - - - \quad (3).$$

This equation is derived in exactly the same way as equation (1), with the only difference that the law of expansion is taken as $p.v^{1.1}=$ constant, thus taking into account the frictional resistance and the properties of steam. The length of the blade for equal speeds can easily be derived from the volume of steam, Fig. 5.

If the speed of steam, circumferential velocity, and angle of vanes are chosen, the diagram of speed can be drawn, Fig. 1;

$$\text{then, } \frac{w_2^2-w_1^2}{2g}+\frac{c_1^2-c_2^2}{2g}=k \quad - - - - - - - - - - - - - \quad (4),$$

represents the energy absorbed by one pair of rows per lb. of steam. In dividing k into the nett energy made available by the expansion of steam from p_1 to p_2; z_n, the number of pairs of rows of vanes required is obtained. The nett energy is got by subtracting from the theoretical energy about 7 per cent. for outlet and 20 per cent. for frictional loss. If, also, the diameter of turbine and length of blade of the first rows of vanes are chosen, the I.H.P. can be calculated from the amount of steam passing and the assumed efficiency. Another method is to choose the diameter and I.H.P., and from these two items calculate the length of blade. In quite a number of cases this first length of blade is found to be so small that the amount of clearance required in a radial direction between the blades and casing is quite a large percentage of the length of the blades; this would mean too great a loss due to leakage, but the difficulty is overcome by choosing a smaller diameter. The diameters must also be chosen so as not to have the last blades in the L.P. turbine exessively long. The arrangement of one H.P. and two L.P. turbines meets this inconvenience; the first length of blade in the H.P. turbine gets long enough; the last in the L.P. turbine also are moderate. The ratio of circumferential velocity to the speed of steam leaving the guiding vanes is, as a rule, ·5 to ·3; therefore the I.H.P. of a turbine can be considered as being proportional to the first annular area, to the circumferential velocity, to the assumed efficiency, and the absolute pressure.

For convenience in manufacturing, the length and width of blade changes, not continually, but by steps; also, the steam speeds and angles of blades are not the same along the turbine, but increase with falling pressures, thus avoiding too great lengths and bending moments at the roots of the blades. Through analysing the results of tests it might be concluded that the whole of the loss is due to friction and eddying of steam in passing the blades, except for a comparatively small loss due to outlet velocity of the steam. This frictional loss is given by experiments to be (1) approximately proportional to the square of the steam speed, and (2) proportional to the surface over which the steam is moving. According to the above hypotheses a great loss might be expected when the circumferential and the steam speeds are taken high (the number of rows of vanes would then be low according to equation 4), owing to the first of the above-mentioned reasons. With low circumferential and steam speeds the number of rows of vanes (which varies inversely as the square of the circumferential velocity) and rubbing surface will be great, therefore the loss will be again great. Between these two extreme cases will be a minimum of loss and maximum of economy, which seems to be attained when the usual working pressures are absorbed in about from 70 to 80 pairs of rows of vanes. The idea seems also reasonable that the friction increases with the sharpness of curvature of vanes and the moisture of the steam. This latter opinion appears to be fully justified by the increase of efficiency obtained when the steam is superheated. Another loss is that due to the flow of heat from the places of higher temperature towards those of a lower temperature in the casing and rotating drum.

It has been already mentioned that the length of blade is made constant for a number of blades, from 15 to 20, for manufacturing convenience, in this case the steam speeds and absorbed energies increase from row to row, see Fig. 5. The curve of pressures along the rows is obtained by integrating the equation

$$-v\Delta p = (-u^2 + 2u.\cos\alpha.c_1)\,\Delta z$$

which equation means that the amount of energy available $-v\Delta p$ by the drop of pressure $-\Delta p$ in the row represented by Δz is equal to the amount which will be absorbed with the speeds u c_1 and the angle a. See also equation (2).

As $-u^2$ and $2\,u\cos a$ are constants they can be denominated by $-$ A and B_1, then $-v\Delta p = (-A + B_1\,c_1)\,\Delta z$, and c_1 being proportional to the volume, also $-v\Delta p = (-A + B\,v)\,\Delta z$.

If this equation is combined with $p.v =$ constant, integrated, and the proper constants introduced, then

$$\log_e \left(\frac{p_1}{p}\,\frac{A-B}{A-B}\right) = \frac{z}{z_n}\,\log_e \left(\frac{p_1}{p_2}\,\frac{A-B}{A-B}\right) \quad \text{- - - - (5).}$$

This curve becomes very flat for the proper ratio, between steam and circumferential velocity, practically a straight line joining the forward and back pressure.

If the energy absorbed by each of the rows of vanes is not the same as was assumed in deducting equations (1) and (3), but varies in a certain way, then the curve of pressures along the turbine, which is useful in calculating the steam thrust, can be derived from the curves represented by (1) and (3) by gradually expanding and contracting the base line in proportion to the energy absorbed.

The reduction of the working pressure at lower powers, in order to have the power varying as the cube of the revolutions, may be calculated by the aid of the general law mentioned. A curve is given in Fig. 6 showing how the pressure must be throttled for lower powers. This curve is approximately a parabola passing through the zero point and having the exponent 2·5. Roughly speaking, 2½ per cent. would have to be added to the pressure for 1 per cent. of speed. It must be borne in mind that the friction and outlet losses increase with the square of the steam speeds, thus reducing the nett available energy and the amount of steam passing at the lower revolutions, but the consumption per I.H.P. is increased by the greater losses. The sizes and weights of turbines can be considerably reduced if high steam speeds, and great losses are accepted. This feature is utilized in astern turbines. The curve of steam consumption has the vertical axis as an asymptote, see Fig. 6; this can be easily derived by theoretical considerations,

In some cases additional turbines have been fitted, through which the steam passes first at lower revolutions, by which the increased steam speed and losses are avoided. In the case of more than the designed revolutions being required, together with overload, it is obvious that the number of rows of vanes that the steam passes through must be reduced (just as with the lower revolutions it had to be increased), this is easily done by introducing steam at any of the rows after the first one, and is commonly called working the by-pass.

If the revolutions are varied, and the working pressures kept constant, a steam turbine might be expected to give the same I H.P. with two different numbers of revolutions; these will be closer to each other the nearer the approach to the maximum possible I.H.P.

The loss due to friction in a turbine can be experimentally obtained from a working turbine, if the entropy at each pressure is calculated from the wetness of the steam and the expansion line drawn in the entropy diagram. The ratio of the areas $\frac{B}{A}$, Fig. 4, gives the proportion of loss. By this expansion line can also be answered the interesting question whether the frictional loss is equally distributed along the turbine, or increases with the wetness and speed of steam.

It can easily be proved that the reciprocating engine with an expansion from 9 to 10-fold attains its maximum economy with a vacuum of from 27 to 28 inches, but the turbine with an expansion of more than 100-fold is quite different, owing to the great volume of steam at the very low pressures, a small difference in the vacuum considerably increases the available energy per lb. of steam; also, the higher the vacuum the nearer the approach to the above mentioned condition of having the I.H.P.'s varying proportionally to the working pressure.

The thrust set up in the axial direction by the steam passing a turbine consists, *firstly*, of the pressure difference before and after the moving vanes; and, *secondly*, of the change of momentum of steam inside the moving vanes in the direction of the axis of rotation. In a reaction turbine the second item is small in comparison to the first, and can be neglected. For reaction grade one-half the free thrust is got by taking the sum of the products obtained by multiplying half the drop of pressure by the annulus area for each step. The free thrust being proportional to the working pressure, the curve of pressures, Fig. 6, also represents the free thrust. The dotted curve represents the propeller thrust assumed to vary as the square of the speed. From these two curves it can be seen that if the steam and propeller thrusts balance each other at full power, they do not balance each other at lower powers. From 70 to 80 was mentioned before as being the most desirable number of rows of vanes in which to have the whole working pressure absorbed, but for marine work, where the revolutions have to be limited owing to the propeller, and the diameter of turbines must be kept down on account of the limited breadth of engine room, the circumferential velocity gets low and this necessitates a greater number of rows of vanes.

The most important point in the question of the installation of turbines for driving a ship is the rate of revolutions. A compromise must be made between keeping the rate of revolutions low in order to have a sufficient propulsive surface without extreme pitch-ratios, and in having the revolutions and circumferential velocity high for lightness and efficiency of the turbines. If from a given ship with a turbine installation, a suitable installation for a similar ship of different length but the same speed is required, then, the well-known formula, by M. Normand, relating to propellers can be applied.

$$n D r^{\frac{3}{4}} = j\frac{F}{V^2};$$ where,

n = number of propellers,
D = diameter of propeller,
F = I.H.P.,
V = speed of ship in knots,
r = ratio of disc area to developed surface of blades of propeller, and,
j = coefficient.

From this formula, the value of which is greatly appreciated by Continental engineers, can be deduced the following law:—The amount of water passing the propeller must be proportional to the thrust. Let R be the ratio of dimensions of the similar ships, then for the same speeds the I.H.P. and thrusts will vary as R^2, therefore, if the diameter of the propellers also bear the ratio R then Mr Normand's formula is satisfied. The pitch-ratio being fixed, (owing to the equal speed) the revolutions have to be reduced in the same ratio as the diameters of the propellers have been increased. The turbines can be arranged in various ways, either the diameter of turbines and length of turbine blades might be increased in the ratio R, when the circumferential velocity will remain unchanged and the same number of rows will be sufficient, and the same efficiency might be expected; or the diameters might be increased in a ratio less than R, then more rows of vanes will be required because the number of rows increases in inverse proportion to the square of the circum-

Mr W. H. Riddlesworth.

ferential velocity. The question is one of arranging for the less weight or greater economy. When the dimensions of ships are altered, and the speeds also changed to the corresponding speeds, the diameters of the propellers must increase faster than the ratio of the length of the ships, which makes it necessary to increase the number of propellers and shafts.

Discussion.

Mr W. H. Riddlesworth, M. Sc. (Associate Member) remarked that the only point to which he would refer was the similarity of the problem to one that was constantly being solved by all designers of multiple-expansion engines. In the paper the first thing that was attempted to be done was to get the drop in pressure from row to row of blades, and the author did that by assuming that the work was equally divided amongst all the rows of blades of the turbine. That to him appeared to be an analogous problem to designing a multiple-expansion engine, so that the work done in each cylinder should be the same. In reality the method of solution of the problems was exactly the same. In connection with the torpedo boat destroyer "Cobra," Mr Parsons, or some one for him, made a statement with regard to the gyroscopic action of the turbine, to the effect that, it would only produce an infinitesimal bending moment on the ship in a short choppy sea. The statement was made semi-officially, at any rate, that the bending moment or twist given to the ship by the turbine due to its gyroscopic action was quite negligible.

Mr James Hamilton (Member) said it did not seem to him that the problem as put forth by the author was the same as for the reciprocating engine, as Mr Riddlesworth had said. One of the opening statements was that "The best method of reducing excessively high revolutions and circumferential velocities of steam turbines is to allow the steam to pass through a number of turbine wheels arranged in series, in order that the pressure and kinetic energy may be absorbed gradually." He thought that the word "gradually" was rather an unfortunate expression. It suggested

Mr James Hamilton.

to him, at least, that the continuous impact could be divided or split up by taking glancing blows of a great number of vanes. The impact on a de Laval vane could be split up and distributed over a number of vanes, and by so doing it was said that the velocity and the revolutions of the turbine were reduced. If, in a reciprocating engine, the piston speed were reduced, the diameter of the cylinder must be increased, and the full pressure must be maintained. It was not a question of sub-dividing. In a turbine the area might be doubled, but it was no use doing so unless the continuous total impact was doubled to correspond with the increased area of the vane. Therefore, it seemed to him that this was not the explanation of why the velocity or the revolutions could be reduced. It was obvious that by increasing the number of wheels an increased vane area could be obtained, but it was not quite so obvious where the increased impacts on that area could be got without increasing the volume of steam, which, of course, was impossible, assuming that the same horse power was maintained. Referring to M. Normand's formula for propellers, Mr Melencovich said :—"From this formula, ... can be deduced the following law—The amount of water passing the propeller must be proportional to the thrust." He thought the author had misunderstood the formula, because, although it was a valuable and beautiful formula, the important thing about it was that it introduced the element of surface. The surface had generally been left out in most formulæ of the kind, but he did not think that the amount of water passing the propeller must be proportional to the thrust. That was not deduced from the formula ; it was an old-fashioned deduction from other formulæ.

Mr J. G. Johnstone B. Sc. (Associate Member) said there had not been much published information on this subject, and the little that had been disclosed dealt with multiple steam turbines generally, and made no special study of the Parsons' turbine, which was acknowledged to be the most suitable type for marine purposes. Although the title in this case was "Multiple Steam Turbines," the paper itself had reference

Mr J. G. Johnstone.

entirely to the Parsons' turbine. The first part of the paper dealt with the curve of pressures during the expansion of the steam in the turbine, and it was stated that if the initial pressure and the back pressure were known that the pressure at any stage of the expansion could be derived. The author gave an equation for this pressure curve, which was derived from the simple equation of the work done, and on the assumption that equal energies were absorbed by each pair of blades. He thought that was a matter which could receive experimental verification. There was nothing, in his mind, to hinder an experimenter fitting a series of cocks along the turbine at different stages of the expansion, and by this means it would be interesting to know if the actual curve of pressures followed the law as derived by the author, and given by that equation. He did not know whether such had really been done. The author assumed that his curve was absolutely correct in the actual case of the turbine, and he made reference to this on page 157, where he said:—"The loss due to friction in a turbine can be experimentally obtained from a working turbine, if the entropy at each pressure is calculated from the wetness of the steam and the expansion line drawn in the entropy diagram." He only took the working pressure and the back pressure, and then he assumed his expansion line. That was a very important statement, and it only emphasised the necessity of knowing if the true expansion curve followed closely that given by the equation. It was well known that for efficient propulsion the number of revolutions must be kept as low as possible for the propellers, but it was desirable, on the other hand, to have the turbine working at a very high number of revolutions. In all ships at present fitted with turbines, the turbines were working under this very severe limiting condition, which caused a loss of efficiency from what there would otherwise be if they were allowed to revolve at a high rate. He had often wondered if it were possible to gear down when using large powers. It was a point for a practical engineer to consider. If the turbine could be allowed to run at a high number of revolutions, there would be a great increase in efficiency and a considerable amount of weight saved. Another interesting point lay in the application of turbines to Atlantic liners for sea service, a matter which involved several questions of importance. Would a turbine be a reliable engine in a sea-going ship, and would the pitching of the ship affect it? The rate of revolution would vary in a heavy seaway due to the motion of the vessel among waves, and this would have an effect on the efficiency of the turbine. This variation of the rate of revolution did not reduce the efficiency of an ordinary reciprocating engine very much, and he would like, therefore, to ask the author how it might affect the efficiency of the turbine? He thought it would be a greater disadvantage in the case of the turbine-propelled vessel having to slow down in rough weather. At a high number of revolutions the heavy rotating part would produce a horizontal couple in the bearings of the turbine due to the pitching of the ship. Would that couple ever be sufficient to deflect the drum or rotating part? If so, then there would be serious cause for vibration.

Professor W. H. Watkinson (Member) thought the paper was one which hardly lent itself to much discussion. It was mainly of a theoretical nature, and Mr Melencovich, unfortunately, had left out most of the explanations. Many of the deductions drawn were not self-evident, and he thought it would have been better if Mr Melencovich had expanded the paper, giving fuller explanations. In connection with the marine turbine, not only might there be vibration set up during pitching, but if there was much deflection of the turbine, then the blades would be stripped by coming into contact with the casing of the turbine, which would be a more serious matter, and the only remedy was to give great rigidity to all the parts. He considered the question of gearing down an exceedingly important one, and it would probably well repay anyone to devise some suitable reducing gear, which would have a reasonably high efficiency, in order that the revolutions per minute might be increased, and the weight and size of the turbine diminished.

Mr E. HALL-BROWN (Vice-President) said it would be remembered that when the paper was read on the de Laval turbine, which turbine he thought was very sensitive to any gyroscopic action, he was assured that no trouble was found even in cases where it was placed athwartships. It was a very interesting point, and he thought it was well worth investigating, and it was as well that it should be considered.

Professor WATKINSON—In connection with the de Laval turbine, the shaft was of very small diameter relatively to its length between the bearings, which made it flexible, and the consequent yielding prevented great stresses coming on the bearings. That was why there was no trouble with the de Laval turbine.

Mr E. HALL-BROWN—That did not raise the point. The point was, if the disc became displaced, was there not a tendency for it to come against the nozzles? With a flexible shaft, the danger of the disc coming against the nozzles was very great if there was rapid rolling.

Professor WATKINSON—But it was not necessary to have an excessively small clearance.

Mr R. W. DICKIE said it was well known that an electric circuit might obtain through the turbine, by the vanes acting in the same way as the part of a dynamo cutting lines of force. Would not an electric current set up in this way require power, and be a source of loss in the turbine? If the pitching of a ship were taken into account, and expanded in any kind of reasonable ratio to apply to a steam turbine of the size of those that were being put on board the "Carmania," there would be a considerable action set up. The gas turbine was now receiving some attention, and if gas could be exploded in a separate chamber, and blown through the turbine the same as steam, and used as a means of driving the turbine, a great saving would be effected. Engineers had struggled for years to eliminate the boiler, and just when they came to approach that happy state the steam turbine came, and took them back to steam again with all its consequent troubles.

Mr J. B. HENDERSON, D.Sc. (Member) said that in answer to a question by Mr Johnstone regarding the gyroscopic couple acting on the rotor of the steam turbine when the vessel pitched in a sea, he had, while Mr Johnstone was speaking, calculated the value of the couple assuming certain values of the variables. In the case of a ship pitching in a sea, the couple necessary to make the turbine pitch with the ship was in the plane of the deck, and was produced by a shearing action on the holding-down bolts, the couple being in one direction as the ship's bow rose, and in the opposite direction as the bow fell. The couple was equal to the product moment of inertia of the rotor × angular velocity of the rotor × angular velocity of pitching. Taking the moment of inertia as a 5-ton mass at 2 feet radius, or 20 tons × (feet)^2, the angular velocity as 750 revolutions per minute, and the angular velocity of pitching as 10 degrees, or one-sixth of a radian in 20 seconds, or 0·0083 radians per second, the couple worked out as 0·4 tons weight × feet. For any other case the couple could be calculated from this by simple proportion.

Mr DICKIE, referring to Dr Henderson's figures for the torque set up by the gyroscopic action of the turbine, said, that, the 5 tons assumed was for a small electric turbine, and not anything like the size of those to be used on the "Carmania."

Professor ANDREW JAMIESON (Member) observed that Mr Melencovich's paper merited careful study by those interested in the science of steam turbines; more especially if read in conjunction with the excellent "Report upon the Tests made at Newcastle-on-Tyne, for the city of Elberfeld, by Messrs Lindley, Schröter, and Weber on a 1000 K.W. Steam-Turbine and Alternator," Manufactured by Messrs C. A. Parsons & Co., of Newcastle-on-Tyne. Manufacturers, designers, draughtsmen, and users of steam turbines have frequently expressed a strong desire to have some simple, reliable method of taking and rating the "Indicated Horse Powers" of these prime movers in a similar manner to that originally devised by James Watt, and still universally adopted, in the case of reciprocating steam engines. Of

Prof. Andrew Jamieson.

course, the fundamental action of the steam was the same in both cases; for a certain weight of steam was taken in at a certain pressure and temperature, and exhausted without loss of weight at a lower pressure and temperature. In doing so, a certain horse power was obtained by the transformation of heat into work per minute. Hence, in each case the following fundamental formula held good if there were no losses due to friction, radiation, convection, condensation, leakage past valves, pistons, and vanes, etc.

$$I.\text{H.P.} = \frac{\text{J}(\text{H} - h)\text{W}s.}{33,000}$$

Where $I.$H.P. = Ideal horse power.

J = Joules' equivalent (778 ft. lbs. of work per B.T.U.).

H = Heat units per lb. of dry saturated steam put into the engine per minute.

h = Heat units per lb. of exhaust and condensed steam which left the engine per minute.

Ws = Weight of steam passed through the engine per minute.

33,000 = Number of foot-pounds of work per minute in *one* horse power.

Now, how many engine makers, designers, or sea-going engineers ever applied this formula to their engines? And, what idea did it give them of the various necessary dimensions for a certain horse power? So far as he could ascertain, no engine of the reciprocating or of the turbine type had attained 65 per cent. of the power given by this formula. For example, from the Elberfeld experiments referred to by the author of the paper, the best results realised at normal full power were only about 50 per cent. of the ideal K.W. output, and about 60 per cent. of the ideal H.P. obtained by this formula The want of appreciation and practical use of this ideal equation was certainly not due to any unsurmountable difficulties in ascertaining the heat units put in and let out or exhausted; but was most probably due to the unwillingness of engineers to compare their engines with such unattainable conditions. Again, take Rankine's cycle, or preferably Macfarlane

Gray's formula, as derived therefrom, where J and W*s* have the same values as before, and τ_2, τ_1 are the absolute temperatures of the steam at the inlet and exhaust, or the condensed positions :—

$$I.H.P. = J\left\{\frac{\left(\frac{1,438 - \cdot 7\tau_2}{\tau_2} + \frac{\tau_2 - \tau_1}{\tau_2 + \tau_1}\right)(\tau_2 - \tau_1)}{33,000}\right\} Ws.$$

Here, again, it might be asked, do engineers in every day practice use this formula? The Hon. C. A. Parsons told him that he had applied it to his turbines, and that he got from 60 to 65 per cent. of the possible work done, as calculated by Macfarlane Gray's formula. He (Prof. Jamieson) had checked these results by assuming that only 12 lbs. of saturated steam per I.H.P.-hour were used, and found the efficiency under these conditions to be 60·8 per cent., when the initial pressure was 215 lbs. absolute, and the exhaust at 100° F., or ·93 lb. absolute back pressure per square inch. Of course, with superheated steam, an efficiency of 65 per cent. might easily be realised. Although the precise way in which turbines work was due to a change of momentum in the active fluid, and the reaction forces on the several blades of a Parsons' turbine was due to the rate of change of the momentum of the steam ; yet there must be a resolved force or pressure on each moving vane acting in the direction of its rotation. This turning force might be found from measuring the actual steam pressure on the faces and on the backs of the moving vanes at several of the most suitable places along the rotor of the turbine. Fig. 7 illustrated the effective pressure p_1 acting at mean effective radius r_1 on each of the vanes of one row of blades. Of course, it was to be understood, that the width of the vanes did not enter into the calculations ; and that their respective lengths only tended to alter the length of the radius at which the effective turning pressure acted upon them, as shown by Fig. 7. Take the case of a single row of vanes in a Parsons' turbine, as shown in Fig. 7, and let r_1 be the radius of action for the resolved or ascertained effective pressure p_1 on

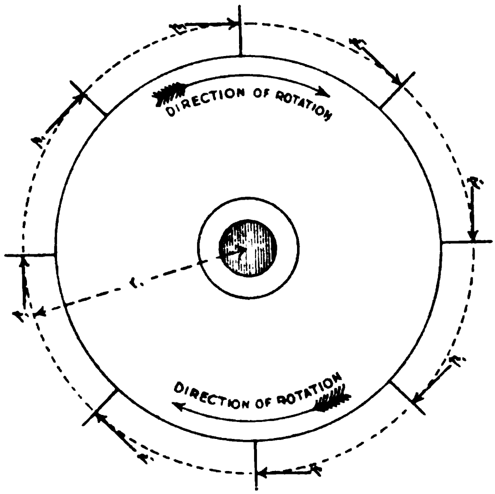


Fig. 7

a vane of that row. Then, since there are, n_{vl} vanes surrounding this row in that particular plane, it would be evident, if p_1 r_1 was the torque produced from the action of the steam on one vane, that $(p_1\ r_1\ n_{vl})$ was the total torque for the whole of that row of vanes. Hence, if the sum of the torques due to all the rows be considered in this way, the total torque would be expressed as $P \times r$ lbs. feet. Further, $2\pi r$ would be the mean effective distance through which the total force P acted in one revolution. Hence, if $L = 2\pi r$, and if the turbine made N revolutions per minute, the work done would be PLN foot-pounds per minute. Or,

$$\text{I.H.P.} = \frac{\text{PLN}}{33{,}000}.$$

COMPARISON BETWEEN THE FORMULA FOR MEASURING THE I.H.P. OF RECIPROCATING ENGINES AND STEAM TURBINES.

RECIPROCATING ENGINES.	STEAM TURBINES.
$\text{I H.P.} = \frac{PLN}{33{,}000}$.	$\text{I.H.P.} = \frac{PLN}{33{,}000}$.
Where, $P = p \times A$, or the net effective pressure (p) per sq. in. × the net effective area (A) of the piston.	Where, P = total effective pressure on all the vanes.
L = distance in feet passed through by the piston in one revolution.	$L = 2\,\pi\,r$ = distance in feet passed through by the force P in one revolution.
N = number of revolutions per minute of crankshaft.	N = number of revolutions per minute of turbine rotor shaft.

The foregoing was an attempt to solve the problem in question. He was well aware that the statical pressures obtained from the steam pressure gauges, as usually arranged and fixed at different positions along the cylinder of a turbine, did not indicate the true net pressures in the direction of rotation on the nearest moving vanes. Still there must be a means of arriving at the actual turning force on these vanes. For example, a turbine of 100 or more horse-power, might be coupled direct to a dynamo of known efficiency, or to a water-brake, when the following equation would hold good if the turbo-dynamo had, say, 80 per cent. electro-mechanical efficiency :—

$$\text{I H.P} = \text{E.H.P} \times 1{\cdot}25 = \frac{PLN}{33{,}000}.$$

Now L and N could be easily measured and observed within an error of 1 per cent., hence a good check was obtained on P, as previously estimated for a particular type of turbine. In order to ascertain whether the above method of taking the I.H.P. of steam turbines was easily applicable and accurate, experiments would have to be conducted with apparatus specially designed for the purpose, so

Prof. Andrew Jamieson.

that the weight of steam passed per minute, the effective pressures on the vanes, revolutions per minute, and the B.H.P. might be simultaneously observed.

Mr J. BLACKLOCK HENDERSON, D.Sc. (Member) observed that Professor Jamieson seemed to be under a misapprehension in his attempts to get the indicated horse power of a steam turbine. In a steam engine of any type the chief interest was in the output or brake horse power, and if the B.H.P. were easily obtained in all cases, little would be heard about the I.H.P.; at least its measurement would be confined to cases in which it was desired to determine the mechanical efficiency of the engine. (The indicator diagram had, of course, other uses than the determination of I.H.P.) The I.H.P. of a reciprocating engine was much more easily obtained than the B.H.P., and consequently the former was being continually determined in cases where it was desired to obtain some information about the latter. With steam turbines the conditions were immediately changed, the I.H.P. was no longer easily obtainable, and hence lost its interest as a measure of the B.H.P. Professor Jamieson actually went so far as to recommend the use of a standardised dynamo coupled to the turbine, in order to get some experimental data required for his formula for I.H.P. The standardised dynamo gave the B.H.P. of the turbine direct, which was what was really required in practice. Why, then, should he try to work the results back into something that was not really wanted? Experiments with a standardised dynamo could easily be plotted in curves, giving the B.H.P. as a function of the variables in the turbine, but the number of experiments required to cover all the variables would be very great, as the B.H.P. was not simply proportional to the speed, nor simply proportional to the difference of steam pressures at the two ends of the turbine. A variation of pressure of one inch in the condenser was by no means compensated by an equal variation at the high pressure end. Professor Jamieson gave a method of finding the mean effective pressure on the blades, but he was only dealing with the steam pressure at the various stages, a pressure which acted on the backs of the blades as well as on the fronts, and this so-called mean effective pressure was ineffective in producing rotation, except in so far as the pressure gradient produced the velocity of the steam. He had entirely neglected the real effective pressure—namely, that due to the change of direction of the motion of the steam, or the change of momentum. The shape of the blades was of paramount importance in considering the change of momentum, and the shape of the blades did not enter into Professor Jamieson's formula. As steam turbines became more common, the term indicated horse power and its dependant mechanical efficiency would probably be much less used in engineering language, and brake horse power and thermal efficiency more frequently spoken of.

Professor W. H. WATKINSON (Member) remarked that Professor Jamieson was mistaken in saying that "No engine of the reciprocating or the turbine type had attained 65 per cent. of the power given by the formula," $IHP = \frac{J(H-h)Ws}{33,000}$. As a matter of fact, steam engines of all types gave approximately the actual power as calculated by this formula, and not a small percentage of it, as stated by Professor Jamieson. The formula given by Professor Jamieson for the I.H.P. of turbines, in which the pressure on the vanes was one of the factors, was much more likely to mislead than to help any one dealing with the subject.

Mr JAMES MOLLISON (Member of Council) thought the meeting should feel indebted to Prof. Jamieson for having put in so simple a form a method of arriving at the horse power of turbine machinery, especially as it followed so closely the familiar lines used for determining the horse power of reciprocating engines. He could assure the meeting that the question was one which exercised the minds of a good many engineers now engaged in the manufacture of turbine machinery, and the formula which Professor Jamieson had put upon the board appeared to him to be worthy of consideration, whether it was mathematically correct or not.

Reply to Discussion.

Mr Melencovich, in reply, hoped that the following remarks would make quite clear to Mr Hamilton what was meant by the expression "gradually." If a pound of steam at, say, 100 lbs. pressure per square inch were exhausted or expanded through a properly shaped nozzle to condenser pressure, then the energy made available by this drop in pressure or temperature would be contained in the steam in the form of kinetic energy, and would be sufficient to give it a velocity of about three-quarters of a mile per second. If this velocity of the fluid were absorbed in one turbine wheel, the bucket speed ought to be about one-half of the fluid speed. Owing, however to friction and other considerations, the bucket speed might only be one-third of the fluid speed. Therefore, one-fourth of a mile per second would represent more nearly the necessary bucket speed, which, for a diameter of wheel of about 10 or 12 inches, would exceed 23,000 revolutions per minute, so that gearing of, say, 1:10 would have to be employed if a dynamo or other machine had to be driven. Should, however, direct coupling be desired, then the revolutions of the turbine wheel, as well as the bucket speed, must necessarily be only one-tenth of the former. The steam speed must also be reduced in the same proportion if anything like the former efficiency were expected, and the energy transmitted to the wheel, also the drop in temperature of the steam, would be only $\frac{1}{100}$ of the former. For this reason the pound of steam, after passing the wheel, still contained $\frac{99}{100}$ of the total energy available, which could be absorbed in 99 other following wheels. The first case, with gearing, was that of a de Laval turbine; the second, without gearing, a multiple action turbine. In the latter, the temperature and pressure of the steam would drop gradually, thus accelerating the steam, the kinetic energy of which would be absorbed in passing the wheels, the number of which (or number of rows of vanes) increased in inverse proportion to the square of the speed of vanes when the same efficiency was expected. Mathematically expressed, $z = \frac{\text{constant}}{u^2}$ for constant efficiency. With respect to

Mr Melencovich.

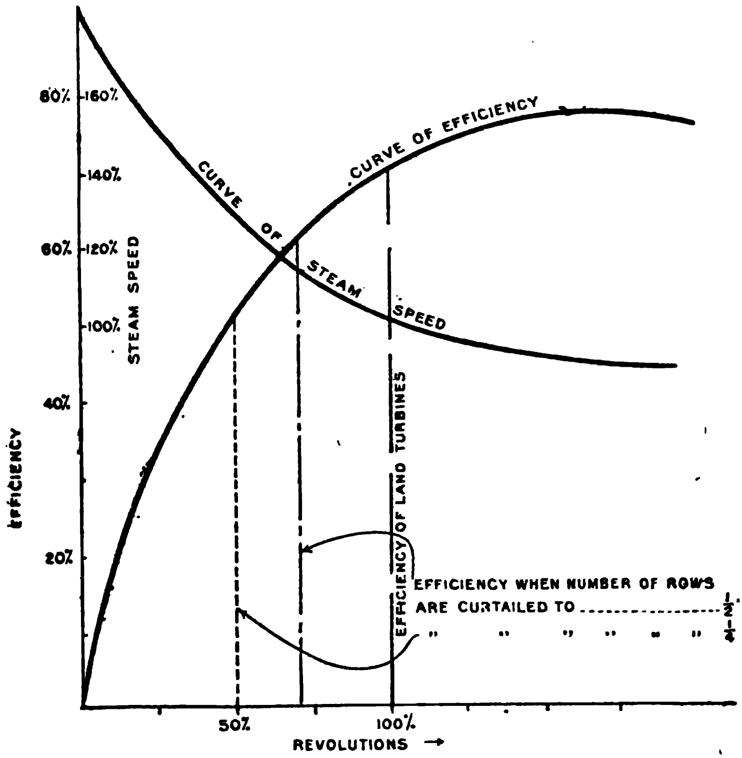
M. Normand's formula, if Mr Hamilton transformed it to $\frac{1}{j}r^{\frac{3}{4}}\text{S}\,\text{D}^2=\frac{\text{I.H.P.}}{\text{S}}$, and noticed that $\frac{1}{j}$ and r were constants, and, according to M. Normand, that $\frac{\text{I.H.P.}}{\text{S}}$ was proportional to thrust, also that SD^2 was proportional to the water passing through the propeller; then the formula became:—

Constant × water passing through the propeller = thrust.

M. Normand regarded $\frac{1}{j}$ as proportional to the acceleration of the water, and pointed out that $\frac{1}{j}$ must be kept below a certain limit if discontinuous motion of the water and considerable drop in efficiency or cavitation were to be avoided. As $\frac{1}{j}$ and also r could not be increased beyond a certain limit, and as this limit had been reached already, and in some cases had been overstepped, it was quite clear from M. Normand's papers that the water passing the propeller must vary as the thrust. Professor Watkinson thought a high number of revolutions desirable, and he fully agreed with him, as the weight of a multiple turbine was almost independent of the I.H.P., and dependent mainly on the revolutions and on the working pressure. The weight varied inversely as the square, or rather the 2·5 power, of the revolutions. This dependence of the weight on the revolutions explained why only in fast steamers the turbine showed advantages and economy in weight. An arrangement of one H.P., one I.P., and one L.P. turbine in a vessel with three shafts would, according to theory, give an economy in weight as compared with the use of one H.P. and two L P. turbines. Mr Parsons, although certain difficulties were experienced in equalising the revolutions, had accepted this arrangement of H.P., I.P., and L.P. in his design where weight was of primary importance. Mr Johnstone expected that the revolutions of a turbine would vary in a seaway. According to accurate German experiments, this was really the case. Mr Johnstone asked how the

Mr Melenoovich.

efficiency would be affected by such a change in revolutions? This question was a most important one, and perhaps the cardinal point in turbine design. That the efficiency varied with the revolutions, as a parabola in a Pelton wheel—the simplest of turbines—would be familiar to most of the Members. Theory showed that for a multiple turbine this curve became hyperbolic, as shown in Fig. 8, and experiments so far confirmed this. He might be allowed to explain here why he thought the efficiency curve in Fig. 8 of such importance. As mentioned before,



CURVES OF EFFICIENCY & STEAM SPEEDS WITH VARYING REVOLUTIONS.

Fig. 8.

$z = \frac{\text{constant}}{u^2}$ for equal efficiencies, but marine turbines, with their necessary low revolutions, would get far too cumbrous and heavy if designed for the maximum efficiency. They might be considered as having for their number of rows of vanes insufficient bucket speed, and the curve in Fig. 8 enabled one to estimate how this affected the efficiency. A turbine efficiency of 70 per cent. might be considered as the best attained by land turbines. If the number of rows of vanes of such a turbine were curtailed to from a half to a quarter, this would correspond to running with from 0·71 to 0·5 of the designed revolutions, thus giving an efficiency of from 60 per cent. to 50 per cent. This would be without taking into account leakage losses and mechanical efficiency. Professor Jamieson took the I.H.P. of a turbine to be proportional to the bucket speed or the revolutions, and proportional to the force acting upon the vanes. There was, however, the difficulty that the force p could not practically be measured. Certainly, the I.H P. of a turbine could be calculated by estimating the efficiency and amount of passing fluid by means of the curves shown in Fig. 8. This method, however, required to be checked by accurate measurements with brakes or torsion dynamometers. Already two prominent firms had developed instruments which gave satisfactory results.

On the motion of the CHAIRMAN, Mr Melencovich was awarded a vote of thanks for his paper.

Correspondence.

Mr RANKIN KENNEDY (Member) thought that the gyroscopic effect in vessels fitted with turbines was not generally understood. A flood of light on this interesting subject was to be found in a paper contributed to the Institution of Naval Architects on 24th March, 1904. A study of this paper would show that there was very little resistance presented by a gyroscope to the oscillation of its axis, if the frame carrying the fly-wheel were fixed. The author of the paper, Herr Otto Schlick, showed how, by gyroscopic

Mr Rankin Kennedy.

effect, to moderate the rolling of a vessel; but to obtain any effect the axis of the gyroscope must have two motions at right angles to each other, and with a phase difference of 90°. This, however, did not occur in a vessel with a turbine fixed rigidly, hence there was no effect. Neither was there any electric current generated in turbines. There might be an electro-motive force set up, but there was no current, as there was no closed circuit for it to flow in. Several gas turbines had been tried on the plan suggested by Mr Dickie, but the chief difficulty met with had been in the compression of the gaseous charge before ignition, as no efficient compressor had been found for the purpose. The best results hitherto obtained had been got by a turbine using the exhaust of an internal combustion engine, which, as was well known, had a high pressure as well as a high temperature.

Mr F. J. Rowan (Member) felt that the great difference between considerations affecting the action of the steam turbine and the compound reciprocating steam engine, was found in the fact that whereas in the reciprocating engine the different steam pressures made available in the various cylinders were demonstrated by means of indicator diagrams, in the turbine as yet no such demonstration had been accomplished, and, as in Mr Melencovich's paper, the pressures acting on the different rows of vanes had to be *assumed*, along with some other elements of the action. He agreed with Mr Johnstone that it was possible by experiment to arrive at a demonstration of the actual curve of expansion in the case of steam acting on several rows of vanes successively, and it was advisable that this should be done in order to arrive at a sure foundation for their subsequent deductions. On the basis of the elements assumed by Mr Melencovich, on page 151 of his paper, the results deduced by calculation were unquestionable, but it was the necessity of having to start from such a basis of assumed elements that emphasised the need for analytical experiments. A writer in "Engineering" of January 13th and February 3rd, 1905, had investigated the theory of the action of turbines from the point of view of the utilisation of the heat of the steam in them, Mr F. J. Rowan.

and he had given a much more detailed calculation than that of Mr Melencovich, although he also had to assume a gradual drop in temperature between the different stages of the turbine. There was, however, friction (including bearing, bucket, guide-plate and disc friction) to be considered, by which "some of the heat theoretically available for producing mechanical work was degraded back from that form of energy into heat," and also a varying degree of dryness of the steam, which would interfere with a regular gradation in the drop of temperature, or subdivision of the energy. Fan action seemed further to exert an influence upon the result, and both bucket form and bucket speed reacted upon the velocity of the steam. So that if Mr Melencovich could follow up his excellent paper by making and giving the results of some analytical experiments, he would greatly increase their obligation to him for elucidating this very interesting subject.

Reply to Correspondence.

In reply to the written communications, M. Melencovich said that a curve of pressures taken along the rows of a Schultz turbine was given in Prof. Stodola's work on "Steam Turbines." Although the working and back pressures in this turbine were different, the curve clearly showed the same character as the calculated curve in the paper. As far as he knew, no pressures were assumed to act upon the rows of vanes. The only assumption made in developing equation 3, which gave the pressures along the rows of vanes, was $p.v^{1 \cdot 1}$=constant, thus allowing for converting the energy back into heat. Further, the power was chosen equally distributed along the rows of vanes, but at the bottom of page 156 was indicated how the curve of pressures for any other distribution of power might be obtained. It must be kept in mind that to each distribution of power along the rows of vanes corresponded a certain curve of pressures, and a certain arrangement of length of blade. Once the theory of the multiple steam turbine was properly understood, it was quite easy to take into account the converting back of energy into heat, also the

Mr Melencovich.

varying dryness of steam, by using the entropy diagram. A splendid example of this was given in the book before mentioned. How the bucket speed and form affected the velocity of steam could be ascertained from the diagram of speeds.

METHODS OF ESTIMATING THE STRENGTH OF SHIPS.

By Dr J. Bruhn (Member).

SEE PLATES VII., VIII., AND IX.

Read 21st February, 1905.

An entirely satisfactory method of dealing with the strength of ships ought to provide means for the proper determination of the principal stresses on all the essential parts of the structure. If a ship strains at some vital place, the broad effect is the same, viz., the lessening of the efficiency of the structure, whether the straining be due to longitudinal bending, shearing, panting of frames, bending of the plating between the frames, or to any other cause. One of the aims of this paper is, therefore, to draw attention to the desirability of employing, as far as practicable, equally efficient methods in the determination of the strength of all the essential parts of the structure; and the word method should here be taken in its widest sense, so as to cover not only mathematical processes but any arrangement whatever, whereby the necessary strength is in actual practice determined from the facts derived from experience. In some instances the methods adopted may be simple, while in others they may involve the use of complex formulæ, and are termed scientific. The difference is really only one of degree. If a point can be decided correctly by a simple method, then that method is as scientific as one which involves the use of higher mathematics; but, unfortunately, it may be necessary to resort to the more cumbersome methods for an equally satisfactory solution of other problems. Some method or other of estimating the strength must necessarily be adopted if ships are to be built to the best of our knowledge independently of the fact that pretty and exact mathematical solutions may not be at hand. It is, further, evident that the strength must bear some relation to the dimensions, construction, and general arrangement of the vessel. It is this relation which it is desirable to establish correctly, but if that cannot be done at present, it is desirable to adopt approximate methods until more satisfactory ones are provided. A method ought, therefore, not to be condemned when it is not correct, but only when a better one can be substituted.

In the physical, chemical, and astronomical sciences, the adoption of some theory has often been found advantageous in furthering the progress of the particular branch of science to which it was applicable; and sometimes that has been so, even though the theory has on further investigation been found to be fundamentally wrong. The mere adoption of such a theory involves the employment of systematic methods in dealing with the problems, and that in itself is of considerable value, where a large field of problems is waiting to be attacked. In all branches of physical science an important step forward is marked by the introduction of methods of measurements, whereby it becomes possible to deal quantitatively with the forces under consideration. In fact, until such methods have been introduced, it is impossible to deal rationally with any problems involving the practical application of the science in question. Engineering forms no exception to this rule. It was only after the introduction of methods of measuring lengths, capacities, weights, etc., that progress could be made in the practical application of logical reasoning to ordinary engineering problems. In many such questions it is, however, still impossible to deal quantitatively with some of the elements involved, such as the complex forces sometimes acting on a structure, or the still more complex straining actions produced by these forces. In such instances it may be advantageous to adopt some simple hypothesis which makes quantitative estimates possible. Such a hypothesis may supply groundwork for a system whereby the forces and strains on a structure can be dealt with, and the various detached results derived from experience brought together and compared. As time goes on improvements will naturally be made in the methods, but it is useless to wait for perfect solutions to be found cut and dried, ready for use. From the nature of the problems, a considerable part of the desired information cannot be discovered, but must be gained gradually by the accumulated evidence of experience, and it is impossible to assimilate the results thus obtained without some method or other, whereby definite knowledge can gradually be evolved. Another object of this paper is, therefore, to draw attention to the advantages of adopting systematic methods in dealing with the strength of ships. It is not the adoption of any particular method that is recommended. Some particular ones will be put forward, but they should be looked upon more as a basis for discussion than anything else. The entire problem is one that can only be dealt with by an exchange of opinion. Many points of the proposed methods are not new, and are only included to make the outline of the suggested system more complete.

When iron ships first began to be built they were constructed very much in the same manner as wooden vessels. It was not to be expected that the different nature and capabilities of the new material should at once be fully appreciated. The first iron vessels were, therefore, necessarily built tentatively, and left to prove themselves strong enough or otherwise as the case might be. Generally speaking, the tendency was to make the scantlings in excess of what was required. The thickness of the shell plating was very large compared with the frame spacing, and the frame girders were also heavy. This, no doubt, was due to the weak appearance of the very small absolute dimensions of the material compared with those previously seen in wood ships. In the general arrangement of the material, the previous practice was also followed pretty closely. The thickest part of the shell plating was at first applied at the middle of the side where the wales were previously. Fore and aft stringers were worked on the inside of the frames, and it is even said that in some instances diagonal tie plates were fitted to the frames. Gradually the different nature of the material, and the possibilities of obtaining more efficient attachments than were possible in wood, were realised, and the method of construction was slowly modified to suit the changed conditions, not without some aid from the experience of bridge builders. There is, however, no doubt that all traces of wood shipbuilding practice have not yet entirely disappeared from the present practice of steel shipbuilding. As time went on, experience proved that here and there in the structure of iron or steel ships the strength was insufficient under certain conditions, and additions were made, and now and again, by accident or design, the strength was reduced and still found sufficient. Structures were in that way evolved for ordinary sea-going vessels which were capable of resisting certain forces without showing signs of weakness; *i e.*, roughly speaking, the ships were able to do their work under ordinary severe conditions as to loading, rolling, and behaviour at sea, but to what extent unnecessary material was present it was impossible to say. In dealing with the strength of ships, there is, therefore, this absolute sound, although limited, foundation to start from, that certain vessels with certain scantlings have not shown any signs of weakness during ordinary severe tests. That at once immensely narrows the problem of the determination of the necessary strength of a ship, considered from the practical side of the question, because it is known that, whatever the magnitudes of the forces acting on ships may be, they cannot be greater than those which would permanently strain the material that has been found unstrained. It is well to bear this fact in mind, as it prevents an exaggerated view being taken of the magnitudes of these forces. The aim of our methods is to make it possible to apply the experience gained by existing or past structures to improvements in new ones. In many problems of strength comparison, it is unnecessary to know the magnitude of the forces acting, because. whatever they be, they will be the same in both cases, and can therefore be eliminated.

In other instances, some knowledge of these forces is, however, essential. From an exact mathematical point of view, the correct estimating of the forces on a ship under the most complex conditions is, of course, an impossibility, and so is, to a yet greater extent, the determination of their straining actions on the structure. An exact mathematical solution is, however, not at all essential for practical purposes; in fact, it often looks pedantic, when all the conditions on which it must be based cannot even be clearly defined, far less provided for in an exact way. What is wanted is a solution on broad lines that is correct in the essential points, and in that respect the difficulties of the problem are perhaps much overrated. The effect of many complex straining actions, which can be more or less easily imagined, and which do exist to a certain extent, is sometimes given quite undue prominence. It can in most cases be proved that, although these complex actions are present, they are so to an extent that makes them quite inessential in the practical determination of the necessary strength of the structure. A proper appreciation of the relative amount of the strains due to the various causes is really quite as valuable as a knowledge of their nature, and there can be no doubt that much attention has often been given to the latter side of the question at the expense of the former.

In commencing to deal with the question of the necessary strength of ships on the basis of the known fact that certain vessels have proved themselves strong enough under certain conditions, the first difficulty met with is the one of determining what those tests were that the structure had been submitted to. What were, in fact, the most trying conditions the vessel encountered during her existence? It is quite clear that no ship is strong enough to resist any kind of loading and any kind of blows from waves, and when a ship is spoken of as strong enough, that does not really convey any definite meaning unless the conditions under which she is strong enough are specified. It would, therefore, be highly desirable, if more definite ideas could be formed as to what are fair conditions to assume with regard to the worst combination of bad loading and bad weather. In their general nature the forces of practical importance that act on a ship are simple enough. They are the gravitation of ship and cargo, which act in a given direction; the pressure of the water, whether due to buoyancy or impacts from waves, which acts normally to the vessel; and the reactions due to the change in the motion of the ship, whether parallel or rotary, which are somewhat more complicated in their action than the two former ones, but of nothing like their importance. The forces due to gravitation and the statical pressure of the water are also easily determined quantitatively. The intensity of impact from waves, the effect of variations in the pressures due to the motions of the ship and the water, and, to a certain extent, the rolling, pitching, and heaving reactions, can only be determined by the results of experience with actual structures, or by experiments. It is somewhat surprising that so little reliable experimental information exists on this subject, considering the ease with which it could be obtained.

Strength of Plating.

The first attempts at rational estimates of the strength of ships were directed towards the determination of the stresses on a cross section, assuming the vessel to bend as a whole owing to the unequal distribution of buoyancy and support in a fore-and-aft direction, and that problem was solved, for practical purposes, many years ago, by what has become known as the girder theory. This point has since received an amount of attention somewhat out of proportion to its relative importance. When the strength of a ship has been mentioned, it has nearly always been that required to resist longitudinal bending which has been referred to. When calculated stresses have been mentioned, they have been those on a cross section. It is not entirely satisfactory that it should be so, because it is, after all, very little use having a ship, that will not bend in a certain direction, if she is weak in other respects. In fact, it is not entirely free from being somewhat irrational when considerable pains are taken in dealing with one particular point in connection with the strength of a ship, while the others are left to look after themselves. The influence of the undue importance attached to the fore-and-aft bending has en responsible for a good deal of misunderstanding, such, for instance, as the idea that the plating near the neutral axis, or at the ends of the vessel, could be of any thickness, as there was assumed to be no stress at these places.

The most logical way of dealing with the strength of a ship would appear to be to commence with the parts that are essential in all floating structures. An outside shell is necessary in all ships, and the determination of its necessary strength ought to be the first problem to be faced. The outside plating being left practically unstiffened between the frame girders, the fundamental problem resolves itself into the determination of the thickness, which will give sufficient strength to resist deformation between the points of support. The plating may not have to resist other forces, but it must always be able to resist the normal pressure of the water, and, in the first instance, all other possible forces may therefore be ignored. The pressure on the plating of a ship, whatever its cause, will be resisted partly by the bending and partly by the stretching of the plating. The load will cause the plating to deflect between its supports. This deflection will, however, at once cause a direct tension to be set up in the plating, as the deflected plate is longer than the straight one. If the plating was bent only (in one direction), the determination of the stresses would be simple enough, and if stretched only (in one direction) it would be equally so. It is the combination of the two straining actions that complicates the problem, as it makes it indeterminable by the ordinary statical methods, seeing that the load might be carried entirely by either one or the other of the straining actions.

To begin with, let it be assumed that the plating is unsupported between the frames, and receives no support from side stringers or keelsons. Under those conditions the following formulæ, which are explained in the Appendix, determine the stresses with an approximation which will probably be found to be sufficiently exact for most practical purposes as long as the stress is below the limit of elasticity :—

Let E be the modulus of elasticity for direct tension,

d the draught of water in feet,

μ the ratio of the distance between the frames and the thickness of the plating,

q the direct tension on the plating,

p the tension due to the bending of the plate at the frame, and

$q+p$, therefore, the total stress on the plating. Then,

$$q = \left[\sqrt[3]{\frac{1872}{10^8} d\mu E^{\frac{1}{2}} + \sqrt{\left(\frac{1872}{10^8} d\mu E^{\frac{1}{2}}\right)^2 + \left(\frac{1 \cdot 4417\, E}{\mu^2}\right)^3 \frac{1}{27}}} + \sqrt[3]{\frac{1872}{10^8} d\mu E^{\frac{1}{2}} - \sqrt{\left(\frac{1872}{10^8} d\mu E^{\frac{1}{2}}\right)^2 + \left(\frac{1 \cdot 4417\, E}{\mu^2}\right)^3 \frac{1}{27}}}\right]^2$$

and

$$p = \frac{9904}{10^8} d\, \mu^2 - 2 \cdot 2056\, q^{\frac{3}{2}} \frac{\mu}{E^{\frac{1}{2}}}$$

Assuming E to be 15,000 tons per square inch, these formulæ are reduced to the following:—

$$q = \left[\sqrt[3]{\frac{2292}{10^6} d\, \mu + \sqrt{\left(\frac{2292}{10^6} d\, \mu\right)^2 + \frac{3746 \times 10^8}{\mu^6}}} + \sqrt[3]{\frac{2292}{10^6} d\, \mu - \sqrt{\left(\frac{2292}{10^6} d\, \mu\right)^2 + \frac{3746 \times 10^8}{\mu^6}}}\right]^2$$

and

$$p = \frac{9904}{10^8} d\, \mu^2 = \frac{1801}{10^5} q^{\frac{3}{2}} \mu$$

In applying these formulæ to the determination of the stresses on the plating of any actual vessel, it will be evident that the virtual length of spans of unsupported plating will be somewhere between the distance from heel to heel of frame, and the distance from heel to toe of flange. It is, therefore, most satisfactory to employ the mean of these two distances in obtaining the ratio of span to thickness of plating, or in other words, the frame spacing minus half the width of the shell flange of the frames.

The quantity d is the depth of water in feet which produces the given pressure, but it need not necessarily represent draught in still water. $d' + d''$ might thus be substituted for d, where

d' is the draught in still water, and

d'' is an equivalent measure of the pressure due to other causes, such as the rise and fall of the level of water agitated by waves, or to shocks from striking seas.

The quantity d' can always be determined, but d'' is one of those quantities that cannot, in the nature of things, be found by calculations. It will depend entirely on the character of the waves, and, to a certain extent, on the size of the vessel. In smooth waters it will be zero, and it will increase with the roughness of the waters that the vessel has to frequent. The quantity d'', therefore, varies with the locality of the ship's voyages, and, as far as the frame spacing is concerned, it is the only factor affected in that way. It should not be impossible to arrive by experience or experiments, or by both combined, at some fair average values for this quantity for certain specified localities. Be the determination ever so rough, it would make a more satisfactory method possible than can be attempted without this information.

If there are side stringers and keelsons fitted and attached to the shell plating, then they will support the plating in the same way as the frames do. The shell of a ship may, therefore, be divided up into what is practically rectangular spaces of unsupported plating.

Let t be the thickness of the plating,

l the spacing of the frames,

b the spacing of the stringers or keelsons, and

δ the deflection of the plating at the centre of one of the rectangular spaces.

If the plating deflected by bending between the frames independently of the stringers, then, if d_1 is the pressure per unit area and c a constant,

$$\delta_1 = c\frac{d_1\, b\, l^4}{b\, t^3}$$

If the plating bent between the stringers independently of the frames for a pressure of d_2 per unit area, then :—

$$\delta_2 = c\,\frac{d_2\, l\, b^4}{l\, t^3}$$

$$\text{If } \delta_1 = \delta_2, \text{ then } \frac{d_1}{d_2} = \frac{b^4}{l^4};$$

or, for the same deflection, the ratio between the loads carried will be in the inverse ratio of the fourth power of the respective spans. It is clear that in reality the plating cannot thus deflect independently in two directions at the same time, but the error in assuming that the ratio of the loads carried at a given deflection is the same as when the plating deflects independently, is probably not great. At any rate, the greater part of the load will be transferred to the long sides of the rectangular spaces, and the less to the shorter sides in some such ratio, and until a more satisfactory and equally simple method is devised, there would appear to be no reason why this ratio between the respective loads carried to the two pairs of sides should not be accepted as sufficiently near the truth for present purposes.

Let d be the entire pressure per unit area,

d_1 and d_2 are then the respective shares of the load taken by the frames and stringers. From

$$d_1 + d_2 = d \text{ and } \frac{d_1}{d_2} = \left(\frac{b}{l}\right)^4,$$

are obtained :—

$$d_1 = \frac{d}{1+\left(\frac{l}{b}\right)^4} \text{ and } d_2 = \frac{d}{1+\left(\frac{b}{l}\right)^4}$$

A glance at these two expressions shows that, when the spacings of the stiffening girders of the two systems are equal, then the shares carried are equal, but where the spacing of the girders of one system is greater than that of the other, nearly the whole of the load is carried to the system having the smaller spacing. In most merchant vessels the frames or floors will therefore take the larger share of the load on the shell plating. When d_1 and d_2 have been determined they can of course be used in lieu of d in the above expressions for the stresses q and p due to tension and bending respectively. As the relations between the stress, pressure of water, and ratio of unsupported span of plating to thickness are not directly apparent from these expressions for the stresses, some results are given in the Table in the Appendix for certain values of d and μ. The stresses are also shown graphically in Fig. 5. In the Table and the diagram d_1 or d_2 can be used instead of d, and it is important that this should be done in comparing, say the strength of shell plating in warships with that of merchant vessels, as the fore and aft girders will in the former instance support the plating to about the same extent as the wide spaced frames. It is, as already said, not contended that the above method of determining the strength of the shell plating of a vessel is exact, but it probably takes account of all the essential factors, and within the limits of elasticity it will probably prove to be satisfactory for most practical purposes. When it is used in comparative estimates of strength, the possible error must be very small. When the limit of elasticity is reached the plating takes a permanent set between the stiffeners and it adapts itself to the conditions of pure stretching, in doing which it assumes the most efficient form for resisting the loads thrown upon it. If the load is increased sufficiently, the plating finally ruptures at a pressure many times in excess of that which was required to produce some permanent set. It is worth noting this point about the plating of a ship, whether it is in the shell or in the bulkheads, that it requires a comparatively small head of water to produce a little permanent set, but it would in most cases take a pressure equal to hundreds of feet to produce rupture. The latter eventuality can in fact never occur in a ship from a normal pressure, because the riveted attachments would always give way long before the load necessary to produce fracture could be reached. This agrees with observations as to the permanent set of tank-tops or bulkheads after some accidental increase in the pressure. The greatest normal pressure that the plating of a ship would usually be subjected to is probably due to impacts on the fore end of the bottom plating, when that part of the vessel has been lifted clear of the surface of the water and meets a rising wave with enormous force. Even under this pressure the plating does not rupture, it merely corrugates between the frames. In a paper read by Mr J. J. Woodward, U.S.N., before the American Society of Naval Architects, a very useful record is given of some tests on a bulkhead, which was submitted to water pressure. The following Table gives the comparison between results taken from that paper and the deflections and stresses worked out by the above method. The spacing of the stiffeners was 48 inches, which gives a span of 46½ inches, after deducting half the width of the flange of the stiffeners. There were no horizontal stiffeners, and the depth of the bulkhead was 23½ feet. The modulus of elasticity has been assumed to be 13,000 tons per square inch. It will be

Head of Water in Feet.	Thickness of Plating in inches.	Ratio of unsupported span to thickness.	Calculated Deflections in inches.	Recorded Deflections in inches.	Calculated Stress in Tons per sq. inch.
d	t	μ	δ		$p+q$
5·8	·245	190	·417	$\frac{7}{16}$	6·40
11·0	·245	190	·520	$\frac{5}{8}$	10·25
15·5	·305	152	·540	$\frac{5}{8}$	10·36
19·8	·305	152	·580	$\frac{5}{8}$	13·06

seen that the estimated deflections agree very closely with the recorded ones. In fact the slight differences can easily be explained by the effect of the rivet holes in the plating having been ignored. The estimated stresses are also entirely consistent with the recorded fact, that there was a permanent set of from 0 to $\frac{1}{8}$ of an inch, particularly when the ignoring of the rivet holes is again borne in mind. These experiments were chiefly carried out with a view to determining the efficiency of the stiffening of the bulkheads, and the information with regard to the plating was only obtained incidentally. It should, however, not be a very difficult matter to test the degree of approximation of the above proposed formulæ by experiments on actual plates. So far the plating has been assumed plane, as the greater part of a ship's shell will practically be when small areas are considered. Any curvature that the plating may possess will usually add to its strength against normal pressure, as long as it is either convex or concave. When the latter is the case, the stresses will be principally only direct tensional. When the curvature is convex the previous formulæ may still hold good, but the direct stresses will be compressive. When the plating has S curvature the stresses will be mainly due to bending, as such a form is inefficient for the transmission of direct stresses. For a vessel 340′ × 50′ × 28·5′ mld., of a draught of 22 feet, a frame spacing of 24 inches, and shell plating $\frac{12 \text{ to } 9}{20}$ of an inch in thickness, the direct tension on the plating due to the normal pressure of 22 feet of water is ·04 and ·18 tons per square inch amidships and at the ends respectively. The corresponding bending stresses are 2·48 and 4·47 tons per square inch, and the total stresses due to the above causes, therefore, 2·52 and 4·65 tons respectively. These stresses will, of course, be increased in agitated waters due to a virtual increase of d the head of water. The reduction in the stress towards amidships is due to the fact that other stresses may have to be allowed for at that place,

Transverse Strength.

The forces causing transverse stresses in ships are the same as those straining the plating locally and bending the vessel as a whole. As vessels are almost invariably built with transverse stiffening ribs made up of floors, frames and beams, the problem of transverse strength resolves itself into the determination of the stresses on these ringformed girders. The only essential point of difference between longitudinal and transverse bending is, that in the former case the stresses can be determined by the ordinary statical methods, whereas the stresses are indeterminate in the latter instance, *i.e.* indeterminate by the usual formulæ, but determinate by other more complex methods. Certain points in connection with the transverse strength of ships cannot be examined without the employment of methods that will admit of the entire ringformed girders of floors, frames, and beams being dealt with at the same time, in order that the mutual influence of the individual parts on each other may be allowed for. It is, for example, clear that an appreciable increase in the strength of the bottom will affect the stresses on frames and beams, and *vice versa*. An increase in the breadth of the vessel will increase the stresses on the framing, or an increase in the depth will similarly increase the stresses on the beams. Such questions can only be solved by means of methods which like that of least work, supply the necessary condition to make the stresses determinate. The employment of these methods does not imply that there is any likelihood of the estimated stresses being farther away from the actual ones than where the usual statical methods are used. It only means more labour in arriving at the results. The most important points in connection with the transverse strength can be dealt with in a much simpler manner, by considering the various parts to a certain extent independent of each other. In the following it is only proposed to deal with these points. The pressure of the water that the frames has to bear is, of course, identical with that borne by the plating, in fact the former receives the load through the latter. In still water the pressure on the side of the vessel will therefore vary as the depth below the surface. Amongst waves the pressure may be considerably increased at or near the load water line, due to impacts from striking seas. At the keel the pressure may for the present purpose reasonably be assumed to be as in still water. At some point above the water line a limit must be found beyond which striking bodies of water do not usually reach, and where the pressure will therefore be zero. From the keel to the load line the statical pressure of the water has, therefore, for seagoing vessels, to be augmented by a certain amount which it is reasonable to assume increases in intensity as the water line is approached, and which at some point vanishes. From the known strength of certain parts of ships one may roughly estimate a maximum pressure at the load line due to impacts. In practice upper deck beams have been found sufficient in scantlings when they were able to carry a load equal to about three feet of water with an ordinary factor of safety. At a higher position, bridge and awning deck beams have been found to be of sufficient strength, when they were able to carry a somewhat smaller load than the upper deck beams. From the known strength of rudder stocks which have been found not to show any signs of twisting, one can roughly estimate what the maximum impacts of striking seas might be after eliminating the pressure due to the speed of the vessel. It will be found to be about $\frac{1}{5}$ of a ton per square foot of rudder area. There are, therefore, rough limits to the pressures that can be applied to the sides of a vessel in the neighbourhood of the load line.

Let CB, Fig. 7, indicate the pressure due to a steady head of water, in which case A B is equal to the draught A C. Assuming that the pressure on the bottom remains as in still water, A B is constant and represents the entire pressure at the keel. The curve of pressures including that due to impacts, must start at B and meet the side of the vessel at some distance above the water line, let it be arbitrarily taken as an arc of a parabola touching C B at B, and A C at a distance above C equal to A C. In that case C D will be equal to $\frac{1}{4}$ A B. It is a reasonable assumption that the magnitude of the impacts which a vessel can receive from striking seas depends on the size or draught of the vessel, or that C D varies as A B, because, if the vessel is small, and the wave large, then the ship will be moved bodily with the water. A curve of pressures constructed in this way cannot claim to be entirely satisfactory, but in the absence of anything better, it may serve the purpose of establishing a somewhat fairer comparison of strength than would otherwise be possible, and it should be borne in mind that, in many problems of comparative strength, a knowledge of the exact load is entirely unnecessary, and that even a large error in the estimated pressure may not appreciably affect the comparison.

In dealing with the strength of the side framing of a ship, the double bottom, or even a single bottom with ordinarily deep floors, may be considered rigid, as its stiffness is immense compared with that of the framing. Where a deck or a complete tier of beams is fitted, another practically rigid point may be assumed if there is a deck above. Both the point L at the bilge, Fig. 7, and the point E at the lower deck, are practically rigidly fixed as regards translation either sideways or upwards, in all vessels having bulkheads. In assuming them to be also rigid as regards alterations in the direction of the girders, no serious error is introduced as long as the arrangement of bottom and decks is similar in the vessels compared. If a load is moderately evenly distributed, the bending moments due to it will be practically as if the same load was distributed quite uniformly over the length of the girder. In the following processes the bending moments have therefore been calculated as if the loads were thus uniformly distributed. Fig. 7 represents a section of a vessel having no web frames or wide spaced beams. Let the distance between two bulkheads be l. The total load on the sides of the vessel between L and E and between the bulkheads is, therefore, equal to the area L E F M multiplied by l. This load is partly transmitted by the framing to the decks and bottom, and partly by the stringers to the bulkheads. If the stringers alone acted, there would usually be a very large deflection owing to their great length. If the frames alone acted, there would usually be a much smaller deflection owing to their lesser length. As both sets of girders are firmly connected together, they must deflect together. For a given deflection it is reasonable to assume that the load carried by each set of girders is in proportion to that which would give the actual deflection for the particular set of girders.

Let W be the total load in tons,

d be equal to L E,

a and b the parts borne respectively by the frames and stringers, and

δ the deflection. Then :—

$$\delta = c\frac{a\,d^3}{I_f} = c\frac{b\,l^3}{I_s}$$

Where I_f and I_s are the moments of inertia in inches [4] of all the frames and all the stringers respectively in the hold considered, including, of course, the shell plating, and c is a constant. Therefore :—

$$a + b = \text{W tons, and } \frac{a}{b} = \frac{I_f\,l^3}{I_s\,d^3} = \text{say } n.$$

$$\text{Hence } a = \frac{n}{n+1}\text{ W tons, and } b = \frac{1}{n+1}\text{ W tons.}$$

The part of the load carried by each set of girders is thus determined, and the stress on each set can be estimated in the ordinary way :—

Let r be the frame spacing in feet, and

i_f the moment of inertia of one frame in inches [4]. Then :—

$$\text{Stress on framing} = \frac{\left(\frac{n}{n+1}\right)\left(\frac{\text{LEFM}}{35}\right) r\,d}{\left(\frac{i}{y}\right)_f}\text{ tons per sq. inch}$$

$$\text{Stress on bottom stringer} = \frac{\left(\frac{1}{n+1}\right)\left(\frac{\text{JGHK}}{35}\right) l^2}{\frac{1}{2}\left(\frac{I}{y}\right)_s}\text{ tons per sq. in.}$$

A proper amount of plating should always be included in the estimate of the moment of resistance both for frames and stringers. With ordinary lengths of holds it will be found that the part of the load carried by the stringers is infinitesimal. It is only when the length of hold approaches the depth of hold that the stringers take an appreciable part of the load, as in the case of oil vessels and deep tanks. For ordinary vessels, the frames may be assumed to take the entire load where the stringers in the hold are not supported by beams or web frames. Let the 340 feet vessel, taken as an example, be fitted with deep framing below a middle deck, as shown in Fig. 7, in a hold 60 feet long. The ratio n then works out at 480, or only $\frac{1}{480}$ of the load is borne by the stringers. The stress on the framing, calculated in the above manner, is 3·67 tons per square inch amidships, assuming the depth d or L E to be taken from the last rivet in the floor bracket to the lowest rivet in the beam knee, and the bending moment being equal to that of the load L E F M, distributed uniformly over the length of the unsupported frame. At the ends of the vessel the stress will be increased very considerably according to the amount of sheer given to the vessel.

In a hold with web frames, as shown in Fig. 8, the ratio between the loads carried by the framing including the webs and the stringers respectively, may be determined as above in the case of deep framing. The moment of inertia of all the frames, including the web frames, and the moment of inertia of the stringers, must be estimated as before. Therefore, again :—

$$a = \frac{n}{n+1} \text{W tons, and } b = \frac{1}{n+1} \text{W tons.}$$

As with deep framing, the greater part of the load will be carried by the web frames to the deck and bottom, and the smaller by the stringers to the bulkheads, except where the length of hold approaches the depth. The total load on the side of the vessel is $\frac{(\text{L E F M})}{35} l$. The part carried by the webs and frames in bending between L and E is :—

$$\frac{n}{n+1} \cdot \frac{(\text{LEFM})}{35} l \text{ tons.}$$

The part carried by the stringers in bending between the bulkheads is :—

$$\frac{1}{n+1} \cdot \frac{(\text{JGHK})}{35} l \text{ tons.}$$

The remainder of the load on the stringers, or the part that is carried through the stringers to the web frames, is :—

$$\frac{n}{n+1} \cdot \frac{(\text{JGHK})}{35} l_1 \text{ tons,}$$

where l_1 is the spacing of the webs in feet. This latter part of the load has to be transmitted from stringer to stringer by ordinary frames bending between these supports. The load carried by the ordinary frames at the lower span is therefore :—

$$\frac{n}{n+1} \cdot \frac{(\text{L}_1\text{NOM}_1)}{35} l \text{ tons.}$$

The bending moment on the web frames, including the frames, is :—

$$\frac{n}{n+1} \cdot \frac{(\text{LEFM})}{35} l\, d \text{ inch tons,}$$

when d is the depth LE.

The bending moment on the stringers is :—

$$\frac{1}{n+1} \cdot \frac{(\text{JGHK})}{35} l^2 + \frac{n}{n+1} \cdot \frac{(\text{JGHK})}{35} l_1^2 \text{ inch tons.}$$

The bending moment on the ordinary frames between the stringers is :—

$$\frac{1}{n+1} \cdot \frac{(\text{L}_1\text{EFM}_1)}{35} l\, d + \frac{n}{n+1} \frac{(\text{L}_1\text{NOM}_1)}{35} l\, d_1.$$

Where d_1 is equal to LN. If r is the distance between the frames in feet, then the bending moment on one frame is :—

$$\frac{1}{n+1} \cdot \frac{(\text{L}_1\text{EFM}_1)}{35} r\, d + \frac{n}{n+1} \cdot \frac{(\text{L}_1\text{NOM}_1)}{35} r\, d_1 \text{ inch tons.}$$

Let $I_{w\&f}$ and I_s be the moments of inertia in inches[4] of the webs and frames, and of the stringers respectively, and let i_f be the moment of inertia of one ordinary frame. Then :—

$$\text{Stress on webs} = \frac{\frac{n}{n+1} \cdot \frac{(\text{LEFM})}{35} ld}{\left(\text{I}/y\right)_{w\&f}} \text{ tons per square inch.}$$

$$\text{Stress on stringers} = \frac{\frac{1}{n+1} \cdot \frac{(\text{JGHK})}{35} l^2 + \frac{n}{n+1} \cdot \frac{(\text{JGHK})}{35} l_1^2}{\left(\text{I}/y\right)_s} \text{ tons per square inch.}$$

$$\text{Stress on frames} = \frac{\frac{1}{n+1} \cdot \frac{(\text{L}_1\text{EFM}_1)}{35} r\,d + \frac{n}{n+1} \cdot \frac{(\text{L}_1\text{NOM}_1)}{35} r\,d_1}{\left(i/y\right)_f} \text{ tons per sq. in.}$$

Let the 340 feet vessel have web frames, stringers, and frames, as shown by Fig. 8, in a hold 60 feet long. The ratio n is, under these circumstances, 287, and the stresses are 4·65, 1·74, and 1·04 tons per square inch on the webs, stringers, and frames respectively, the depths d and d_1 being taken amidships. At the ends of the vessel the stresses on the web frames and on the frames will again be increased according to the amount of sheer given to the vessel.

Where wide spaced beams are fitted, they may be considered as forming rigid points, as far as the framing and stringers are concerned. Although a deep-plate stringer gives a very rigid support to the frames between two wide spaced beams, it will, nevertheless, deflect to a certain extent when subjected to a load. Part of the pressure (a) will, therefore, be carried through the frames, as before, to the deck and bottom, and part (b) through the stringer to the wide spaced beams. Using the same symbols as before, then :—

$$a = \frac{n}{n+1} \text{ W tons, and } b = \frac{1}{n+1} \text{ W tons.}$$

Owing to the reduced fore-and-aft span, and the increased depth of stringer, the greater part of the load will now be transmitted through the stringers to the beams, and the smaller part through the frames to the deck and bottom. The bending moment on the deep-plate stringer, Fig. 9, is, l being the distance between the wide spaced beams:—

$$\frac{1}{n+1} \cdot \frac{(JGHK)}{35} l^2 \text{ inch tons.}$$

The load transmitted through the framing between the deck and the bottom is :—

$$\frac{n}{n+1} \cdot \frac{(LEFM)}{35} l \text{ tons.}$$

The bending moment, due to this load distributed over the length L E, is :—

$$\frac{n}{n+1} \cdot \frac{LEFM}{35} l\, d \text{ inch tons.}$$

The remainder of the load which is carried by the stringer has to be transmitted to the stringer through the frames bending between the stringer and the bottom, and between the stringer and the deck. The load carried on the frames between L and N is, therefore :—

$$\frac{1}{n+1} \cdot \frac{(LNOM)}{35} l \text{ tons}$$

The bending moment due to this load is :—

$$\frac{1}{n+1} \cdot \frac{(LNOM)}{35} l\, d_1 \text{ inch tons,}$$

d_1 being the distance from the top of floor brackets to the deep stringer. The total bending moment at L is, therefore :—

$$\frac{n}{n+1} \cdot \frac{(LEFM)}{35} l\, d + \frac{1}{n+1} \cdot \frac{(LNOM)}{35} l\, d_1 \text{ inch tons.}$$

Consequently if r is again the frame spacing, in feet, then :—

$$\text{Stress on framing} = \frac{\frac{n}{n+1}\cdot\frac{(\text{LEFM})}{35}\,r\,d + \frac{1}{n+1}\cdot\frac{(\text{LNOM})}{35}\,r\,d_1}{\left(\frac{i}{y}\right)_f}$$

$$\text{Stress on stringer} = \frac{\frac{1}{n+1}\cdot\frac{(\text{JGHK})}{35}\,l^2}{\left(\frac{I}{y}\right)_s}$$

With ordinary depth of hold stringers, the second part of the bending moment on the frames will usually be found to be the most important one. The bilge stringer may be ignored, as it will have no direct influence on the stress on the framing. In the 340-feet vessel, the value of n will now be only ·133, and the stresses will be 3·74 and 1·36 tons per square inch on the frames and stringers respectively.

In the above the framing below a middle or lower deck has been considered. In the 'tween decks the same method might be applied, but, in addition to the stresses thus determined, these parts of the frames will have to bear the bending moments thrown upon them by the upper deck beams. With an efficient distribution of material the strength of the frames in the 'tween decks should not be less than that of the upper deck beams, as it has to resist at least the same bending moment. A minimum size of frames is thus determined apart from what the pressure on the side of the vessel might require. In single deck vessels the same consideration ought to be borne in mind, as it is in such vessels of little use to have beams attached to frames of very much smaller dimensions, or *vice versa*.

The above method of estimating the strength of the side framing of a ship cannot, of course, be considered either exact or complete; but it includes probably the chief factors affecting the question, such as the depth and length of hold, the size and number of stringers, the spacing of webs and strong beams, the draught, the impacts from striking seas, and the size of the upper deck beams. The method is simple in its application, and where other things are similar, such as the stiffness of decks and bottoms, it probably gives results practically as near the truth as any that might be obtained by more complicated methods. The most important element it ignores is probably the variations in the loads that may be carried by the bottom, due to changes in buoyancy and loading.

The bottom of a ship is supported along the edges by the sides of the vessel, and, at the ends of a hold, by the transverse bulkheads. The support derived from pillars will usually be small and may be ignored. If the pressure of the water on the outside is equal to the load of cargo on the inside, and the weight of the bottom is neglected, then the stresses will be simply compressive. If these forces do not balance each other, the bottom will bend between the supports, as the side of the vessel was assumed to bend between its supports. In a fore and aft direction the bottom will bend between the bulkheads, as if it were held rigidly at these points. In a transverse direction it will bend as if only supported by the sides of the vessel. If the breadth therefore is equal to the length of the hold, the greater part of the load will be transmitted to the bulkheads and the lesser to the side framing, because, for the same deflection, the load carried by a girder supported only at its ends will be only $\frac{1}{5}$ that carried by a girder held rigidly at the ends.

If W_t and W_l are the loads carried in a transverse and longitudinal direction respectively,

I_t and I_l the moments of inertia of corresponding sections of the bottom, and

l and b the length and breadth of the hold, then :—

$$\frac{W_t}{W_l} = \frac{I_t}{5\,I_l} \cdot \frac{l^3}{b^3}$$

and $W_t + W_l = W$, the total load.

The bending moments and stresses on the bottom can therefore be determined on the above assumptions. In the middle of the bottom the resultant of the stresses in the two directions should be taken. In a 60 feet hold of the vessel 340′ × 50′ × 28·5′, the ratio of $\frac{W_t}{W_l}$ is 1·38 for an ordinary double bottom, and,

$$W_t = \cdot 58\,W, \text{ and } W_l = \cdot 42\,W.$$

Let W be the pressure on the bottom due to the head of water, viz., 22 feet, and, neglecting the weight of the bottom, the fore and aft compressive stress on the inner bottom plating at the ends of the hold is 4·58 tons per square inch. The tension at the middle of the hold due to longitudinal bending is 3 tons, and that due to transverse bending is 2·29 tons, the resultant is, therefore, 3·76 tons per square inch. It is not often that a hold would be entirely empty while the vessel was at her load draught as assumed, but it may occur when the vessel is light and amongst waves, and in any case a different method of loading the bottom is easily allowed for in the estimates of the stresses. When it is only a question of comparing the strength of the bottom of one vessel with that of another, it is convenient to assume the hold empty, and probably as satisfactory as any other arrangement of loading that might be assumed.

When the loads are known the stresses on the beams, pillars, and girders under decks, can be estimated by the usual formulæ for girders and stanchions. The most uncertain factor in the estimates is the amount of the load due to falling bodies of water on the weather decks, and to reactions caused by the motion of the vessel. The higher the weather deck is above the water line the less will be the amount of water that falls on the deck. The height in connection with the locality the ship is to trade in ought, therefore, to govern the factor for the weight that may have to be borne by the weather deck beams. The rolling, pitching, and heaving reactions will depend in the first instance on the state of the sea and weather, and only in the second degree on points connected with the design of the vessel. The amount to allow for these forces ought, therefore, to depend entirely upon the locality the vessel is intended for, and it would be very desirable if some more definite information than is at present available could be established by experiments or otherwise with regard to these points.

Longitudinal Bending.

The plating and framing of a ship must under any circumstances be submitted to the principal stresses so far dealt with, even though the vessel may be at rest in still water. It is possible that there may be other stresses, such for instance as those due to longitudinal bending of the vessel as a whole. This action will take place, if the fore and aft distribution of weight and buoyancy does not balance at each point, and only then. In long vessels there may, in a sea-way particularly, be a considerable difference between the weight and buoyancy at the various points, and consequently the bending moments set up thereby may be very important. The usual method of estimating the effect of such actions is probably as satisfactory as can be expected. It takes account of the essential factors, such as the variation in the fore and aft distribution of the weight and buoyancy, the moment of inertia of the cross section, and to a certain extent of the locality of the waters frequented in so far as that may be included in the height of wave assumed in the calculations. It would, however, also here be advantageous if the method could be standardized somewhat. As it is, the bare statement that there is such and such a stress on the gunwale of a ship conveys very little meaning, unless all the particulars are stated with regard to the method of calculating it. In the moment of inertia calculation, it would be desirable to include only all continuous steel material, and to make no correction in the moment of inertia itself due to rivet holes, as that would imply a jumping up and down of the neutral axis at and between the frames; an impossible state of affairs. The usual method of assuming the height of the wave to be in a constant ratio to the length, is also not so satisfactory as it might be, as the larger the waves are the less their relative height is likely to be. To assume a height equal to the square root of the length would probably be a fairer method of determining this factor for ordinary sea-going vessels, *i.e.*, fairer in the comparison between the stresses on short and long vessels. The height of the wave in proportion to its length ought, however, to be governed also by the locality, and here again it would be desirable if some more definite information could be established as to the relative heights of waves in the open ocean and in the more or less closed-in spaces of the sea, such as channels, estuaries, etc.

The ordinary method of calculating the shearing stresses, due to the uneven distribution of weight and buoyancy in a fore-and-aft direction, is probably also as satisfactory as need be under present conditions. Although the entire question of the longitudinal bending of the vessel as a whole may thus be said to be solved, it is not so in an exact sense any more than the problems of the strength of the plating between the frames and the strength of the frames themselves can be said to have been solved. In respect to the determination of the forces producing the straining, all these problems are in the same state of exactness, or inexactness, as it is the identical forces that produce the local transverse and longitudinal straining, whether they be due to static or dynamic causes. The distribution of the bending moments and shearing forces can be determined by ordinary statical methods in the case of the fore-and-aft bending of the structure. The distribution of the bending moments on the framing can only be found by employing methods other than the usual statical ones, but that in itself does not imply any greater probability of discrepancies between the actual and the calculated stresses. At the discontinuities in the transverse girders all the conditions, on which the estimates of the stresses are based, are upset, and elements of uncertainty are introduced; but it is exactly the same at the discontinuities in the longitudinal strength as at the ends of the bridges, at deck openings, or at doors in the side of the vessel. The ordinary method of dealing with longitudinal stresses neglects one important factor, viz., the distance between the frames and beams, and between the longitudinal girders when the plating is in compression. It is evident that plating of the same thickness will yield at greatly different amounts of compressive stresses according as the spacing of the local stiffeners is, say two feet or four feet. A comparison, however rough, which takes account of this fact, is, therefore, better than one that neglects it. Until a better method is suggested, the usual pillar formula may conveniently be adapted for this purpose.

Let p be the calculated direct compressive stress,

p_1 the total stress,

l the distance between the frames or beams, and

t the thickness of the plating, then :—

$$p_1 = p\left(1 + \left(\frac{l}{t}\right)^2 \frac{1}{3000}\right).$$

Let b be the distance between the longitudinal girders. If it be assumed that the bulging, which necessarily takes place in the plating under compression, is distributed to the local supports at right angles to each other in the same ratio as the bulging due to normal pressure, then :—

$$p_1 = p\left(1 + \frac{1}{3000}\,\frac{\left(\frac{l}{t}\right)^2}{1 + \left(\frac{l}{b}\right)^4}\right).$$

In this way a rough account is taken in a simple manner of the important effect of frame, beam, and girder spacing, on the compressive stresses due to the longitudinal bending of the structure as a whole. It is not to be understood that the above formula really indicates the exact conditions. The stress need not actually be increased where the plating has the greatest tendency to bend, and it may even be less there than elsewhere, but at some point the stress will be increased in some such ratio as indicated by the formula, where the spacing of the girders is increased.

It is an important question to decide how far it is necessary to combine the various estimated stresses on the plating, framing, and structure as a whole, in order to obtain a proper resultant stress for comparison. Generally speaking the maximum stress on the plating itself will be in the bottom, and the maximum stress on the framing in the side of the vessel. Moreover, the stress on the plating due to the bending of the frames is not very great, and is usually at right angles to the local stress on the plating. The strength of the framing may therefore be considered as practically independent of the stress on the shell plating. The stress due to the longitudinal bending, although not affecting the transverse stress materially, may have to be added to the local stress on the bottom plating. The tension due to the normal pressure of the water will exist mainly in the plating between the longitudinal girders, and it must be balanced by the corresponding amount of compression on the fore and aft girders themselves and on the neighbouring plating. If, therefore, the stresses due to the main structural bending are superimposed upon the local ones, then it will be seen that when the former are compressive, they will add to the latter in the regions of the longitudinal girders, but when they are tensional they will add to the local stress on the shell plating between the girders.

Conclusions.

The making of comparative strength calculations is not entirely satisfactory, as long as the comparison is confined to one particular point, such as the necessity of having sufficient material to resist the effect of giving a vessel great length. It is desirable as far as possible to give equal attention to all equally important points of the structure. It would appear most natural to deal first with the strength of the shell plating itself, then with that of the transverse framing, including beams, etc., and finally to consider the additions that may be necessary on account of the length of the vessel. The methods that can be adopted for the estimating of the strength of the shell plating itself and of the framing, give results probably as near the truth as those arrived at by the usual method of estimating the effect of the longitudinal bending of the vessel as a whole. The employment of such a general method of comparison, even though it may be defective in detail, would be desirable in itself, as it affords a basis whereby the results gained by experience can be compared, and whereby it may be possible to gradually assign more definite values to the effects of rolling, pitching, and heaving reactions, impacts from striking seas, height of waves, etc. The fact that the stresses due to the main or essential straining actions are often very high proves that, the effect of other and complex actions must often be much overrated. Although the problems cannot be solved with scientific exactness, the methods available are probably satisfactory for the present requirements of practice, and have not at any rate so far been used to their full advantage. Experimental investigations are, nevertheless, very desirable, particularly with a view to determine the forces that act on a vessel in a sea-way more exactly than is possible by the rough results gained by experience where structures have broken down. The tendency to adopt special types of vessels for ordinary work, or ordinary vessels for special trades, must in future make it more and more desirable to improve the methods of strength comparison, in order that they may be efficiently employed in deciding whether ships under the changed conditions require more or less strength than the previous vessels with which experience was gained. It will, on the other hand, require considerable improvements in construction and considerable changes in the present uncertain methods of distributing the cargo in a ship, before scientific exactness becomes necessary in the practical methods employed in arriving at the required strength. Under any circumstances better results are likely to be obtained by using the imperfect methods at hand than by waiting for perfect ones to be discovered.

APPENDIX.

Let Fig. 1 represent a plate of thickness t, breadth b, unsupported length l, and loaded with a uniform pressure of w per unit area of plate. If the ends of the plate are resting freely on the supports at A and B, then the maximum stress will be at the middle of the free span. Call this stress p, then :—

$$p = \frac{3}{4} w \left(\frac{l}{t}\right)^2.$$

If the ends of the plate are rigidly prevented from inclining, but are free to slide horizontally, then the maximum stress will be at the ends of the span, and :—

$$p = \frac{1}{2} w \left(\frac{l}{t}\right)^2.$$

As the loads here dealt with are mainly due to water pressure, it is convenient to modify this formula by substituting the depth of water d for w. The ratio $\frac{l}{t}$ may also be designated by μ, then :—

$$p = \frac{99}{10^6} d \mu^2 \qquad - \quad - \quad - \qquad \text{I.}$$

where d is measured in feet and p in tons per square inch.

If the ends of the plate are free to incline, but are rigidly prevented from moving in a horizontal direction, then the plate will still be able to support a load, but there can, as in the first case, be no bending moment at the ends of the plate. Let it be assumed that the plate is very thin or very flexible. It will then, under a distributed load, assume the form of a suspended chain, as indicated by Fig. 2, and the load it carries will be supported by the direct tension on the plate. Let this tension across the middle of the plate be T, the breadth of the plate b, and let y be the amount of depression of the centre below a point on the plate at a horizontal distance x from the centre, then :—

$$T \times y = \frac{w\, b\, x^2}{2}.$$

Which shows that the curve assumed by the plate is a parabola. Let δ be the depression when $x = \frac{l}{2}$, then :—

$$T\,\delta = \frac{w\,b\,l^2}{8}.$$

This formula enables one to determine the tension across the middle of the plate when the depression is known. At the ends of the span the tensions will be somewhat greater, owing to the slope of the curve assumed by the plate. As the deflections dealt with here will be very small compared with the span, and the curve of the depressed plate therefore very flat, it may be assumed that the tension is uniform over the length of the plate without introducing any material error in the results obtained. Let q be the tension per square inch of sectional area, then :—

$$q\,b\,t\,\delta = \frac{w\,b\,l^2}{8},$$

$$\text{or } \delta = \frac{w\,l^2}{8\,t\,q}.$$

In being loaded the plate deflects from the original line, A B to the curved one, A C B, which is longer than the straight line, A B. The plate must, therefore, stretch during this operation. The greater the stretch, the greater the tension will be, and the plate will elongate until the moment of the tension at the centre about B is sufficient to balance the moment of the load.

The length s of a parabolic curve from the apex to the point considered is approximately given by the following formula, viz. :—

$$s = x + \frac{2\,y^2}{3x},$$

where x is the abscissa, and y the ordinate of the point, say N, Fig. 2, and the axis of the parabola is parallel to the ordinates.

When $x = \frac{l}{2}$, and $y = \delta$, then :—

$$s = \frac{l}{2} + \frac{4\,\delta^2}{3\,l},$$

$$\text{or } 2\,s = l + \frac{8\,\delta^2}{3\,l}.$$

The difference between the lengths of the curve $2s$ and l represents the elongation e of the plate, and it is seen that,

$$e = \frac{8\,\delta^2}{3\,l}.$$

Within the limits of elasticity of the material of the plate, if E is the modulus of elasticity, then :—

$$q = \mathrm{E} \times \frac{e}{l},$$

$$\text{Hence} \quad q = \mathrm{E}\,\frac{8\,\delta^2}{3\,l^2}.$$

Substituting the value found for δ, then :—

$$q = \mathrm{E} \times \left(\frac{w\,l^2}{8\,t\,q}\right)^2 \cdot \frac{8}{3\,l^2} = \mathrm{E}\,\frac{w^2\,l^2}{24\,t^2\,q^2},$$

$$\text{or} \quad q = \sqrt[3]{\frac{\mathrm{E}\,w^2\,l^2}{24\,t^2}}.$$

In this expression it is again convenient to substitute d, the depth of water in feet, for w, and μ for $\frac{l}{t}$, when

$$q = \sqrt[3]{\frac{\mathrm{E}}{35^2 \times 12^4 \times 24}\,d^2\,\mu^2},$$

where q and E are measured in tons per square inch. E does not vary greatly for ordinary structural steel, and the cube root of E varies to a still less extent. Let the value of E be 15,000 tons per square inch, and the above equation becomes

$$q = \sqrt[3]{\frac{d^2\,\mu^2}{41{,}000}} \quad - \quad - \quad - \quad \text{II.}$$

By the use of this formula it is possible to determine the stresses on the plate within the limits of elasticity of the material, assuming it simply to stretch without offering any resistance to bending, which will practically be the case when μ is large, *i.e.*, when the span is large in proportion to the thickness of the plate. Formula I., giving the stress when bending alone takes place, will be nearly correct even beyond the limits of elasticity. It is not so, however, with Formula II., because, when the limit of elasticity is exceeded, the stretch for a given addition to the tension becomes much greater than before, and the stress q is no longer equal to $\text{E} \times \frac{e}{l}$. In the ordinary stress and strain diagram for a material, the formula

$$q = \text{E}\,\frac{e}{l},$$

implies that the strains vary as the stresses, or that the curve of strains is a straight line up to the limit of elasticity. Beyond this point the strains become greater for a given increase of stress, and the curve of strains commences to bend away from the straight line. The bent part of the curve may roughly be assumed to be part of a parabola, in which case

$$q = c\sqrt{\frac{e}{l}} + c_1,$$

where c and c_1 are constants. Let the breaking strength of the material be 30 tons per square inch, the limit of elasticity 15 tons per square inch, and the modulus of elasticity 15,000 tons per square inch. The elongation at the limit of elasticity is then $\frac{1}{1000}$, and consequently,

$$15 = c\sqrt{\frac{1}{1000}} + c_1,$$

The maximum elongation of ordinary mild steel, just before local extension takes place, may roughly be taken to be $\frac{14}{100}$, then :—

$$30 = c\sqrt{\frac{14}{100}} + c_1.$$

From the above two expressions $c = 43$ and $c_1 = 13{\cdot}8$. The formula for the strain beyond the limit of elasticity is therefore :—

$$q = 43 \sqrt{\frac{e}{l}} + 13{\cdot}8.$$

The assumption that the strain curve is a common parabola beyond the limit of elasticity may or may not be quite correct, but this part of the curve is not in any case of a very definite character, its form depending largely on the time and other elements. If the exact relation between the strain and stress is known for any particular kind of material, then the above equation can be modified accordingly. For ordinary steel, the values at the principal points of interest, viz., at the limit of elasticity, and at the breaking point, do not vary greatly from those assumed.

As before :—

$$\frac{e}{l} = \frac{8\,\delta^2}{3\,l^2},$$

Whence,

$$q = 43 \frac{\delta}{l} \sqrt{\frac{8}{3}} + 13{\cdot}8,$$

$$= 70 \frac{\delta}{l} + 13{\cdot}8.$$

It was seen that,

$$\delta = \frac{w\,l^2}{8\,t\,q}$$

and introducing, as before, d the draught for w and μ for $\frac{l}{t}$, then :—

$$q = \frac{70\,d\,\mu}{35 \times 12^2 \times 8 \times q} + 13{\cdot}8.$$

$$\text{or} \quad q = 6{\cdot}9 + \sqrt{6{\cdot}9^2 + \frac{d\,\mu}{576}} \quad - \quad - \quad \text{III.}$$

By equations II. and III. the stress on the plate can be determined from zero to the breaking limit, assuming that there is no bending moment, or that the plate behaves as a flexible chain. Equation III. must, of course, be taken to give only rough results.

indicating the nature of what takes place when the limit of elasticity is exceeded. To illustrate the difference between the results of the plate bending only and its stretching only, an example may be taken. Let μ be 100, then equations I., II., and III. become respectively,

$$q = \cdot 99\, d,\ q = \cdot 69\, d^{\frac{2}{3}}, \text{ and}$$

$$q = 6{\cdot}9 + \sqrt{6{\cdot}9^2 + \cdot 174\, d}.$$

The curves in Fig. 3 show graphically the enormous difference in the stresses due to the two kinds of straining. It will be seen that at very small loads indeed, the stress on the bent plate is less than that on the stretched plate. This state of affairs is, however, very soon reversed, and the limit of elasticity is reached, in the case of bending, at a pressure equal to 15 feet of water, whereas, when the plate is stretched this point is not reached until the pressure is equal to 100 feet of water, or 44·5 lbs. per square inch. The ultimate stress is reached for the bent plate at a pressure of twice that required to reach the limit of elasticity, or 30 feet of water; but this point is not arrived at in the case of the stretched plate until the pressure is equal to a head of water of 2,800 feet, or 1,240 lbs. per square inch, which is 28 times that required to reach the limit of elasticity. It will thus be seen that the history of the bent plate is entirely over at a comparatively small load, but the stretched plate sustains a load nearly a hundred times greater.

When the plate shown in Fig. 1 is prevented from inclining at the ends, and also from sliding horizontally, then a combination of bending and stretching will take place, when a load is applied. The exact and general determination of the stresses under these conditions involves the use of complex higher mathematical methods. An approximate formula sufficiently near the truth for most practical purposes, may, however, be determined as follows:—Let Fig. 4 represent half the span of a deflected plate fixed at the ends, and uniformly loaded. If the plate does not stretch, the curve to which the originally straight plate is deflected may be determined by the usual equation for a girder strained under these conditions. This curve is shown by the line *a*, Fig. 4. If the plate is stretched without bending, then the curve of deflection will be a parabola, as shown by the line *b*, Fig. 4. It is reasonable to assume that the form of this curve under the combined action of bending and stretching lies somewhere between the two extremes of bending without stretching and stretching without bending. The maximum deflection being the same, there will be only small differences between the deflections at other places when the curves are flat, *i.e.*, when the maximum deflection is small compared with the span. The curve *c*, Fig. 4, corresponding to the combined actions, may, therefore, without appreciable error, be assumed to have its deflections equal to the mean of those of the curves *a* and *b*. In being deflected to the line *c*, the plate must elongate an amount equal to the difference in length between the curve and the original straight line. For a parabola, as the curve *b*, it was seen that this difference in length was equal to $\frac{4\,\delta^2}{3l}$, where δ is the deflection at the centre, and l the span of the plate. The curve *a* is made up of two parts, which are practically parabolic ones, and the total length is, therefore, practically the same as that of *b*. The length of the curve *c* will be slightly less than either of the two other curves, but for small deflections such as those being dealt with, it may be taken to be equal to that of *a* and *b*. The elongation of the plate in the span l is therefore:—

$$e = \frac{8\,\delta^2}{3\,l}.$$

Let T_n be the tension on the plate. As the deflections are small, it may be assumed uniform throughout. If A is the sectional area and E the modulus of elasticity, then :—

$$T_n = E\,A\,\frac{e}{l} = E\,A\,\frac{8\,\delta^2}{3\,l^2},$$

$$\text{or} \quad \delta = \cdot 6124\,l\left(\frac{T_n}{E\,A}\right)^{\frac{1}{2}} \quad - \quad \cdot \quad - \quad \text{IV.}$$

The ordinates of the curve may now be expressed by

$$y = \cdot 6124\,\eta\, l \left(\frac{T_o}{E A}\right)^{\frac{1}{2}},$$

where η is a ratio that may be determined for a sufficient number of points on the curve, say, at 0, 1, 2, 3, and 4, Fig. 4, where the values are respectively ·0000, ·0918, ·3438, ·6856 and 1·0000, as found from the means of the ordinates of the two curves, *a* and *b*.

Let M_o be the bending moment, and

T_o the tension at the point 0, and,

let M and T be the corresponding quantities at a point having x and y for its abscissa and ordinate respectively.

Then, as the deflections are small:—

$$T = T_o \qquad \text{V.}$$

$$\text{and } M = M_o - T_o y + \frac{w b x^2}{2} = M_o - T^{\frac{3}{2}} \times \frac{\cdot 6124 \eta l}{(E A)^{\frac{1}{2}}} + \frac{w b x^2}{2} \qquad \text{VI.}$$

where w is the load per unit area, and b the breadth of the plate.

These two equations make it possible to determine the tension and bending moment at any point of the plate if the tension and bending moment at the point 0 are known.

The work done in stretching the plate is:—

$$\frac{1}{2E}\int_{-\frac{l}{2}}^{\frac{l}{2}} \frac{T^2}{A}\, d x.$$

The work done in bending the plate is:—

$$\frac{1}{2E}\int_{-\frac{l}{2}}^{\frac{l}{2}} \frac{M^2}{I}\, d x,$$

where I is the moment of inertia of a cross section of the plate. The total amount of work done in straining the plate is, therefore:—

$$W = \frac{1}{2E}\int_{-\frac{l}{2}}^{\frac{l}{2}} \frac{T^2}{A}\, d x + \frac{1}{2E}\int_{-\frac{l}{2}}^{\frac{l}{2}} \frac{M^2}{I}\, d x$$

$$=\frac{1}{2\,EA}\int_{-\frac{l}{2}}^{\frac{l}{2}} T_o^2 d\,x + \frac{1}{2EI}\int_{-\frac{l}{2}}^{\frac{l}{2}}\left(M_o - T_o^{\frac{3}{2}}\ \frac{\cdot 6124\,\eta\,l}{(E\,A)^{\frac{1}{2}}} + \frac{w\,b\,x^2}{2}\right)^2 d\,x$$

Stresses and strains will always adjust themselves in such a way that the work performed in the straining action is the least possible. The duty of supporting the load will, therefore, in the present instance be distributed between the bending and stretching actions in such a manner that the entire work done is a minimum.* In order that W may have a minimum value,

$\frac{d\,W}{dM_o} = O$, and $\frac{d\,W}{d\,T_o} = O$. Hence :—

$$\frac{d\,W}{d\,M_o} = \frac{1}{EI}\int_{-\frac{l}{2}}^{\frac{l}{2}}\left(M_o - T_o^{\frac{3}{2}}\frac{\cdot 6124\,\eta\,l}{(E\,A)^{\frac{1}{2}}} + \frac{w\,b\,x^2}{2}\right) d\,x = O\,;$$

$$\text{or,}\int_{0}^{\frac{l}{2}}\left(M_o - T^{\frac{3}{2}}\ \frac{\cdot 6124\,\eta\,l}{(E\,A)^{\frac{1}{2}}} + \frac{w\,b\,x^2}{2}\right) d\,x = O \qquad \text{VII.}$$

and

$$\frac{d\,W}{d\,T_o} = \frac{1}{EA}\int_{-\frac{l}{2}}^{\frac{l}{2}} T_o\,d\,x + \frac{1}{EI}\int_{-\frac{l}{2}}^{\frac{l}{2}}\left(M_o - T_o^{\frac{3}{2}}\ \frac{\cdot 6124\,\eta\,l}{(E\,A)^{\frac{1}{2}}} + \frac{w\,b\,x^2}{2}\right)\times$$

$$\left(-\frac{\cdot 6124\,\eta\,l}{(E\,A)^{\frac{1}{2}}}\times\frac{3}{2}T_o^{\frac{1}{2}}\right) d\,x = O.$$

$$\text{or, } T_o^{\frac{1}{2}}\,\frac{I}{A}\frac{(E\,A)^{\frac{1}{2}}}{\cdot 6124\,l}\cdot\frac{2}{3}x - \int_{0}^{\frac{l}{2}}\left(M_o - T_o^{\frac{3}{2}}\frac{\cdot 6124\,\eta\,l}{(E\,A)^{\frac{1}{2}}} + \frac{wbx^2}{2}\right)\eta dx = O \qquad \text{VIII.}$$

*A fuller explanation of this principle will be found in the Transactions of the Institution of Naval Architects, Vol. XLIII., page 270, and Vol. XLVI., page 193.

The integration or summation required in equations VII. and VIII. may be done by Simpson's rule, as follows :—

Write down the expressions for the bending moments at each of the points 0, 1, 2, 3, and 4, Fig. 4, or instead of the moments, the variable coefficients of the unknown quantities and the constants may be used, as has been done in Table I.

For equation VII., it is only necessary to write down the coefficients representing the bending moments, to multiply by Simpson's multipliers, and add up. The totals, multiplied by one-third the interval, are the coefficients in the integrated equation, which, therefore, is :—

$$12\,M_o - 4{\cdot}7972\,T^{\frac{3}{2}}\,\frac{\cdot 6124}{(EA)^{\frac{1}{2}}} + \frac{w\,b\,l^2}{2} = O. \quad - \quad - \quad \text{IX.}$$

To integrate the second term of equation VIII., the products of the moments and Simpson's multipliers have to be multiplied by η and added up. The totals multiplied by one-third the interval, *i.e.*, $\frac{l}{24}$, are the coefficients in the integrated term. Hence :—

$$T_o^{\frac{1}{2}}\,\frac{I}{A}\,\frac{24}{l}\,\frac{(E\,A)^{\frac{1}{2}}}{\cdot 6124\,l \times 3} - 4{\cdot}7972\,M_o + \frac{3{\cdot}1503 \times \cdot 6124}{(E\,A)^{\frac{1}{2}}}\,T^{\frac{3}{2}}\,l$$

$$- \cdot 6844\frac{w\,b\,l^2}{2} = O. \quad - \quad - \quad - \quad - \quad \text{X.}$$

Eliminating M_o from equations IX. and X., the following obtained from which T_o may be determined :—

$$T_o^{\frac{3}{2}} + 17{\cdot}3000\,T^{\frac{1}{2}}\,\frac{I\,E}{l^2} - \cdot 1887\,\frac{w\,b\,l}{(E\,A)^{\frac{1}{2}}} = O \quad - \quad \text{XI.}$$

When T_o is found, M_o may be determined from equation IX. It will be found that the greatest bending moment occurs at the end of the span or at the point 4, Fig. 4. M_4 may be obtained from the following equations :—

$$M_4 = M_o - T_o^{\frac{3}{2}}\,\frac{\cdot 6124\,l}{(E\,A)^{\frac{1}{2}}} + \frac{w\,b\,l}{8}$$

$$= - \cdot 3676\,T^{\frac{3}{2}}\,\frac{l}{(E\,A)^{\frac{1}{2}}} + \cdot 0834\,w\,b\,l^2 \quad - \quad - \quad \text{XII.}$$

TABLE I.

Number of Points.	Coefficients for Moments. M	Coefficients for Moments. η	Coefficients for Moments. x	Simpson's Multipliers.	Coefficients for Products of Moments and Simpson's Multipliers. M	Coefficients for Products of Moments and Simpson's Multipliers. η	Coefficients for Products of Moments and Simpson's Multipliers. x	η	Coefficients for Products of Moments, Simpson's Multipliers and η. M	Coefficients for Products of Moments, Simpson's Multipliers and η. η	Coefficients for Products of Moments, Simpson's Multipliers and η. x
0	+ 1	− ·0000	+ ·0000	1	+ 1	− ·0000	+ ·0000	·0000	+ ·0000	− ·0000	+ ·0000
1	1	·0918	·0156	4	4	·3672	·0625	·0918	·3672	·0337	·0057
2	1	·3438	·0625	2	2	·6876	·1250	·3438	·6876	·2364	·0430
3	1	·6856	·1406	4	4	2·7424	·5625	·6856	2·7424	1·8802	·3857
4	1	1·0000	·2500	1	1	1·0000	·2500	1·0000	1·0000	1·0000	·2500
			Total,		12	− 4·7972	+ 1·0000		4·7972	− 3·1503	+ ·6844

Let p be the maximum tension due to bending,

q the tension due to direct stretching,

t the thickness of the plating, and substituting

d, the depth of water in feet, for w, then :—

$$p_4 = -2\cdot2056\, q^{\frac{3}{2}} \left(\frac{l}{t}\right) \frac{1}{E^{\frac{1}{2}}} + \frac{9904}{10^8}\, d \left(\frac{l}{t}\right)^2,$$

$$\text{and } q^{\frac{3}{2}} + 1\cdot4417 \left(\frac{t}{l}\right)^2 E\, q^{\frac{1}{2}} - \frac{3744}{10^8}\, d \left(\frac{l}{t}\right) E^{\frac{1}{2}} = 0\,;$$

or if μ be written for $\frac{l}{t}$,

$$p_4 = -2\cdot2056\, q^{\frac{3}{2}} \frac{\mu}{E^{\frac{1}{2}}} + \frac{9904}{10^8}\, d\, \mu^2 \quad - \quad - \quad \text{XIII.}$$

$$\text{and } q^{\frac{3}{2}} + 1\cdot4417 \frac{E}{\mu^2} q^{\frac{1}{2}} - \frac{3744}{10^8}\, d\, \mu\, E^{\frac{1}{2}} = 0 \quad - \quad \text{XIV.}$$

Solving the last equation :—

$$q = \left(\sqrt[3]{\frac{1872}{10^8}\, d\, \mu\, E^{\frac{1}{2}} + \sqrt{\left(\frac{1872}{10^8}\, d\, \mu\, E^{\frac{1}{2}}\right)^2 + \left(\frac{1\cdot4417 \times E}{\mu^2}\right)^3 \frac{1}{27}}} \right.$$

$$\left. + \sqrt[3]{\frac{1872}{10^8}\, d\, \mu\, E^{\frac{1}{2}} - \sqrt{\left(\frac{1872}{10^8}\, d\, \mu\, E^{\frac{1}{2}}\right)^2 + \left(\frac{1\cdot4417 \times E}{\mu^2}\right)^3 \frac{1}{27}}} \right)^2 \quad - \quad \text{XV.}$$

Equations XV. and XIII. make it possible under the given conditions to determine the stress on the plating when the load, the ratio of span to thickness, and the modulus of elasticity are known. Although the modulus of elasticity enters into the formulæ, a modification in its value does not materially affect the magnitude of the stresses. A glance at equation IV. will, however, show that the modulus of elasticity has a considerable influence on the deflections. From equation xv. it will be found that when μ is very large the term containing μ^6 will be very small, and the expression for q will practically approach that given in equation II. When μ is small, the term containing μ^6 will be the predominant one, and it will easily be seen that q will then be very small. When d is small the term not containing it will become the important one, and q will again be small. When d is large the expression for q will again approach that given in equation II. In other words, the direct tension on the plating will be relatively small when the load is small and when the span is small, and it will be relatively large when the reverse is the case. From equation XIII. it will be seen that the last term of the expression for p_4 is the bending stress, when there is no stretching, and the first term represents the reduction in the bending stress due to the direct tension taking part of the load. As the expressions for the stresses are somewhat complex, and the influence of the various factors not easily grasped by direct inspection, certain values have been assumed for the variables, and the corresponding values for the stresses determined and recorded in Table II. The values assumed for the draught d, and the ratio of span to thickness μ, will cover nearly all cases met with in ordinary merchant shipbuilding practice. The results have been worked out by a slide rule. They are also shown graphically in Fig. 5.

Fig. 6 shows the stresses due to combined bending and stretching in relation to those due either to independent bending or independent stretching under the same conditions as represented in Fig. 3. It should be borne in mind that the formulæ for the stresses due to combined actions only hold good within the limits of elasticity. When this point is reached permanent set will take place, and the plate will rapidly approach the conditions due to stretching only, or the curve c, Fig. 6, will approach that of b, and the plate will finally rupture at the large load approximately given by equation III.

From the expression for the deflection given by equation IV., q may be determined, as

$$\delta = \cdot 6124\, l \left(\frac{q}{E}\right)^{\frac{1}{4}},$$

$$\text{or, } q^{\frac{1}{4}} = \frac{\delta\, E^{\frac{1}{4}}}{\cdot 6124\, l}.$$

If the reduction in the bending stress in equation XIII., due to the direct tension, is equal to this tension, then the total stress due to combined bending and stretching is equal to the stress due to independent bending. Under those conditions,

$$2{\cdot}2056\, q^{\frac{3}{4}} \cdot \frac{\mu}{E^{\frac{1}{4}}} = q,$$

$$\text{or, } q^{\frac{1}{4}} = \frac{E^{\frac{1}{4}}}{2{\cdot}2056\, \mu} = \frac{E^{\frac{1}{4}} \times t}{2{\cdot}2056 l}.$$

Comparing this with the above expression for $q^{\frac{1}{4}}$ it is seen that

$$\frac{\delta}{t} = \frac{\cdot 6124}{2{\cdot}2056} = \cdot 277.$$

When, therefore, the ratio of the deflection to the thickness of the plating is less than ·277, then the stress due to combined bending and stretching is greater than that due to independent bending. If this ratio is greater than ·277, then there will be a reduction in the stress, if the plating can be subjected to direct tension as well as bending.

The degree of accuracy of the above formulæ depends on the extent to which the assumed deflected curve of the plating departs from the exact actual form of the strained plating. As the deflection is in actual practice always very small compared with the span, the curve of the plating must be very flat, and any slight difference in its character will not greatly influence the estimated results. The degree of accuracy of the formulæ might be tested experimentally by submitting plates to normal pressures, but there are some difficulties in the way of insuring sufficiently rigid attachments for a plate strained in this fashion.

TABLE II.

Stresses in tons per square inch.
E = 15,000 tons per square inch.

	d in feet.					μ
	8	16	24	32	40	
q p $q+p$	·00 ·71 ·71	·01 1·42 1·43	·03 2.14 2·17	·04 2·85 2·89	·05 3·55 3·60	30
q p $q+p$	·02 1·27 1·29	·06 2·55 2·61	·11 3·77 3·88	·19 5·01 5·20	·27 6·25 6·52	40
q p $q+p$	·08 1·96 2·04	·26 3·83 4·09	·46 5·67 6·13	·67 7·41 8·08	·92 9·11 10·03	50
q p $q+p$	·20 2·74 2·94	·61 5·16 5·77	1·00 7·42 8·42	1·40 9·56 10·96	2·00 11·00 13·00	60
q p $q+p$	·41 3·55 3·96	1·04 6·47 7·51	1·63 9·02 10·65	2·35 10·98 13·33	3·04 12·56 15·60	70
q p $q+p$	·67 4·26 4·93	1·50 7·80 9·30	2·37 9·94 12·31	3·20 11·95 15·15	4·05 13·65 17·70	80
q p $q+p$	·95 4·90 5·85	2·00 8·25 10·25	3·02 10·65 13·67	4·05 12·45 16·50	4·90 14·50 19·40	90
q p $q+p$	1·19 5·58 6·77	2·50 8·72 11·22	3·69 11·00 14·69	4·85 13·00 17·85	5·70 15·30 21·00	100

Discussion.

Mr J. Foster King (Member) confessed his inability to grasp the exact standpoint from which the author meant the paper to be viewed, an inability which was probably caused in some measure by the difficulty of dissociating one's impressions from those made by the author's previous utterances on similar subjects. He did not see clearly whether Dr Bruhn meant his suggestions to be discussed as definite methods of arriving at correct sizes, or as merely comparative methods which would enable one who knew that a certain thing was strong enough, to provide another similar thing equally strong under somewhat different conditions. If the former, it would mean a prolonged and probably unappreciated controversy, into which he did not propose to enter. If the latter, it might be said that they seemed a little like academic elaborations of methods in ordinary use. They had learned to regard Dr Bruhn as a leading exponent of the higher mathematical methods of investigating transverse and other strains in ships, and they now found him treating the higher mathematics with something like mild contempt. He took the liberty of congratulating Dr Bruhn upon taking up a more useful line of thought, and of reminding him that when discussing his earlier papers on transverse strength, he emphasised the failure of previous mathematical investigations; and the failure which he thought must attend any attempt to obtain quantitative results from integrations, of which the chief claim for regard seemed to be the largeness of the number of assumptions which formed their basis. He would like to draw attention to Dr Bruhn's statement that "no ship was strong enough to resist any kind of loading, and any kind of blows from waves," a statement which contained a somewhat dangerous doctrine if taken too literally. Was it not the duty of naval architects to endeavour to construct ships with hulls strong enough in their vital parts to resist any kind of loading or any kind of blows from the seas such as they were ever likely to meet, so long as they remained afloat, and those responsible for their loading were moderately sane? He ventured

Mr J. Foster King.

to say that the hulls of the classed ships built nowadays were structurally so well designed as to be fit to comply with these conditions when properly put together. He was also struck by the inferior position to which Dr Bruhn seemed desirous of relegating the question of longitudinal strength, and confessed that he did not quite see the underlying object. Everyone knew, or thought he knew, that the longitudinal stresses upon a ship were the most important, because they were by far the largest. It must, therefore, be the primary and the most important duty of the designer to provide the necessary longitudinal strength, and he did not think that too much attention was paid to longitudinal stresses in making strength comparisons, or that others were relatively neglected. As a matter of fact, the real importance of longitudinal strength had perhaps been placed too much in the background during the past few years, by the public attention paid to transverse and other stresses by Dr Bruhn himself, Professor Jenkins, Mr Read, and others. Contrary to his intention, he felt he must refer to those parts of the paper where it was stated or inferred that the stresses upon bottom plating due to water pressure might be regarded as a measure of the required thickness of shell plating, because (if he was right in his reading of the paper) the stresses due to longitudinal bending moments were said to take effect only on the bottom longitudinals and the plating immediately attached thereto. The bottom plating of a ship afloat was always subjected to water pressure, and consequently to a tendency to bend inwards, the material was necessarily under stress, and he failed to see how sound mathematical reasoning could justify the expectation that, when the ship was in a sea-way any part of the bottom plating could be relieved from the additional stresses due to its function as the most important part of the bottom member of the girder. He was strongly of opinion that the two stresses must not only be conjoined, but that in the majority of ships the longitudinal stresses, instead of being relatively inferior to those due to water pressure, formed by far the major portion of the bottom stresses. It seemed to be a little difficult for Dr Bruhn to free himself from very complicated formulæ, and in the particular instance of this matter of water pressure, very pretty equations had been given to show its probable effect on shell plating. In preparing these equations, Dr Bruhn had departed from his expressed idea that much might be done by simple methods, as his combination of the work of Mr Yates and Captain Boobnoff, which assumed that the bottom plating might be partly considered as a beam subjected to bending, and partly as a piece of material subjected to stretching, was so very long and very complicated as to be practically outside ordinary use. What was the real use of excessive refinement upon what, after all, was an approximation founded upon an assumption of molecular freedom in the structure of a solid section? The simple bending was in itself quite a safe comparative guide within reasonable limits—that was to say, if one knew the load which a certain plate had safely carried, one could tell just as well by the simple method what greater thickness would be required for a greater span or load. He would refer briefly to the suggestion, which was made more than once, that, the application of simple methods to complicated strength investigations were more or less novel. To consider the work which was known must be done by each part of a structure, and to provide a sufficient margin of strength to cover that work, together with such work as could not be estimated, was the general principle underlying all engineering design, and was not new even in ship design. After long endeavour to obtain satisfactory results from consideration of the stresses upon hull structures as a whole, he had found a process of devolution on the lines now advocated by Dr Bruhn of the utmost practical assistance, and fourteen years' experience had proved them to be reliable methods.

Mr James R. Jack (Member) said those who had to determine the scantlings of new vessels often found difficulty in deciding the proper scantlings. In the case of an ordinary cargo steamer, one did not need to trouble much, as she would be built to the rules of a classification society, and the builder had no responsibility

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beyond that of adherence to the rules ; but in the case of vessels of special type, such as high-speed cross-channel steamers, for the strength of which the builder and the designer were responsible, some method, such as shown in the paper, was essential, and he personally felt very grateful to Dr Bruhn for the information contained in his paper, and for the manner in which he had brought the subject into a form which might be readily grasped. In start ng with the strength of the shell plating, the author had certainly begun at the beginning, but it was a point on which there was a good deal of difference of opinion. He, himself, thought that the strength of plating necessary to resist water pressure had been a little over-estimated, and that the method indicated led to more thickness than was really necessary. In stating that considerable pains had been generally taken in calculating the longitudinal strength of the ship, other points of importance were left to look after themselves. He thought that Dr Bruhn was hardly fair to the ship designers, as most people who had the weight and responsibility of determining the scantlings of new vessels went further into the problem than was indicated, although in classified ships some points were left to look after themselves. For example, in some such vessels the butt connections were simply made according to a rule which had been drawn up on an abstract basis, and it was sometimes found in applying a rule to practice that the omission of some rivets made the job stronger ; but it was difficult to get permission to omit those rivets. As to the strength of plating necessary to resist shearing forces, the majority who had to deal with high-speed channel vessels considered this very carefully, and in most of the type the stress due to shearing was more important than that due to bending, and the scantling of the shell plating was practically determined by that factor. Another point of very great importance brought prominently forward was the distribution of the pressure of the water on the framing. Dr Bruhn pointed out, very rightly, where the framing was divided up into rectangular spaces, having a long and short side, that the pressure was divided up in such a manner that the long side got practically the whole of it. He thought that in vessels framed as were ordinary merchant ships, with close spaced frames and wide spaced keelsons, they ought to have less material in the keelsons. With regard to the close spacing of frames at the ends of vessels, particularly forward, from a strength point of view, it was a good thing; but in the actual building of a ship it was a nuisance, especially in laying down the vessel on the mould loft floor. If faired on the contracted system, the complication of frame spacings was very apt to lead to confusion. Another important point was raised in dealing with the deflection of the plating under pressure, but there was no notice taken of the difference as to which side was under pressure. In the case of a bulkhead, it might be on the stiffener side, or it might be on the other side. When it was on the stiffener side the bulkhead was more liable to buckle, and it corresponded in that case to the inner bottom of the vessel, where the tank was under pressure. With the shell plating the pressure was on the outside, and it was transmitted to the frames by direct contact over a large surface. On the other hand, when the pressure was on the stiffener side, it was transmitted through the rivets. The surface of contact here was small, and, therefore, the stress intensity much greater in the locality of the rivets, which might easily yield a little to it, and so more readily produce buckling. There was a sample case worked out on page 191, but the stresses seemed somewhat large. He had had occasion lately to conduct some experiments in that direction, and although, being for private purposes, he was not at liberty to publish results, had this formula held good the shell plating would have been badly buckled. There was a pressure equivalent to eight or nine times that in Dr Bruhn's case, and the ratio of the plating to frame spacing was very much the same. The framing had set badly, and was wrecked beyond all hope, while the shell plating went back when the pressure was relieved, and showed no permanent set at all, showing that the stress was nothing like so great as was indicated by the method in the

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paper. The "method of least work," that Dr Bruhn had made so particularly his own—while involving the minimum of work for the destroying forces—required anything but a minimum of work from the man who made the calculation, and the time which it required would almost prohibit its application in practice. Generally two or three proposed vessels were under consideration at one time, and one could not afford to spend so much time on a proposed vessel which might never materialise. When a contract was fixed, it was imperative that the steel orders should be immediately issued in order that the work might proceed without delay, so that any methods of calculation to be successful must conform to commercial requirements, and not involve an excessive amount of time and labour. In connection with the transverse strength, Dr Bruhn advanced a most ingenious suggestion for dealing with the effect of striking seas. In making a comparison between one ship and another, one did not profess to have absolute quantities to deal with, and endeavoured always to get a type ship which had been satisfactory, and which was as near as possible to the same dimensions of the new vessel. When such was obtainable the wave factor could be taken as common to both, and could, therefore, be ignored. He, himself, was forturate in having a pretty large range of type ships to go back upon, and, therefore, in most instances, could get a vessel somewhat near the design. Where, however, the data available did not include any close approximation, Dr Bruhn's suggestion would be well worth the slight additional work, and would enable the designer to make useful comparisons between vessels which differed considerably. On page 196, in dealing with the moment of resistance, Dr Bruhn said:—"A proper amount of plating should always be included in the estimate of the moment of resistance both for frames and stringers." He would like very much to know what Dr Bruhn considered was a right amount to use. It was a quantity that he had always been a little doubtful about himself. He believed that the whole plating from centre of frame space to centre of frame space should be included, but on that point he would value

Dr Bruhn's opinion. Dr Bruhn further said:—"With ordinary lengths of holds it will be found that the part of the load carried by the stringers is infinitesimal." He was pleased to see that Dr Bruhn had so thoroughly met that point. That statement was worthy of being printed in red letters in the Transactions of the Institution. On page 200, Dr Bruhn dealt with the stringers, and said that the bilge stringer might be ignored, as it would have no direct influence on the stress on the framing. That was, he thought, the gem of the whole paper. If ignored in the calculation, why not ignore it in the ship, and leave it out altogether? Some few had the courage of this opinion. About two years ago a friend of his had to design a very particular vessel, and had a bilge stringer in the construction. He strongly urged his friend to take it out, and put the material where it would do more good. This was done, but it was only when observations of the deflection were made and compared with those of a similar previous ship that his friend was satisfied that he had done the right thing. With regard to vessels of the ordinary type, a few months ago this same point came up, and it was arranged between the builder and the registration society that the bilge stringer should be omitted for the midship portion of the vessel's length. It was fitted at the ends of the vessel, however, for the reason pointed out by the author of the paper, viz., that owing to the sheer at the ends additional stringers were required. In dealing with longitudinal strength, the author suggested that a wave height equal to the square root of the length would be a fair method of determining the bending moment. This was the only point in the paper on which he preferred to differ from Dr Bruhn. Apart from the fact that a constant ratio had been the almost universal practice in the past, and all recorded data was based upon this, and consequently would require revision before it could be applied to the purposes of a new design. He considered that in designing a larger vessel from a previous smaller one, as was usually the case, the larger design would have a proportionally smaller bending moment, and as it was the larger vessels which most frequently

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showed signs of straining, he thought it better to retain the older method. As to being governed by locality, one could not tell that the weather which was normal in one place might be abnormal in another, and the vessel must be made to suit the worst possible condition, so that a class of vessel should have a wave proportion of her own—an Atlantic liner one proportion, a channel steamer another, and so on. Finally, Dr Bruhn asked that experimental investigation should be made, and he thought that was particularly desirable. Practical experience was a very untrustworthy guide, particularly in this regard. Two or three years ago a case had occurred with a large vessel leaking very badly at some of the rivets, and the officers in charge said that the vessel was structurally weak. What had happened was that she had got nipped in the dock gate, and there was some local damage done. In another case, a vessel had come in with her deck down, and again the officers in command said that it was entirely due to structural weakness. What had really happened was that the vessel had loaded up a cargo of locomotive engines, and they had been put into the bottom of the hold. The stevedore's men had hauled them into place by attaching tackles to the hold pillars at about the middle of their height, and instead of the locomotive engine going over to the pillar, the pillar had gone over to the locomotive engine. If practical experiments were carried out by Lloyd's Registry, or by some equally unbiassed authority, where every outside factor was eliminated, trustworthy information would be obtained, and if it were analysed and given in the manner that Dr Bruhn had given it in this paper, it would be a contribution of great value to those who were responsible for the scantlings of vessels.

Mr. J. G. Johnstone, B.Sc. (Associate Member), considered that this paper was one more for the student than for the practical man, and he would advise anyone intending to investigate this subject to first study the principle of least work (or, as it was known on the Continent, the principle of Alberto Castigliano), and its application to the determination of stresses in engineering structures. He did not see how any one could pursue the subject of transverse strength with success without having first studied this principle. The author only briefly alluded to it in the paper. On the Continent he believed civil engineers and naval architects were all pretty familiar with it, but he had never seen it treated fully in any English text-book. Investigators in the field of strength calculations had been working in the dark in so far as the results obtained were only comparative, and they were unable to say how near they were estimating the actual maximum stresses likely to come on the vessel during service. It was generally recognised that strength calculations for ships did not give an adequate idea of the actual stresses likely to come upon different parts of the structure, and, therefore, it could not be said whether the ship was just strong enough, or too strong, unless by comparison with the structure of a similar vessel. Since this paper was written there had been an important communication submitted to the Institution of Naval Architects on the results of experiments on the torpedo boat destroyer "Wolf." The importance of this communication lay in the fact that it gave a comparison between certain calculated stresses and the actual stresses that were experienced at sea, and he thought it would be of great interest in this discussion to have Dr Bruhn's opinion as to how far the ordinary methods of making standard calculations for longitudinal stresses could be relied on in estimating the probable actual stresses likely to come upon the vessel. The longitudinal stresses, he thought, were the most important. The whole subject of ship strength calculations was very interesting, and he thought this paper was of great value to the Institution.

Mr J. J. O'Neill (Member) said that Dr Bruhn had omitted to mention the fact that in the disposition of ships' scantlings too much pains had been given to the principle for finding out the stresses in the midship portion of the structure alone; whereas, the longitudinal distribution was equally important. It seemed to him that the moment of resistance should be calculated not only for the midship section, but at certain stated distances from the centre and near the ends of the vessel. He quite agreed with him that at the ends of the ship the transverse framing should be more closely spaced than amidships. If, however, warships were taken as illustrations, it appeared sufficient for the purpose to take this spacing as twice that which Lloyd's demanded, and he thought that was a point which should be further extended. Towards the ends of the ship, where the fineness of the vessel came in, closer spacing than amidships might be adopted with advantage. The point, however, he wished to emphasise, was that scantlings should be considered especially so far as the ends of the ship were concerned.

Mr C. S. Douglas, B.Sc. (Member) remarked that this paper formed one of an interesting and valuable series which Dr Bruhn had contributed to this and kindred institutions, during the past few years, on the fascinating subject of strength of ships. He much appreciated the efforts here made to systematise methods of investigating the various stresses encountered by ships. The further the strength problem was investigated, the better value would be obtained from the material built into the hulls of ships. Dr Bruhn suggested the use of various formulæ in addition, he presumed, to the common ones for comparison of tensile and shearing stresses due to simple longitudinal bending. These treated of the principal structural stresses, but there were still other stresses which complicated the problem, and with this in mind it could not be expected that other than comparative results would be got. With what were comparisons to be made? Certainly with the results obtained by similar calculations on similar types of ships that had been at sea and returned in a sound condition. Such ships had proved themselves to be strong enough, but it was not known how much too strong they were; they had margins of safety of unknown amounts for all the different stresses they had encountered. If now a vessel of the same dimensions and type, and of lighter structural construction, survived the same storms, and came back to harbour in a sound condition, that ship had earned the right to be considered the type ship for the standard of structural strength until a still lighter ship was constructed which was able to do the work as satisfactorily. Vessels which showed signs of weakness, or had reached the point of fracture through stress of weather or other matters incidental to their ordinary working, set the limit in the other direction. Dr Bruhn controlled to a great extent the rules by which the scantlings of vessels were determined when it was desired to classify a vessel in Lloyd's Register. Now, it was a well known fact that other registration societies and the Board of Trade would pass a structural design of a ship that Lloyd's Registration Society would not, on account of lighter scantlings. Yet ships built to these lighter scantlings encountered the same storms and incidental events as the vessels of heavier scantlings, and came back in a sound condition. This seemed to him to indicate that the "type" ship had an unnecessarily high margin of strength in some direction, and it might be that the analysis of the various stresses by the methods here suggested would show, what practice seemed to, that economy of material could be effected. If a uniform systematised method of dealing with strength of ships were adopted, and the various registration societies would indicate in some term of the dimensions the intensities of the various principal stresses in the several directions that they would allow designers, to work to, naval architects would have more scope for their inventive faculties in the preparation of structural designs for the building of classed ships. Dr Bruhn's investigations had supplied a uniform system of treatment necessary, and the constants could be modified, if necessary, as experimental results dictated. He concurred with Dr Bruhn in thinking that experimental investigations were very desirable, both on built structures, such as described in Dr Bruhn's valuable communication this year to the Institution of Naval Architects, and on ships, both at sea and in dry dock.

Mr JOHN WARD (Vice-President) said that Dr Bruhn's treatment of this very important subject deserved their heartiest

Mr John Ward.

thanks, both for the amount of work expended upon it and the skill which Dr Bruhn had shown in dealing with the problem. The Doctor explained that the aim of his methods was to make it possible to apply the experience gained by existing or past structures to improvements in new ones, and that what was wanted was a solution on broad lines, and correct in essential points. It was quite true that there had hitherto been a want of suitable method of approximating the strength required under various conditions, but Dr Bruhn's method, if not absolutely supplying the method called for, at least went a very long way in the right direction. In attacking the problem as he did, first at the point of contact of the ship and water, namely, shell plating, he began at the right end; and while he tended to over-estimate the effect of the water pressure, the formulæ could be used by each designer as a means of comparison between vessels which he knew and the new vessel which he was designing. The distribution of the pressure from the shell plating to the frames and keelsons was interesting, as proving mathematically what most of them had learned from practical experience, that in vessels constructed, as were merchant ships, with close spaced frames and wide spaced keelsons, the share taken by the latter was practically negligible. As the length of holds usually was much greater than their depth, keelsons might be considered to have no function beyond that of preventing the frames from tripping, and this was the obvious explanation of the fact that in recent years keelsons had been very much reduced in weight. In dealing with longitudinal bending, it was interesting to note that Dr Bruhn preferred to make no correction in the moment of inertia calculation for rivet holes. This had always been the practice for the reason which he gave. He did not endorse his suggestion to assume the height of the wave equal to the square root of the length, as he thought it would be somewhat unfair to the larger vessels. Dr Bruhn's suggestion that experimental investigations were very desirable was worthy of every support, as it was only by experiments carried out entirely under the direction and supervision of a thoroughly qualified and unbiassed observer, such as Dr Bruhn himself, that all extraneous factors could be eliminated, and different effects referred to their own particular causes. It was a matter of congratulation that talented experts, like Dr Bruhn, formed an essential part of the staffs of the various registration societies, under whose rules for scantlings, special survey, and inspection for workmanship, the vessels of the mercantile marine were principally built, and in their life's work proved both safe and seaworthy, for those who manned and owned them, in all weathers and under all conditions of service. There were many professions, in which it might be said that perfection was reached generations ago. In painting, sculpture, and architecture that held true; but in engineering and shipbuilding it was different. In these professions the problems were ever changing and expanding. Much of the success in solving these was due to men like Dr Bruhn, whose expert knowledge Members of this and kindred institutions gladly acknowledged, both in the work they did and the benefits they conferred upon their profession through the reading of papers such as the one which had just been discussed.

Dr Bruhn, in reply to Mr Foster King's remarks, observed that he certainly intended his suggestions to be discussed as definite methods of arriving at correct sizes, but he might also say that he thought the question as to whether the calculated stresses represented absolute or relative values was a little futile. The actual stress was a continually varying quantity depending on a hundred different conditions. Whether or not the estimated maximum stress, which was a fixed quantity, would agree with the actual stress depended, of course, on the extent to which the assumptions agreed with the actual conditions at the moment of consideration. At some time or other this agreement would no doubt exist, and the actual stresses would then be equal to the calculated ones; but in a general way, the figures could only be taken to be relative measures of strength. He was very careful in defining at the beginning of the paper what he meant by the word method, as it was often in this connection associated only with what were

Dr Bruhn.
called mathematical methods. The primary object of the methods employed was to establish a connection between the experience gained by a previous structure and the scantlings necessary for efficient new structures. It was possible to imagine some genius effecting this connection by intuition, and being able to lay down at sight the suitable scantlings of the new structure. The ordinary mortal must, however, have resort to the more or less cumbersome methods provided by mathematics. Mr Foster King seemed to differentiate between mathematical methods and others. There were no others except those of intuition. Mathematics was the science of dimensions and numbers, and it supplied the means, and, to ordinary people, the only means of bridging the gulf between past experience and future results. It operated like a machine in which certain figures representing facts were inserted at the one end, and in which certain other figures appeared at the opposite end representing certain new facts. This operation might in some instances be very simple, and would not be looked upon as a mathematical one, although in reality it was so, just as much as those more complex in their execution. Mr Foster King appeared to have a particularly deep-rooted objection to integrations, although even he must perform them daily in making ordinary additions, finding of sectional areas, etc. To refuse to perform these operations when they involved a little labour, and to perform them without grumbling when they happened by accident to be easily carried out, appeared a little like what the action of a bank would be if, in its accounts, it only performed the simple additions and refused to carry out the more complex calculations involved, say, in the estimating of compound interest. Wherever it was possible to adopt a simple method instead of a complex one it should certainly be done. But unfortunately this was not always possible, and he wished Mr Foster King would suggest some way out of the difficulty in such cases, because he saw no other than that of using the objectionable complex methods. There were many instances, where even the merest approximation could not be arrived at by simple processes which might give

quite correct results in other cases, owing to accidental circumstances. In one instance Mr Foster King did make a suggestion in this direction, namely, where he proposed that the plating should be dealt with from the bending point of view only. He (Dr Bruhn) failed, however, to see how the method of simple bending could be considered at all satisfactory, when the actual load carried by the plating before destruction might be more than one hundred times that indicated by the bending theory. M. Boobnoff, in the paper he read before the Institution of Naval Architects in 1902, gave exact differential equations for the equilibrium of the stresses on areas of plating of certain specific shapes, viz., rectangles and ellipses, and subjected to a uniformly distributed pressure. If Mr Foster King had studied the details of that paper, he would know that to appreciate the methods there adopted required a mathematical knowledge of a much higher order than would be necessary to be able to employ the method of least work. He (Dr Bruhn) adopted the latter in working out the proposed approximate formula on account of its general character being adapted, for instance, to variations in the distribution of the load and in the thickness of the plating, and also on account of the ease with which at least its actual operations fell in with ordinary drawing-office methods. Having established the formula for determining the thickness of the plating, it was really a very simple matter to obtain the result for any values of the span, thickness of plating, and intensity of bend. With a slide rule the operation might be performed in a couple of minutes; and, from a practical point of view, the complexity of a formula was measured by the time it took to obtain the result, and not by the number of square or cube root signs it might contain. He agreed with Mr Foster King that ships were now, on the whole, strong enough to meet the conditions they encountered. It was, however, no discredit to them that they could not be strong enough under all conceivable circumstances. They could not be so any more than a waggon could be strong enough to carry any load that might be put upon it. The loading of a ship might be controlled by those

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responsible, but the encountering of exceptional forces of nature, such as those due to abnormal waves, could not be provided against even at the expense of sacrificing the ship's primary reason for existence, namely, its commercial utility. Mr Foster King said "That the longitudinal stresses upon a ship were the most important, because they were by far the largest." He (Dr Bruhn) did not think the longitudinal stresses were always the largest. In fact, there had been many instances of straining due to transverse weakness in vessels where there was no sign of longitudinal movements in the structure, showing that in these cases the transverse stresses were certainly greater. But even if the longitudinal stresses were the greater of the two, he confessed he did not follow the logic in Mr Foster King's remark. The longitudinal and transverse materials were of the same quality, and would stand the same stress. Might not, then, the fact that the longitudinal stresses were the greater—but not too great—point to the conclusion that too much material had been applied in the transverse direction, as the smaller transverse stresses would appear to be unnecessarily low, and had therefore not received the attention they deserved. He thought an example would convince Mr Foster King that part of a structure might be relieved by the application of additional stresses. If a bent beam, or say a ship hogging, had a stress of 5 tons tension at the top, and 5 tons compression at the bottom; by the application of compressive forces at the ends of the beam or vessel sufficient to cause a uniform stress of 5 tons per square inch, the stress at the top would vanish entirely, but the stress at the bottom would, of course, be increased. He was pleased to learn from Mr Jack that most ship designers went more closely into the question of strength than was suggested in the paper. It was, however, hardly fair to the registration societies to say that in classed vessels some points had to look after themselves. Speaking for the society with which he was connected, he could only say that that was not correct. Every point received careful attention. The butt connections required had not been drawn up

on any abstract basis, but on the results derived from experience. If Mr Jack could show that a modified arrangement of rivets would result in an equally strong and otherwise efficient and watertight arrangement, it would no doubt be approved by the Committee of Lloyd's Register. He was surprised at Mr Jack's remark that, in his opinion, the shearing stresses were so high that they became the deciding factor in the determination of the thickness of the shell plating in such small vessels as channel steamers. That had not been his experience; and he thought the fact that the double or even single riveted edge laps were found to be sufficient to meet the shearing stresses, proved that the stronger plating should be more than sufficient for the same duty. He was sorry Mr Jack was unable to supply the information derived from the experiments he carried out, as it would have been useful to compare the results with those foreshadowed by the proposed calculations. The results of the American experiments mentioned, which were fully reported in the "Transactions of the Society of Naval Architects and Marine Engineers," were in entire accord with those estimated by the suggested process both with respect to deflections and stresses. With regard to the amount of shell plating to be included in the moment of inertia calculation for the framing, he always included the entire amount. It was all there, and must all take part in the bending actions. His suggestion to take the square root of the length as the height of the wave in the longitudinal strength calculations, instead of $\frac{1}{20}$ of the length, was made with a view to obtain a more correct comparison between the stresses on short and long vessels. The fact that it was usually the larger or longer vessel that gave trouble did not prove that the estimated bending moments were relatively too small for the larger ships. It might show that these vessels were relatively deficient in material. The fact, on the other hand, that smaller ships had been known to give trouble with estimated stresses of the same magnitude as those which larger vessels stood without straining, proved that the actual stresses were in such cases lower in the longer vessels than in the shorter ones. In other words, it

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was known that the stresses estimated by the present method might safely be higher in the longer vessels than in the shorter ones. The retention of the twentieth of the length as the height of the wave might be convenient in view of the recorded information, but it necessitated the retention of a standard stress, which varied according to the length of the vessel. If merchant vessels were built of the same proportions as war ships, were subdivided to the same extent by bulkheads, fitted with closer spaced longitudinal girders, and were sailed and worked under the same conditions, then no doubt their frames could be spaced the same distance apart as those of warships, as suggested by Mr O'Neill. With regard to experiments, he might say that he thought those carried out on sample structures very valuable; but those that might be carried out at sea on the complete ship would be still more useful. It was at sea that the vessel had to encounter the forces that strained her, and it was by the experience derived from work at sea that suitable scantlings were determined. Such experience must necessarily be based more or less on isolated cases of failure, as it was, and ought to be, the exception that a vessel showed actual signs of straining. Carrying out systematic experiments at sea by means of strain indicators would extend, in this connection, knowledge enormously, as information could be obtained about the magnitude of the stresses before they reached the limit of elasticity. What was wanted was—Firstly, a continuous record of the strains at the various parts of the structure; and secondly, a simultaneous record of the forces and conditions producing those strains, such as the height and length of the waves, the pressures exerted by the rising and falling waves, the effect of the impacts from falling bodies of water, the distribution of the weights, the rolling, pitching, and heaving reactions, etc. In this way parallel records would be produced of cause and effect, which would be of the utmost value in the determination of the most efficient distribution of the material. There would naturally be difficulties in the way of carrying out such experiments, particularly at the com-

mencement, but if they became more general they would lead to improvements in the construction of strain indicators, and in the methods of making the experiments, and the difficulties should then not be unsurmountable.

On the motion of the CHAIRMAN, Mr Bruhn was awarded a vote of thanks for his paper.

THE COMPOUNDING OF LOCOMOTIVE ENGINES.

By Mr John Riekie (Member).

SEE PLATES X. AND XI.

Held as read, 21st February, 1905.

"Compounding," as applied to marine and stationary engines, has been universally attended by the most successful results; but, as applied to locomotive engines, it has been accompanied by results of such a varying and conflicting nature that British engineers almost unanimously, and foreign engineers in considerable numbers, hold that the simple locomotive can and does successfully compete with the compound.

The contrast is significant, and, in the home of the marine compound and the centre of the locomotive engine industry, the author thinks that a statement of the subject should be of interest to the Members of this Institution.

In practice there are two methods of allowing for the expansion of steam, viz.:—

Simple.—The first and earliest method of attaining economy in steam consumption was in the expansion of steam by an early cut-off in the cylinders of a one-stage expansion engine, and this is still a successful method.

Compound.—The modern method of attaining economy in steam consumption is in the expansion of steam by a later cut-off in one or more high-pressure cylinders of a two-stage or multiple-expansion engine.

The author considers that the use of a "*later cut-off*" in the compound method has not been called for in non-condensing engines. By adhering to the "*early cut-off*" of the simple engine, there appears every reason for a still further economy. What follows will show the application of this deviation from the present practice of compounding locomotives, and by way of a preface a synopsis of the representative systems of expansive working in locomotives is here given.

I. The Simple System.

Fig. 1 shows the arrangement for a modern express locomotive with cylinders 20 inches in diameter by 26 inches stroke. In actual working the driver throttles the steam sufficiently to get a pressure in the steam chest, varying with the required work, and sets the cut-off from 20 to 25 per cent. of the stroke of the piston. Such is the practice to-day, and it was the same 35 years ago. In answer to the call for more power, the boiler pressure has risen from 100 or 120 lbs. to 200 lbs. per square inch, and cylinders have been increased in size, but there has been no improvement in the working.

II. Compound Systems.

(*a*) *Two-Cylinder Compound.*—Fig. 2. Primarily introduced by "Mallet" of the Bayonne and Biarritz Railway, and now principally identified with the names of "Worsdell" and "Von Borries." Comparing this system with the simple—one of the high-pressure cylinders has been taken away, and a low-pressure one substituted. This low-pressure cylinder is usually placed similarly to the high pressure in relation to the frame plates, but in the illustration it is shown inside with the high-pressure cylinder outside, as would be necessitated by the limitation of the loading gauge on British railways if cylinders of such large diameters were used.

(*b*) *Three-Cylinder Compound.*—Fig. 3. Shows the system adopted by Mr "Webb" on the London and North-Western Railway. In this system, as compared with the two-cylinder compound, the high-pressure cylinder is divided, half being placed on each side of the engine, while the low-pressure cylinder remains as in Fig. 2.

(*c*) *Three-Cylinder Compound.*—Fig. 4. Exhibited* in the Paris

* See "Engineering," December 6th, 1889.

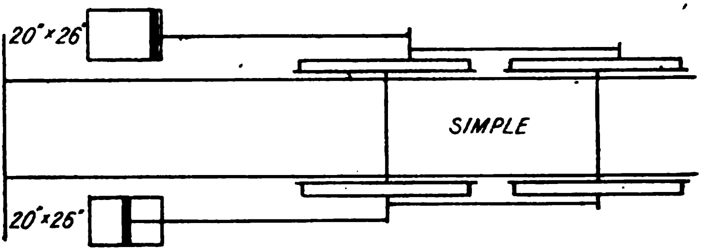

FIG. I.

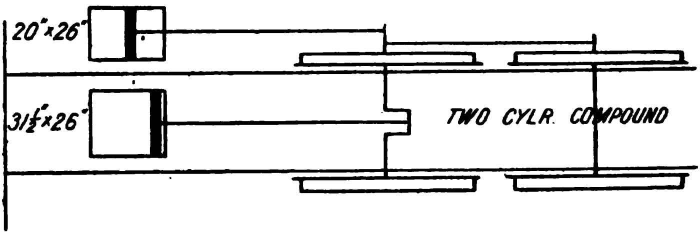

FIG. II

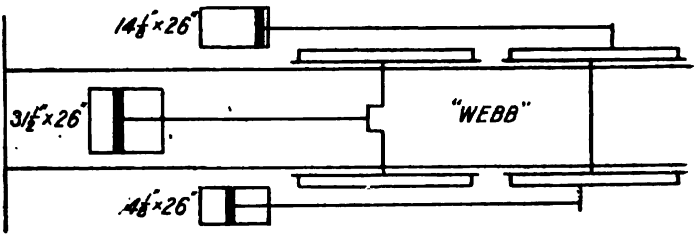

FIG. III

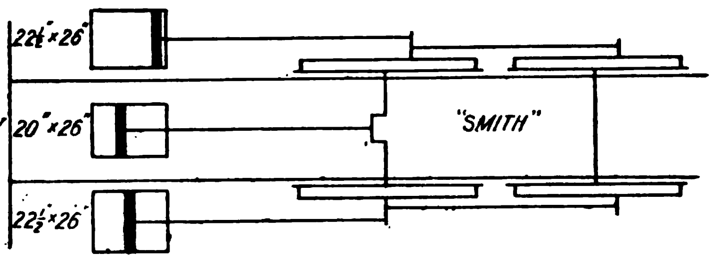

FIG. IV

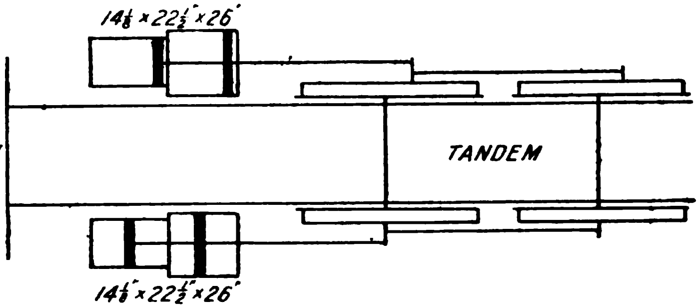

FIG. V.

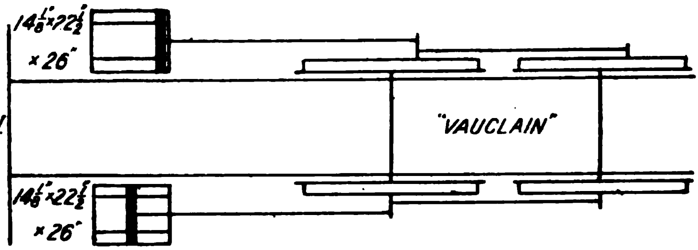

FIG. VI.

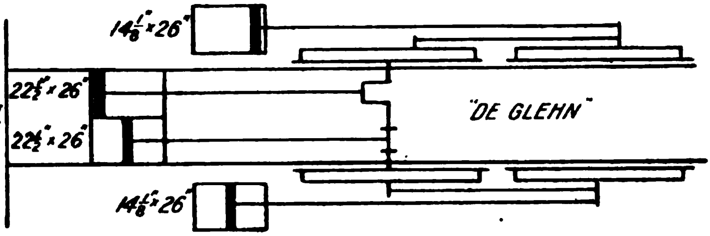

FIG. VII.

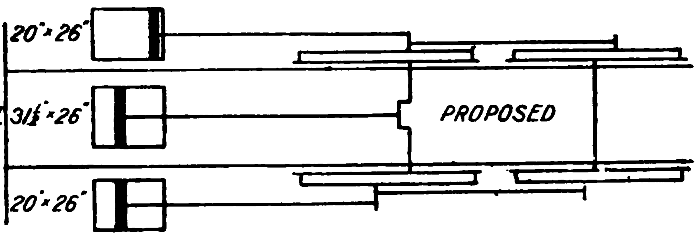

FIG. VIII.

Exhibition of 1889 by the Northern Railway of France, and now principally identified with Mr Smith's system on the Midland and North-Eastern Railways. This is the alternative method of that shown in Fig. 3—one high-pressure cylinder being, in this case, situated between the frames, the low-pressure cylinder being divided into two, one being placed on each side of the engine.

(*d*) *Four-Cylinder Tandem Compound.*—Fig. 5. Experimented with on various railways, and represents the high- and low-pressure cylinders of Fig. 2 divided, half of each being placed on each side of the engine.

(*e*) *Four-Cylinder Vauclain Compound.*—Fig. 6. Is similar to Fig. 5, except that the cylinders are superposed on one another.

(*f*) *Four-Cylinder Compound with Independent Cranks.*—Fig. 7. Latterly introduced by Mr Webb, of the London and North-Western Railway, and Mr De Glehn, in France. In this system the high- and low-pressure cylinders of Fig. 2 are divided and connected to separate cranks.

The latter three types, viz., *d*, *e*, and *f*, are, correctly speaking, duplex, or the large cylinders of Fig. 2 divided into two sets of small compound engines.

All compound engines built on these systems require starting gears, *i.e.*, they have to be arranged for temporary conversion to the simple system to enable them to start with a heavy load, or to exert a maximum effort in times of stress (say, on negotiating inclines).

Two-cylinder compound experiments, extending over many years, were made with cut-offs, earlier than 40 per cent. of the stroke of the high-pressure piston, but it was found that under the existing cylinder proportions the limits of economical working lay between 40 and 50 per cent. cut-off.

An engine of the type, illustrated by Fig. 4, was tested on heavy grades in India in 1897. A simple engine, having two cylinders each 19 inches in diameter by 26 inches stroke, had a third cylinder, also 19 inches in diameter, added, and was arranged to work either "simple" or "compound." Working compound, its tractive capability was less than that of the original simple engine. Working simple with three cylinders, the boiler failed to supply sufficient steam.

The author has further experimented with the system of three cylinder compound, shown in Fig. 8, the special features of which are as follows, viz. :—

Both high-pressure cylinders of the simple engine are retained, the diameter also remaining the same. The low-pressure cylinder added has a capacity of about 1¼ times that of the combined capacity of the two high-pressure cylinders. The pistons are connected to a three-throw crank set at angles of 120 degrees in relation to one another. There is no special starting gear. With an engine of this type, having two high-pressure cylinders 20 inches in diameter and 24 inches stroke, and one low-pressure cylinder 31½ inches in diameter by 26 inches stroke, working with a boiler pressure of 180 lbs. per square inch, and a cut-off of 25 per cent. in the high-pressure cylinders, a gross load of 900 tons was taken up a gradient of 1 in 150. The simple engine, Fig. 1, when undertaking this work, would require a cut-off of 40 per cent. of the stroke of the pistons.

Comparing this last compound with that of the simple engine, the author claims that with the same weight of steam utilized, *i.e.*, a cut-off of 25 per cent. in each case, there is an increased efficiency due to the further expansion of the steam in the third cylinder, and a further increase of efficiency due to the better distribution of power and balance by the use of the three-crank system. It may be objected that the further expansion would be more simply obtained by lengthening the stroke. This has been done on the Great Western Railway, a stroke of 30 inches having been tried, but the ordinary limitations in design are a serious obstacle to anything further being done in this way. Piston speed, etc., also have their limitations.

Comparing this three-cylinder compound system with the two-cylinder type, Fig. 2, there is, with the same weight of steam —*i.e.*, a cut-off of 25 per cent. in the two high-pressure cylinders of the former, and a 50 per cent. cut-off in the high-pressure cylinder of the latter—a gain in efficiency due to further expansion, and to the better distribution of power and balancing in the former. Also, the fluctuation of pressure in the low-pressure steam chest disappears in the three-cylinder type, the disposition of cranks at 120 degrees allowing one high-pressure cylinder to exhaust just as the low-pressure piston commences a stroke, and the other high-pressure cylinder to exhaust when the low-pressure piston has moved through 40 per cent. of the stroke, thus maintaining a constant supply to the receiver. The starting difficulties are entirely overcome as the high-pressure cylinders can be utilized to the same power as in the simple engine.

In general compound practice, the ratio of high-pressure to low-pressure volume, based on a 40 to 50 per cent. cut-off, is as 1 to 2 or 2¼. As already stated, the author adopts a ratio of 1 to 1¼, for he finds in practice that this gives an equal distribution of power on the basis of a 25 per cent. cut-off.

The admission pressure in the low-pressure cylinder is in practice never lower than the terminal pressure of the high-pressure cylinders. A condition of working with this three-cylinder system is that the low-pressure cylinder has a constant cut-off at 80 per cent. of the stroke of the piston. The author has found that with a receiver pressure as low as 10 lbs. per square inch, or even lower, there was still such force in the final exhaust as to create sufficient draught in the smoke box.

Figs. 10 and 11 show one of the methods of applying this compound system to an "Atlantic" type of express locomotive engine. This design is by Mr Charles Lake, who for many years has made a careful study of locomotive engineering practice, and who has kindly given me permission to reproduce it as an illustration for this paper.

A portable engine of 12 horse power on the system just described has been made by a well-known firm, and the brake tests for this engine are given in Fig. 12. The two high-pressure cylinders were each 7½ inches in diameter, and the low-pressure cylinders 12 inches in diameter, the stroke in each case being 14 inches. The three cylinders were in one casting, and no provision for increasing the receiver capacity was made. The tests given in Fig. 9 were taken from a three-cylinder compound locomotive engine with two high-pressure cylinders 16½ inches in diameter, and one low-pressure cylinder 26 inches in diameter, with a common stroke of 24 inches, and a working pressure in the boiler of 140 lbs. per square inch. The brake tests, however, show fairly good results, and would probably have been better with the use of a higher boiler pressure.

In conclusion, the great diversity of opinion as to the merits of the various types of locomotives now at work, both simple and compound, and the urgent requirements for standardization of the locomotive engine, point to the necessity for having brake tests made from each type of engine designed before leaving the builder's hands, so as to reduce the various types to one common standard. With such brake tests, the author has no hesitation in offering an opinion that the compound locomotive would take first place, and that the simple locomotive engine would be relegated to the same position as the simple marine engine.

Discussion.

Mr G. W. Reid (Member) observed that Mr Riekie had done well in bringing forward this question of simple and compound locomotives. It was by no means one that was already settled. For years the London and North-Western Railway Company favoured compound locomotives, but the latest type on that railway was the simple engine; and the same might be said of the North-Eastern Railway, which had favoured the compound engine and now adhered to the simple engine. The Great Western Railway Company was at present experimenting with both. The results were not yet known, but he had no doubt that when they were made known they would be a great help to locomotive superintendents. On the other hand, the Midland Railway Com-

Mr G. W. Reid.

pany, which did not go in for compound engines till recently, was now building compound locomotives. The compound locomotive was much in evidence on the Continent and also in America. Mr Riekie favoured the compound locomotive, and he had given a paper, no doubt, with the intention of calling attention to this very important question. The author seemed to differ with former practice to the extent that he would in no case reduce the present capacity of the cylinders of the simple engine, and would add a third cylinder, making the capacities of the low-pressure cylinder 1¼ times that of the high-pressure cylinders. Mr Riekie was a practical man, and had rebuilt an engine to his own design somewhere, but did not give the date. Probably it was in India, and he found that this engine, with the 25 per cent. cut-off, could do the work of an engine that formerly did the same work with 40 per cent. cut-off. That was an immense saving, and if it could be guaranteed it would certainly settle the question. However, he did not think Mr Riekie depended altogether on the third cylinder for that result. He put a great deal of value on the introduction of the three-throw-crank, which introduced a continuous turning moment, and from that he expected very good results. How much Mr Riekie derived from the third cylinder and how much from the three-throw-crank he was not in any way able to determine. Mr Riekie was present himself, and perhaps would explain. Any locomotive superintendent would be very proud if he could have a locomotive that would save about 37 per cent. of the steam, even with the introduction of a third cylinder, the additional crank, its connecting rod, &c., and extra valve motion. With respect to upkeep, Mr Riekie might mention, in reply to the discussion, how long the engine which he rebuilt worked, and how its working expenses compared with the simple engine of the same construction, or perhaps the same engine before it was altered. If the three throw-crank reduced the severe knocking action, and saved wear and tear in that direction, then the expense of maintaining the three-cylinder engine might not be so much greater than the expense of the simple engine.

Mr W. P. Reid, (Member), expressed the opinion that it was now a recognised fact that the locomotives built as shown in Figs. 2 to 7 had not been the success claimed for them, or: Why should railway companies after giving them a very exhaustive trial revert to the simple engine? If the proposed engine illustrated on Fig. 8 be compared with a simple engine of two cylinders each having 20 inches diameter, no doubt the former would show a greater degree of efficiency. In engines with a cut-off of 40 per cent. of the stroke, and a boiler pressure of 180 lbs. per square inch, the average pressure of steam in lbs. per square inch for the whole stroke was about 143, and on the two pistons that was equal to 89,800 lbs. With a compound engine having a cut-off of 25 per cent., and a steam pressure of 180 lbs. per square inch on the two high pressure cylinders, the average pressure of steam in lbs. per square inch for the whole stroke was 107, and on the two pistons 67,400 lbs. With a low pressure cut-off of 80 per cent., and an initial pressure of 50 lbs. per square inch, the average pressure of steam in lbs. per square inch for the whole stroke was 48·4 lbs., and on one piston 37,640 lbs. That gave a gain of 15,200 lbs. in favour of the compound engine, but other factors had to be taken into consideration—the author's views on back pressure, extra friction, and upkeep of wearing parts. A very important point in favour of the compound type of engine was the continuous turning moment gained through the position of the three cranks. He had no doubt this added to the tractive power of the engine and did away with knocks on the crank shafts. The above figures were approximate, but quite near enough to give a fair comparison. At a meeting of the Institution of Mechanical Engineers in April, some extracts from a letter by Mr S. Johnson were read, in which he spoke very highly of the "Smith" system (Fig. 4) and stated that, "It is desirable that the relative merits of simple and compounds should be settled, and suggested that the railway companies should conduct a series of experiments under absolutely identical conditions so that there might be no question of the result." He considered that a good deal of very inaccurate data had been

Mr W. P. Reid.

published from time to time, which to him went to show that as far as the compound engine had developed itself there was yet a kind of uncertainty about it. Of course a locomotive was very different from a marine engine. To get any satisfactory results from a locomotive in the way of compounding, it must be tried over a long run without a stop, and he quite agreed that some of the English Companies might adopt the compound system where they had from 100 to 130 miles of a run at a stretch.

Mr R. T. Napier, (Member), said that he had looked with admiration on the fine compound locomotives which Mr Webb had placed on the London and North-Western Railway. It appeared to some that these locomotives took a considerable time to get up their speed. Time, as well as coal, cost money to a Railway Company, and the saving of a minute in getting up speed when leaving a station was a consideration. He would like to know if the simple locomotive had an advantage in that respect.

Mr. Riekie, in reply, said Mr. G. W. Reid's experience on the African railways, where the grades and curves were severe, had apparently been similar to the experience he had gained on the Indian State Railway in Beluchistan. It was not singular, therefore, that Mr. Reid should be in sympathy with his views that the adoption of a third crank might be of equal, if not greater moment than the use of a third cylinder in his proposed system. The wear and tear on grade climbing was quite abnormal in locomotive practice, and he had known the driving journals of a locomotive to be pounded out of shape to the extent which reduced them from eight to seven inches in diameter by repeated lathe turning to keep them round after the engine had run only 25,000 miles. This pounding action was due to the design which gave an unequal turning effort owing to the two cranks being alternately above and below the axle during each revolution of the wheel. It was a simple remedy to adopt a third crank so as to impart a more uniform turning effort to the wheel. Regarding the use of these cylinders, nothing short of two high pressure cylinders was permissible for heavy grade work, and as no boiler had yet

Mr J. Riekie.

been designed which would supply steam to three large high pressure cylinders it was natural that compounding should follow, so as to make use of the exhaust steam from the two high pressure cylinders. The system he advocated was looked upon with some suspicion on account of the unusual ratio of cylinder area adopted. This ratio suggested itself to the auther to obtain equal work on each crank pin when using an economical cut-off in the high-pressure cylinders. The fact that the ratio turned out to be an entire departure from modern practice was, therefore, due to the fact that the proposed method of expanding the steam was also a new departure in compound practice. Although he had referred to the abnormal wear on heavy grades, an equally serious condition of affairs existed on level tracks which was mainly brought about by applying an unequal turning effort to the crank shaft. This had reference to the severe wear which took place in one of the driving wheel tyres, especially in goods' engines with multiple-coupled wheels. Such wear was usually attributed to faulty balancing of the wheel, whereas it was entirely due to the unequal turning effort which caused a partial slip to take place during every revolution. This could only be overcome, (*a*) by placing the whole of the adhesive weight of the engine on the one driving axle so as to exceed the tractive force, or (*b*) by improving the turning effort. So serious was this wear and tear to tyres in a class of six-wheel coupled goods' engines that the tyres had to be reduced in diameter by one inch and a half after every 25,000 miles run; not that the coupled wheel tyres required turning up, but simply to make good the damage done to the one driving wheel tyre. In other words, 100,000 life miles of the tyres of the wheels had to be turned off in the lathe to make good the damage done through using two cranks. Such a condition of affairs was, he considered, quite sufficient excuse for departing from the orthodox practice of locomotive design. Mr Reid asked how long this engine had been at work? Unfortunately he had to leave India before he could carry out any extended experiments. The engine, moreover, was only a conversion, and until one

Mr J. Riekie.
was designed and built by a good firm of locomotive builders, accurate and reliable data was not likely to be forthcoming. He was glad to see that Mr W. P. Reid had been giving the question some attention, especially with respect to the improved turning effort from the use of three cranks. The gain in power was similar to that of increasing the piston stroke of the simple engine by one-third. No matter, therefore, how powerful a simple engine might be made, the power of the same could always be enhanced by using an additional large low-pressure cylinder, making it impracticable for the former to live in competition with a well-designed compound engine when both made use of an equal weight of steam. He had had some experience with an engine on the "Smith" system, and it failed to accomplish the work required, and it had to be converted back to a simple engine. The reason was obvious, the two low-pressure cylinders had been merely a sub-division of the one large cylinder shown in Fig. 2. He agreed with Mr Reid that long runs were necessary to bring any slight advantage to be gained by existing methods of compounding. If, however, the simple engine was improved by the addition of a third cylinder, it could be made to be more flexible at work, no matter what the length of run might be, and should therefore prove economical under all conditions of working. Mr Napier's reference to the time the compound engines on the London and North-Western Railway took in getting up speed was very much to the point, for it explained why this type of engine was being converted to simple, and was entirely due to their having been designed with small high-pressure cylinders, and 50 per cent. less power than the simple engine. This explained why it was that the simple engine was able to hold its own in competition against the compound system.

On the motion of the CHAIRMAN, Mr Riekie was awarded a vote of thanks for his paper.

Correspondence.

MR J. N. JACKSON, (Crewe), after reading Mr Riekie's paper found that he was not in agreement with him as to the practical advantages of compounding the locomotive. It was easy to prove from a theoretical point of view that there was an advantage in compounding, but in practice these advantages quickly disappeared. But before stating his views on the subject he desired to point out an error in Mr Riekie's description of Mr Webb's four-cylinder compound engine as given on page 246. Fig. 7 was not a correct representation of the Webb four-cylinder compound, inasmuch as in these engines all the cylinders worked on to one axle and were not divided and connected to seperate cranks. The H.P. cylinders were outside the frames and were connected to crank-pins in the driving wheels, while the L.P. cylinders were placed between the frames and coupled to cranks on the same axle on which the H.P. driving wheels were fixed; so that all the cylinders worked on to one axle. Again on the same page a little lower down Mr Riekie said that "all compound engines built on these systems require starting gear etc. etc." With the exception of a few of the earlier compound engines built by Mr Webb, none of his engines had any special starting gear, having only the ordinary regulator and valve. In some of his earlier engines he connected a small pipe to the L.P. cylinder which conveyed live steam thereto for starting purposes, but these were soon taken off as useless. This was the only special starting gear, if it could be called by that name, that was ever used on the Webb compounds. Now as to the views expressed by Mr Riekie on the advantages of compounding in locomotives. He did not propose to discuss them in detail, but would simply confine himself to giving his opinion on the subject, based on eighteen years experience in the designing and practical working of compound locomotives. As he had already remarked, theoretically there might be a slight advantage in compounding as applied to locomotives, but he submitted that the value of any type of locomotive was estimated by the cost of its construction, the work got out of it, and the total cost of getting that work. As to cost of construction a compound locomotive was certainly a more expensive machine than a non-compound, Mr J. N. Jackson.

and therefore a Railway Company adopting the compound system had to sink more capital for engine power than would be the case if the simple or non-compound locomotive were adopted. Then as to the work got out of an engine for the same weight of steam used, there might be a slight advantage in favour of the compound, but when one came to reckon the cost, that advantage was wiped out entirely. In this way—in the compound there were far more working parts than in the simple engine and consequently the former required more attention and more repairs, hence increased cost under that head. Again the compound, by reason of its having more moving parts, required more oil for lubrication than the simple engine, thus making the former more expensive in the use of oil. Further the increased number of joints necessary in the compound rendered it more liable to failure through some pin or joint giving way. On the other hand it was claimed that the consumption of fuel was less in the compound than in the simple engine and although, as the result of special trials, this had proved true to a small extent, yet, in actual practice in everyday working, when a number of engines were compared, this advantage somehow disappeared. Indeed there was now a class of engine running on the London and North-Western Railway—eight coupled goods—which, as originally built, was three cylinder compound—but was now being converted into two cylinder simple—and these latter engines were at present doing the same class of work and taking the same loads on a slightly less coal consumption than before they were converted. Therefore, taking all these several points into consideration and having experienced the working of both compound and non-compound locomotives over a long time, he had formed the opinion that the non-compound engine was far superior for working the varying traffic on British railways. He expressed the hope that the discussion on Mr Riekie's paper might result in obtaining the opinions of many practical engineers on this question of compound and simple locomotives.

Mr G. R. Sisterson (London) wished to compliment Mr Riekie upon his persistent advocacy of the compound principle as applied to locomotives. It was a happy idea to lay the question before experts in marine engine building. The marine engine with condenser had been brought to a very high state of perfection, but the same headway, however, had not been made with the locomotive. The first difficulty the designer of compound locomotives had to face was the absence of the condenser, which reduced the possible margin of gain greatly. The second difficulty was the variation of cut-off required. The cut-off varied in locomotives from 50 to 15 per cent., never remaining fixed for any length of time. The efficiency of the compound engine fell, of course, as the designed cut-off was deviated from. The third difficulty was the excessive compression towards the end of the piston stroke, assuming a boiler pressure of 200 lbs. absolute. In the engine designed by Mr Riekie, with cylinder ratios 1 and $1\frac{1}{4}$, and cut-offs 25 and 80 per cent., thus :— $\frac{0{\cdot}25}{1\frac{1}{4} \times 0{\cdot}8} \times 200 = 50$ lbs. receiver pressure. Steam of this pressure must be compressed into the clearance space when the H.P. valve had closed to exhaust. For 25 per cent. cut-off, compression began at 70 per cent. of the stroke. Taking the clearance volume at $\frac{1}{10}$, the ratio of compression was 4, and the terminal compression $50 \times 4 = 200$ lbs. This was a serious matter when dealing with engines having piston speeds of 1200 or 1300 feet per minute, and this compression increased with the piston speed. Linking up further was no remedy, and although this no doubt reduced the receiver pressure, it also increased the compression ratio. In the de Glehn system the terminal compression was about 120 lbs., and in the ordinary non-compound exhausting down to 20 lbs. absolute, with 25 per cent. cut-off, the terminal compression was only $20 \times 4 = 80$ lbs. He laid stress upon this because he found from repeated observations that high compression, even with the non-compound, soon put a limit to the speed. If attempts were made to force the non-compound at high speeds, a little more than usual, the pistons worked with a knock at the ends of the stroke. Indicator diagrams taken under these conditions showed invariably a negative loop at

Mr G. R. Sisterson.

the commencement of the diagram. When this loop appeared, however slight, the speeds fell off, and fast running was impossible. The diagrams, Fig. 9, showed this defect most clearly. All compound locomotives were deficient in this respect, and he was afraid Mr Riekie's system was worse than others due to the low cylinder ratio employed. In order that the compound should compete with the simple engine at high speeds, some means would have to be adopted for relieving compression. His last difficulty was that, after careful observation of the performances of locomotives of the various systems at present in use, he had been unable to find any appreciable economy in coal consumption. The importance of this would be understood when he said that on the London and South-Western Railway a gain of 1 lb. of coal per mile run represented a saving of £7000 per annum. The designers of compound locomotives contended that one should not judge only by reference to coal consumption; but this, to him, seemed the only safe standard of reference. It should be remembered also that compounding on any of the systems at present in use meant a great increase in the cylinders and working parts, consequent complications, and increased cost of upkeep. Great increase of cylinder volume alone meant increased internal resistance when running with steam shut off. It would be seen that the task of modifying the marine compound to suit railway conditions was a task of no slight difficulty. The ideal compound should have, as compared with the non-compound, no appreciable increase either of the cylinder volume, the ratio of compression, or the number of the cylinders. The system should be capable of easy application to existing locomotives, otherwise the cost of conversion became excessive. These might be considered drastic and impossible conditions, but he was not without hope of their ultimate realization. A factor, no doubt, tending to these desirable results was the advocacy of engineers like Mr Riekie, who had done so much to bring this question to the front. Referring again to the de Glehn compounds, these engines gave evidence of most careful design, and the cylinder arrangement lent itself to

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most perfect balance. The compression ratio was not excessive, being further relieved by inside clearance on the L.P. slide and large cylinder clearance. The high boiler pressure employed gave great flexibility to the cut-off, but at the same time it seemed to preclude the general adoption of this type, if flat-sided fire boxes were to be still employed. The large cylinder volume of compound engines enabled them to deal with excessive loads at moderate speeds; but locomotives must be economical with small as well as with large loads. Suppose a non-compound locomotive working a light, fast-timed, train, on a long down grade, with the cut-off 15 per cent., the regulator half open, and only just sufficient steam admitted to the cylinders to prevent the pistons pumping air. Under the same conditions, a compound locomotive could not be linked up to that degree, because the L.P. cylinders would be pumping air, and the compression would be severe in the H.P. cylinder. A much longer cut-off had to be employed, which meant that the engine had to be forced down hill. This explained why compound locomotives on test runs with large loads did very well indeed, but, nevertheless, when put in service along with non-compounds, with difficulty held their own.

Mr CHARLES S. LAKE (London) expressed an opinion that the near future would see British locomotive engineers taking up the question of locomotive compounding with the same amount of zest and earnestness as was evinced among their professional brethren abroad; indeed, there were already ample signs that the movement in that direction had, *de facto*, begun, for not only were the engineers of the Great Western and Midland Railways —hitherto numbered among the strictly "non-compound" lines —introducing additional compound locomotives for working their most important express passenger services, but early summer would see compound locomotives at work upon two additional great railway systems—viz., the Great Northern and Great Central; whilst, if rumour were correct, a fifth railway, of equal importance to those mentioned, was contemplating following suit. His conviction that the compound locomotive would before long become a prominent feature of British practice, was, however, not so much based upon these potential signs as upon the experience he had gained during recent years whilst travelling upon the footplate of locomotives engaged in hauling some of the most important express trains in the country, which he had done for the purpose of observing the character of the work performed, both from the point of view of efficiency and economy. One result of these observations had been to convince him that, although "simple" locomotives were, beyond doubt, capable of hauling maximum loads at high consecutive rates of speed, they did so with a woeful disregard of economy; indeed, it was sad to reflect upon the enormous wastage which occurred as a result of operating these high-speed locomotives on the single expansion principle. No doubt whatever existed in his mind that the bulk of the heavy and fast express trains on the great trunk lines had to be worked nowadays on the "get-there-at-any-price" system, and a coal consumption of from 40 to 48 lbs. per mile and more, was tolerated because it was only by such means that the loads could be got over the ground in the scheduled time allowance. The real point to his mind was, however, not so strictly based upon the question of "fuel economy" as that of conserving power. True, the one should, and naturally did, follow upon the other, but the distinction he would like to draw was this:—Under the British loading gauge restrictions, it was not easy to build a sufficiently large and powerful boiler to meet the needs of the greatly increased cylinder capacities of the present day, under every condition of service. Large cylinders, to be effective, demanded equal advancement in the power of the boiler, but that this was not easy to devise there was ample evidence to show, for it was only too apparent that many "simple" locomotives of the present day were badly "over cylindered," and the natural consequence was that a sufficient volume of steam was not forthcoming when the conditions of running were in anyway of the ultra-plus character. The use of compound cylinders reduced the demand upon the powers of the boiler for rapid steam generation, the volume of steam available being consumed at a slower rate, and in view of the fact that the time had now arrived when, for the reason referred to above, locomotive boilers on British railways were being made as large as it was possible to make them, this slower rate of consumption constituted an all important advantage. The particulars of a recent experience which fell to his lot, and which, he thought, served to demonstrate more than anything the need for compound cylinders in locomotives, might perhaps be of interest. The engine upon which he was travelling was one of the largest of its class and of recent design, with large cylinders and boiler. It was set the task of hauling a load of 200 tons a distance of 100 miles in 1 hour 43 minutes, equal to a speed of 58·3 miles per hour, without any intermediate stop. The road was an easy one, taken all round, and in the main favourable for fast running, but the engine was in trouble the whole way because of shortage of steam, and instead of 180 lbs. per square inch, the pressure rarely rose above 160 lbs., although the fireman's exertions were hardly relaxed for a moment, the shovel being seldom out of his hands throughout the run. It was true that the tender had been loaded up with "dirty" coal, and this, doubtless, contributed towards difficulty in maintaining steam, but it seemed equally certain that a third cylinder, adapted for low pressure working, would on this, as on other similar occasions, have made all the difference between ease and difficulty in working the train. With regard to the relative merits of different systems, the most successful abroad was undoubtedly the de Glehn four-cylinder system, but, to adopt this, one must be prepared to accept rather more complication of detailed construction and methods of working than was usual in British locomotive practice. In his opinion the system invented by Mr John Riekie had its chief advantage in that it avoided all complication either in mechanism or working method, and the driver who could run a single-expansion locomotive to advantage would, he thought, experience no difficulty whatever in showing immeasurably better results when handling a Riekie compound of the same proportions and on the

Mr Charles S. Lake.

same work. He would like to ask the Members of the Institution if any one of them could suggest a reason why that in Scotland —the home of the engineer—there was not a single example of the compound locomotive to be seen, whilst Southerners were going in for them in increasing numbers?

Reply to Correspondence.

Mr RIEKIE, in reply to the written communications, thanked Mr. Jackson for pointing out the error in Fig. 7 regarding the Webb system of compound. With reference to Mr. Jackson's remarks *re* starting gears, he would point out that although the Webb engines were not fitted with starting gears, it was permissible to think that they sadly required it considering that the tractive power of the combined two high-pressure cylinders was only half that of the cylinders of a simple engine when equal boiler pressure was used. Mr. Jackson's valuation of a locomotive was correct, and his long experience on the London and North-Western Railway with both simple and compound engines rendered his statement as to their comparative working of considerable importance. His experience, however, had taught him that more working parts did not necessarily require more attention or additional repairs. On engines performing similar work in a sandy district, some with ordinary link motion, and others with a link motion and a rocking shaft and several other extra joints, there was, over seven years of working, no difference in cost of upkeep. This was because both gears were well designed. The risk of failure could be met in the same way. Again, the ever increasing steam pressure set up strains on the two cranks of a simple engine which could only be mitigated by the adoption of multiple cranks, which allowed of a distribution of strains that obviously tended to minimise wear and tear, to say nothing of the more perfect balance due to the latter when the engine was running at high speed. Mr. Jackson's reference to the Webb eight-wheel coupled goods' engine being converted from compound to simple might appear discouraging to the advocates of the compound system, but it was brought about by Mr. Webb having adopted a ratio of cylinder area high to low-pressure cylinders which admitted of the two high-pressure cylinders possessing a tractive effort 50 per cent. less than that of the simple engine. In this connection it might be of interest to point out that Mr. Webb made a complete departure when designing this three-cylinder compound goods' engine, inasmuch as he connected the three cylinders to the one crank shaft. In such a design of engine it was important to make such an allowance that the power developed by each cylinder should be practically equal. It was, however, well known that in the "Webb" system the low-pressure cylinder developed power equal to the combined two high-pressure cylinders. There could, therefore, be no wonder that this type of engine was not a complete success, nor was it surprising to learn that, when the engine was converted to simple and fitted with high-pressure cylinders having 50 per cent. more starting power, it gave better results. Even this, however, was inconclusive, except as concerned the "Webb" system of compounding. Mr Sisterson's contribution was very much to the point. The two advantages of the marine engine over the locomotive were the "condenser" and "long runs at constant cut-off." As to long runs at constant cut-off he considered that if the engine were designed to exert its maximum tractive effort at 20 per cent. cut-off (simple or compound) the varying load could be hauled at this cut-off by varying the steam pressure in the high-pressure steam chest. Referring to the evils of compression, Mr. Sisterson said that "Mr. Riekie's system was worse than others due to the low cylinder ratio employed." Cylinder ratio was a factor of compression, but expansion was also a factor, and his whole motive was to work with increased expansion. Thus he got, as Mr. Sisterson said, with cylinder ratios 1 to $1\frac{1}{4}$, and cut-offs of 25 and 80 per cent. $\frac{1 \times 0{\cdot}25}{1\frac{1}{4} \times 0{\cdot}8} \times 200 = 50$ lbs. receiver pressure, and with compression taking place at 70 per cent. the terminal pressure became $50 \times 4 = 200$ lbs. Comparing this, however, with the usual cylinder ratio of 1 : 2 and cut-offs of 50 and 60

Mr Rickie.

per cent. $\frac{1 \times 0 \cdot 5}{2 \times 0 \cdot 6} \times 200 = 83 \cdot 3$ lbs. receiver pressure, and with compression taking place at 80 per cent. the terminal compression became $83 \cdot 3 \times 3 = 250$ lbs. He thought it was quite evident that the compression in his system must be less. But there was a third factor of compression, namely, the valve-gear, and he had demonstrated that compression could be still further reduced by improved action there. Mr Sisterson's figure of 1 lb. of coal per mile, or, say, 3 per cent., meaning £7000 per annum, seemed to emphasise the small margin of gain as being of great importance. It had, of course, to be borne in mind that 1 lb. per mile on the gross mileage (with lighting up and standing in steam included) would probably require at least 5 per cent. on the "compound" mileage. He looked for nothing under 20 per cent. of a saving from a well-designed compound engine. He agreed with Mr Sisterson that it was impracticable to run the *existing* type of compound similarly to non-compounds on long down grades. The conditions were undoubtedly different with his system, and it became quite practicable not only to work down grades with a 15 per cent. cut-off in the high pressure cylinders, but to deal with loads on the level with this same cut-off and run up to time in a manner which a simple engine could not do. Mr Lake's wide experience on the foot-plate and his practical knowledge lent weight to his views. It was interesting to learn that all railways south of the Tweed were not in unison with the London and North-Western Railway. Although the northern locomotive engineers were not giving practical effect to compounding, the question was not altogether lost sight of, and he could safely promise Mr Lake that when compounding was taken up it would be in such a form that it would not be likely to lead to conversion back to simple again.

SOME NOTES ON THE EFFECTS LIKELY TO BE PRODUCED BY THE GYROSCOPIC ACTION OF STEAM TURBINES ON BOARD VESSELS PITCHING IN A SEA.

By J. BLACKLOCK HENDERSON, D.Sc. (Member).

Held as Read 21st March, 1905.

IN connection with the discussion of Mr Melencovich's paper on "Steam Turbines,"* the writer gave a short explanation of the nature and value of the stresses which the gyroscopic action of the rotor of a steam turbine on board vessels will produce on the holding-down bolts, when the vessel pitches in a sea. The rotor of the turbine tends to keep the direction of its axis of rotation constant, and the rotation of this axis in one plane can only be produced by the application of a couple in a plane, at right angles to the first and to the plane of rotation. Thus the axis of the turbine and the axis about which pitching takes place being horizontal and at right angles to each other, the couple required to make the turbine pitch with the ship must have its axis vertical. A turbine therefore can only be made to pitch with the ship if a couple is applied to it in the plane of the deck, and this couple is supplied by a shearing action on the holding-down bolts. The value of this couple is given by the equation

$$\tau = I \, \omega \, \dot{\theta}$$

where I = moment of inertia of the rotor about its axis,

ω = angular velocity of the rotor, and

$\dot{\theta}$ = angular velocity of pitching.

* See page 165.

If dimensions somewhat similar to those in the new Cunard Liner "Carmania" are taken, then the mass of the rotor is about 40 tons. Its external diameter varies from 7 to 11 feet, so the radius of gyration may be taken as about 4 feet. The moment of inertia $I = 40 \text{ tons} \times 16 \text{ (feet)}^2 = 640 \text{ tons} \times \text{(feet)}^2$. The angular velocity of the rotor is 200 revolutions per minute $= \frac{200}{60} \times \frac{2\pi \text{ radians}}{\text{seconds.}} = 20{\cdot}9$ radians per second. The angular velocity of pitching will vary very considerably, but let the period of pitching be taken as 10 seconds and the amplitude of the pitching motion as 6 degrees or ·105 radian. Assuming the angular motion of pitching to be simple harmonic in character (to which it will closely approximate in the majority of cases), the maximum angular velocity is then given by $\frac{2\pi \times \text{amplitude}}{\text{period}}$, or

$$\dot{\theta}_{(max)} = \frac{2\pi \times {\cdot}105 \text{ radian}}{10 \text{ secs.}} = {\cdot}066 \frac{\text{radians}}{\text{sec.}}.$$

The maximum couple exerted by the shearing action on holding-down bolts is therefore

$$\begin{aligned} \tau_{(max)} &= 640 \text{ tons} \times \text{feet}^2 \times \frac{20{\cdot}9}{\text{sec.}} \times \frac{{\cdot}066}{\text{sec.}} \\ &= 884 \text{ tons} \times \frac{\text{feet}^2}{\text{sec}^2} \\ &= \frac{884}{32} \text{ tons weight} \times \text{feet} \\ &= 27{\cdot}6 \text{ tons weight} \times \text{feet} \end{aligned}$$

If the turbine were held down by two sets of bolts 20 feet apart there would be a maximum shearing force on each set of about 1·4 tons weight, this force alternating with the rising and falling of the ship's bow. The magnitude is not large enough to constitute an important factor influencing the size of the bolts, in fact in this connection it might be neglected. But is it negligible in other respects?

The couple must, of course, act on the rotor, and must be produced by side pressure on the two end bearings, which side pressure will alternate with the rising and falling of the ship's bow. Any play in the bearings will tend to increase under the action of such reciprocating stresses, but the period of alternation is so long that the action must be negligible. The turbine and its connected shaft is an elastic structure to which a periodic couple is applied. At each application a transverse flexural wave will run along the shaft, be reflected at the first bearing, and return as a reversed wave. If on its return it synchronises with the reversal of the couple, the effects will be additive, and the shaft will get into a state of cumulative transverse vibration. The lateral stiffness and flexural rigidity of all propeller shafts is such that the velocity of the transverse wave is very much greater than that required to give sympathetic vibration with the gyroscopic couple —of 10 seconds period in the case under consideration. The rotor of the turbine is also an elastic structure subject to deformation, but its enormous lateral stiffness should exclude the possibility of any sympathetic vibrations occurring in it of a period such as that of pitching.

There only remains now to examine the possible effect which this alternating couple can produce on the ship itself. The couple is transmitted through the holding-down bolts to the ship's frame, and since in the "Carmania" there are three turbines, the magnitude of the couple applied to the ship would be that due to three turbines if the three rotors rotated in similar directions, but since two of the rotors rotate in opposite directions, it is only equal to that due to one turbine. Since the ship is an elastic structure, a transverse wave will be propagated in her body at each alternation of the couple, and if the period of these waves is equal to one of the natural periods of the ship's transverse vibrations, then lateral vibrations of considerable amplitude will be produced.

The complete theoretical investigation of the transverse vibrations in a loaded frame structure like that of a ship, is a problem beyond the scope of this paper, and is unnecessary for the object in view. In the case of a uniform bar free at both ends and vibrating laterally, the frequency of vibration is given by:—

$$n_i = \frac{m_i^2}{2\pi} \cdot \frac{k}{l^2}\sqrt{\frac{E}{\rho}}$$

where m_i are the roots of the equation, $\cos m \cosh m = 1$.

n_i the frequency of the vibration of mode m_i.

E = Young's modulus.

l = length of the bar.

ρ = density of the material, and

k = radius of gyration of the section of the rod about the neutral axis.

The same laws that apply to the case of the bar, will apply to the ship, so it will be seen that the frequency will vary directly as the square root of the flexural rigidity, which varies as Ek^2, and approximately inversely as the square of the length of the ship. The various frequencies of the free vibrations of different modes will also be approximately proportional to the squares of the odd numbers, 3^2, 5^2, 7^2, 9^2, etc. A rod free at the ends when vibrating in its fundamental mode has two nodes or points of no vibration, three nodes when vibrating in the first harmonic, four nodes with nine times, etc., and the same will apply approximately to the ship.

The writer is indebted to Professor Biles for information regarding the experimental determination of the natural period of vertical vibration of the "Caronia," the sister ship of the "Carmania." This ship is fitted with reciprocating engines, and the vibrations in her frame at different speeds of the engines were recorded by means of a Schlick's pallograph. Definite natural vibrations in the vertical plane were noted at a frequency of 82 per minute, but no horizontal vibrations of any magnitude were recorded. The absence of horizontal vibrations might be due either to the horizontal balancing of the engines being very good, or to the fact that the frequency necessary for producing synchronous horizontal vibrations was never reached. The former is the more probable.

The frequency of lateral vibrations will be different from that of vertical vibrations since the moments of inertia of the ship's section about the horizontal and vertical neutral axes are different. For a ship of over 500 feet in length, Mr Johnston informs me that the moment of inertia of the midship section about the vertical neutral axis was 1·9 times the moment of inertia about the horizontal neutral axis. Near the bow and stern the moment of inertia about the horizontal axis would be the greater, but in a ship of large block coefficient the moment of inertia of the section about the vertical axis will be the greater over the greater part of the length. The frequency of horizontal vibration will therefore be greater than the frequency of vertical vibration, that is, greater than 82 per minute. If this number 82 is the frequency of the *fundamental* vibrations, then the ship would have two nodes in her length when thus vibrating. The writer has no record of the number of nodes present, but Professor Biles thinks it is extremely unlikely that there were more than two nodes. It is evident therefore that in such a ship as the "Carmania," there is no possibility of obtaining synchronism between the natural lateral vibrations of the ship and the period of the gyroscopic couple, the period of pitching.

In the event of sympathetic vibrations being possible in any particular case and actually occurring at sea, the easiest method of stopping them would be by altering the speed of the vessel, thereby altering the period of pitching, and destroying the synchronism between the pitching and the ship's natural period of lateral vibration. In order to avoid all risk of sympathetic vibration, an even number of turbines would be required, equal sized rotors being arranged in pairs to rotate in opposite directions.*

* For the discussion on this and the following paper see page 313.—ED.

GYROSTATS AND GYROSTATIC ACTION.

By Professor ANDREW GRAY, LL.D., F.R.S.

Read 21st March, 1905.

SEE PLATES XII. AND XIII.

I. PRELIMINARY DESCRIPTION OF EXAMPLES OF GYROSTATIC ACTION.

EVERYBODY has experimented with spinning tops. But it is possible to make many experiments without really learning very much from them, and of the thousands who spend a good deal of their spare time in early years in playing with tops, only a very few ever really gain any idea of the why and wherefore of the remarkable phenomena which a spinning top presents to a curious observer. The pastime is universal, and is for a certain part of the year, and especially in the country, followed by schoolboys with enthusiasm; indeed, a visitor from another planet who was conversant with the motions of the heavenly bodies, might easily imagine that top-spinning was symbolical of the enormous interest taken by human beings in the spinning and precessional motion of the earth which they inhabit. For the earth is a top, and the dynamics of the spinning earth, with its motions which are called precession and nutation, are, to a considerable extent, identical with the dynamics of a top. Hence, apart from any possible application of dynamical lessons obtained from top-spinning to engineering, or to the action of marine engines of different kinds, we might well feel a very keen interest in the subject.

Nowhere is top-spinning practised with greater skill and ingenuity than in Japan, and to the many causes to which I have seen the great success of the Japanese in their present gigantic struggle attributed, I might venture to add their proficiency in this amusement. It would at least be as reasonable a theory of the superiority of Japan as some of the theories which have been advanced, and it is indicative of the true theory.

The modifications of the conditions of stability of equilibrium of bodies, which are produced by rotation, meet us at every turn. Here, for example, Fig. 1, are a number of bodies which can be attached to a whirling table, so as to be spun about a vertical axis. One is a wooden disc, another is a cone of wood, a third is a closed loop of chain. When these are spun, the disc, which is hung from a point in its edge, rises up to a horizontal position, and is stable there so long as the spin exists. The cone places itself with its axis of figure horizontal; and the strings, in these two cases, are now inclined to the vertical, about which they revolve in cones as the solid spins.

The chain, which without spin is quite limp and flexible, also rises up, and spreads out into a horizontal circle, in which it remains as if it were a rigid ring, which, in a sense, it is for the time. The suspension cord in this case also revolves in a cone.

This kind of rigidity of the chain is well shown by spinning the chain on a vertical pulley or drum, and then tipping it off on a horizontal table, along which it runs for some distance like a rigid hoop.

A top with a well-rounded point, spinning rapidly on a stone slab, if it is started spinning with its axis inclined to the vertical, actually has its centre of gravity gradually raised to a higher level, and only gradually declines as its spin, in consequence mainly of the damping action of the air, falls off in rapidity. This is the dynamical solution of the problem of Columbus, to make an egg stand on end. First boil the egg until the contents have become solid, and then place it in the position of stable (and also neutral) equilibrium on a glass plate, and give it a rapid spin. The egg will quickly change from the position, that of lying on its side, in which its centre of gravity is lowest, to one in which its axis is vertical, and will remain stably in that position until its spin has been sufficiently diminished, when it will gradually fall down with the conical swaying motion of the axis, with which a top always falls away from the vertical or "sleeping" position.

When the spinning body is a fly-wheel with a heavy rim, and is mounted on pivots either within a case or on a movable frame, still more remarkable and at first sight puzzling phenomena are displayed. Here, for example, is a *gyrostat*, constructed as shown in Fig. 2. A massive fly-wheel, the chief part of the mass of which is in the rim, is mounted symmetrically on an axis, the ends of which are carefully rounded points held in cup bearings adjustable by screws, as shown. These bearings are attached to a case shaped to enclose the fly-wheel and its axis, so that the central part is a wide and shallow cylinder surrounding the fly-wheel, with, at each side, a longer, narrower cylinder surrounding the axle. Round the wide cylindrical box is a projecting edge, on which in the diagram the gyrostat is shown resting.

A simple form is that familiar to nearly everybody as a scientific toy, in which the case is reduced to a ring carrying the bearings of the fly-wheel, and provided with a stand on which the gyrostat can be placed in different positions.

The gyrostatic action of a bicycle wheel is more or less known to everyone. The angular momentum of such a wheel is great though its speed of rotation be small. A simple form of gyrostat may be constructed, as has been done by Professor Greenhill, by mounting a bicycle wheel at one end of a straight rod as axle, and hanging it from a fixed point by a universal joint at the other end. The wheel can then be spun by a stick placed between the spokes, and the phenomena of precession, reactions, etc., studied. The gyrostatic action of the wheels of a vehicle (a rapidly moving motor car or railway carriage, for example), moving round a curve, gives a torque aiding centrifugal force to upset the vehicle, which must be balanced by the reaction of the ground or rails. The reader may calculate this torque by the methods explained below.

Here are two positions of a gyrostat which experiment and theory show are stable, Figs. 3 and 4. In the first, the gyrostat is supported on two stilts, one rigidly attached to the case and parallel to the plane of the wheel, the other merely a stiff wire with rounded points, the upper of which rests loosely in a hollow in the projecting arm seen in the diagram. The lower ends of the stilts rest on a metal plate. If the gyrostat is free to oscillate in azimuth, it will be stable when thus supported.

In the second case, the gyrostat is supported on gimbals, with its axis nearly vertical. It can thus turn its axis away from or towards the vertical in any direction. The upright position is thoroughly stable when the fly-wheel is spinning.

In Fig. 5 a gyrostat is shown supported on a bifilar sling, arranged in different ways. In the third and fourth diagrams of this Figure the two threads are crossed by putting one through a ring placed on the other. Here azimuthal oscillations are possible. It is clear that the inclinational equilibrium in 1 and 3 is stable without rotation, and in 2 and 4 is rendered stable by rotation of the fly-wheel. The azimuthal equilibrium in 3 and 4 is only rendered stable by rotation. These arrangements are due to Lord Kelvin.

One of the most striking experiments which can be made with a gyrostat is that shown, carried out in slightly different ways, in Figs. 6, 7, and 8. In Fig. 6 the cased gyrostat is shown hung by its rim, while a weight is hung from one end of the part of the case surrounding the axis. The gyrostat thus supported is pulled by the weight so that it is acted on by two equal and vertical forces at a considerable distance apart. and would, if the wheel were not rotating, turn round so as to bring the centre of gravity of the whole under the supporting thread. But if the wheel is in rapid rotation, the axis of rotation remains approximately horizontal while the whole revolves about a vertical axis. The axis of rotation of the fly-wheel turns round in a horizontal plane, that is to say, turning is produced about an axis perpendicular at once to the axis of rotation, and to the axis about which the vertical forces tend to turn the gyrostat. One expects, and would almost say naturally expects (though any other behaviour of the gyrostat than that which actually takes place would be really unnatural), the axis to be tilted down. This does not happen; the axis moves round sideways.

The same thing is shown in Figs. 7 and 8, and perhaps in the latter case more strikingly. The whole gyrostat is hung by a cord attached outside the containing ring, and by its weight pulls the centre of gravity down. As before, the axis, if free to do so, turns round in azimuth.

It may be noticed here that the direction of this azimuthal turning of the whole gyrostat is always towards making the fly-wheel face in that direction in which it would face if the rotational motion of the wheel were produced by the turning motive, or torque, due to the weight of the gyrostat and the pull in the supporting cord. As the vertical line of action of the weight moves round with the gyrostat, the turning in azimuth goes on continuously. I shall try to explain this turning presently. In the meantime, it is to be carefully noticed that the turning is always towards giving to the system angular momentum about the axis round which gravity tends to generate such momentum.

I shall call this azimuthal motion of the axis of rotation the *precession*. There is propriety in doing so, as this motion of the axis is perfectly analogous to the conical motion of the earth's axis, by which the point in which the earth's axis intersects the celestial sphere describes a circle in a period of about 26,000 years about the pole of the ecliptic. It is this conical motion which produces the astronomical change called the precession of the equinoxes, and the motion of the earth's axis is very frequently called the *precessional motion* of the earth. This is well illustrated by the model upon the table. This model, in fact, illustrates further the geometry of all such motions, by showing that rolling of a cone fixed in the body on a cone fixed in space, in which such motions of a rigid body as we are here concerned with really consist. Here, then, Fig. 9, is a terrestrial globe, the lower part of which is cut away, and from the north pole of which projects a cylindrical spike, which may represent the earth's axis. The model is pivoted at the centre, and the cylindrical axis is made to rest on the inner surface of this ring at the top. The ring is just wide enough to enable its diameter to subtend at the centre of the model an angle equal to twice the so-called obliquity of the ecliptic. Thus the axis in this position is inclined to the plane of the table, which represents the plane of the ecliptic or plane of the earth's motion round the sun, at approximately the same angle as that which the earth's axis really makes with the ecliptic. If now the model is made to rotate on its axis in the direction in which the earth would be seen to turn if looked at by an observer beyond the north pole, the cylindrical axis rolls on the inside of the ring, and the axis moves round in a cone (see Fig. 10). In this way the earth would seem to turn and its axis to move if the observer looked at it for a few thousand years! Now, while we have been looking on, the cone has been once completely described—26,000 years have elapsed!

The circle of points round this cylindrical axis, if joined by straight lines to the centre of the model, gives the cone fixed in the model; the points of the ring joined in the same way give the cone fixed in space on which the former cone rolls. Of course, for the earth and its precessional motion, the diameters of the circles of contact of these cones are out of all proportion. The diameter of the ring in a full-sized model would be over 3000 miles, the diameter of the cylinder only 21 inches. This conical motion of the earth's axis is illustrated in Fig. 10, which shows successive positions of the axis at intervals of 6500 years. The cone here shown is the cone fixed in space when the earth s orbital motion is abstracted.

Returning now to the precessing gyrostat, notice that when the precessional motion is impeded by applying a torque round the vertical axis, the gyrostat at once begins to fall down, and that if a torque is applied in the opposite direction, that is so as to hurry up the precession, the axis actually rises. It is thus, as was long ago pointed out by Jellett in his theory of friction, and told also by Lord Kelvin in his lectures on dynamics, that a top is made to rise in the first part of its spin and fall in the latter part. In the first part of the spin the rotation is so rapid that the point of contact of the peg with the surface of the stone slab is moving relatively to that surface in the direction opposite to that indicated for the precession in Fig. 11, so that the friction applied to the top gives a torque about its axis hurrying up the precession; in the latter part the spin is so slow that the point of contact is moving the other way, so that the torque due to friction delays the precession, and the top falls. [It is very instructive to experiment with two identical tops, one with a peg ground sharp, the other with a well-rounded peg. The former, if supported on a glass or marble slab, does not rise up from its initial inclined position—the latter does.] A dynamical explanation of all this will be found presently; and the phenomena here described, though apparently not directly connected with the subject, will help to make clear the dynamical discussion.

Another experiment I desire to make, is with the gyrostat, Fig. 12, spun as before. It is provided with a pair of trunnions, attached at extremities of a diameter to the edge surrounding the case in the plane of the fly-wheel. These rest in bearings on the two sides of this rectangular frame of wood; and the gyrostat when thus supported, and the frame held level, has its axis nearly vertical. Moreover, the centre of gravity of the gyrostat (wheel and case) is almost exactly in the plane through the trunnions at right angles to the axis of rotation, so that there is little or no stability due to gravity with either end of the axis uppermost.

Now, the direction of rotation of the fly-wheel is shown by the arrow-head marked on the case. If then, holding the tray in my hands, I carry it with the gyrostat round in azimuth in the direction in which the wheel is rotating, the gyrostat remains in stable equilibrium. If, however, the whole is carried round in the opposite direction, the gyrostat immediately turns upside down on the tray, and if the motion in the same direction is continued, remains in stable equilibrium. Thus the gyrostat is stable so long as the azimuthal motion imposed by me on the whole system coincides with the rotation; but if the azimuthal motion is reversed, the gyrostat at once capsizes so as to bring its rotational motion into coincidence with the azimuthal motion. This will also afford an illustration of the theory of the instrument.

Finally, before dealing with the dynamical theory, consider this other arrangement (that shown in Fig. 6 without the attached weight). A gyrostat has the centre of gravity of the fly-wheel and the case (which is supposed to be symmetrical on the two sides of the fly-wheel), at the centre of the fly-wheel. The fly-wheel is spun rapidly, and the gyrostat is hung at the lower end of a long vertical steel wire, so that the axis of rotation is very nearly, if not quite, horizontal. If the gyrostat is turned round in azimuth, so that the wire is twisted, and is then left to itself, it swings in azimuth about the vertical in consequence of the torsional elasticity of the wire, performing also inclinational oscillations in the same period, and the period of this torsional vibration is much greater than that of the vibrations which the same system would execute if the fly-wheel had no rotation. The moment of inertia of the gyrostat round the vertical axis is virtually enormously increased.

This arrangement is analogous to that of a large and very rapidly rotating fly-wheel supported in a certain way on board ship, with its axis across the horizontal line about which the ship rolls. If this wheel were of great enough moment of inertia and rotated sufficiently rapidly it would virtually increase the moment of inertia of the rolling vessel and lengthen the period of rolling. The virtual increase of moment of inertia is proportional to the square of the angular momentum of the fly-wheel. I shall refer later to this arrangement.

Explanations of gyrostatic action have been given in papers communicated to this Institution: I may mention, in particular, Mr Matthey's paper on "The Mechanics of the Centrifugal Machine," which appears in Vol. XLII,. 1898-9. This paper contains much that is interesting on my present subject, freshly and clearly put. Then the subject came up again in connection with the loss of the "Cobra" in the German Ocean in 1901, when a correspondence took place in the technical journals as to whether the vessel might not have been acted on by gyrostatic forces, in consequence of the turbine machinery, sufficient to endanger her safety. I may say here at once that the conclusion come to by the writers who seemed qualified to give an opinion, that the gyrostatic action could not possibly have been of an amount sufficient to endanger the ship in any possible circumstances, seems the right one. There was a lack of data at that time as to the weights and dimensions of the turbines, only their speeds were approximately known, and it was only possible to take what were probably outside figures, and find what they gave. I am in a somewhat better position to-day, for I have received from Mr Luke, Professor Biles, and the Hon. C. A. Parsons, data wherewith to calculate gyrostatic moments in various extreme cases of pitching, or of rapid change of course of the vessel. The moments of inertia and the speeds are all that is required. What I propose to do to-night is to refer to gyrostatic action generally, to explain as well as I can the manner in which this action arises, bring before you various gyrostatic problems, and to give you, in conclusion, some figures on the subject of gyrostatic action of machinery on board ship. I make no pretence of bringing before you a new dynamics, or of describing novel devices which may have important applications in practice. But the modes of explanation which I adopt, though they make use of well-known dynamical principles, are in the main of my own framing, and the only excuse I can offer for troubling you with them is that they have helped to make my own conceptions of the action of rotating bodies clearer and more precise. The subject is not an easy one, if you are not content to be led merely by a set of equations, but like to visualise, as it were, every point in your own mind. For an elementary and yet sound account of the dynamical principles of the rotational motions of bodies, I strongly recommend to each of you who does not already know all about the subject, and there may be one or two, the perusal of Mr A. M. Worthington's excellent little book entitled "The Dynamics of Rotation."

II. Fundamental Principles of Dynamical Explanation.

The fundamental principles on which depend the explanation of gyrostatic action are few, and are easily apprehended by engineers. They are, in the main, the following:—

1. Rates of turning, or *angular velocities*, about different axes are capable of being compounded, like velocities or forces, so as to give a resultant rate of turning about a single axis, which represents the whole turning motion of the body.

The direction of this axis is to be found by drawing from a point, O, say, lines in the direction of the different axes (drawing them from the point O always so that to an observer looking along the line towards O, the turning motion of the body represented would be in a certain direction, which is taken as positive), and making these lines of lengths proportional to the angular velocities to be represented. Then the resultant of these lines, regarded as so many ordinary velocities or forces to be combined, has the direction of the resultant axis of turning, and its length represents the resultant angular velocity. In dynamical treatises the direction taken as positive is the direction opposite to that in which the hands of a watch appear to turn to an observer looking at the face.

2. Moments of momentum of the body about different axes may be combined, and a resultant axis of moment of momentum, and a resultant moment of momentum about it found by the process just specified for angular velocities.

By *moment of momentum* of a body about an axis is here meant what is frequently also called *angular momentum*, that is the product of the moment of inertia of the body about the axis into the angular velocity with which the body is turning about the axis. In what follows, moments of momentum will be taken in some cases in gramme-centimetre-second units, and in others in pound-foot-second or ton-foot-second units. Angular velocities will be taken not in revolutions per minute, but in radians per second. If π be the ratio of the circumference of a circle to its diameter, there are 2π radians in a revolution. Hence, to convert revolutions per minute into radians per second, the former must be multiplied by $\pi/30$.

3. The moment of momentum (or, as I shall generally call it, angular momentum) of the body about any axis is growing at each instant of time at a rate equal to the moment round that axis of the external forces exerted on the body at that instant.

It follows that if there are no external forces acting on the body which have moments about the axis in question, or, if there are such forces, if the sum of their moments about the axis is zero, the moment of momentum about the axis must remain constant.

And here, to prevent a possible ambiguity, it is to be understood that the rate of growth of angular momentum about an axis at any instant is understood of an axis regarded as fixed for the instant. I may have to consider the rate of growth of angular momentum about one such axis at one instant, and about another at a succeeding instant; but at each instant the axis is to be understood to be at rest. This is necessary, because it is usual to refer the motion of the body to axes, so to speak, fixed in the body, and as any such axis moves with the body, the motion referred to it at successive instants of time is really the motion referred to a succession of different axes taken in the former sense. Thus at any instant the motion about a fixed axis, OX, say, coinciding with a certain line, OA, in the body at that instant may be undergoing change at a certain rate G, that is to say, in a certain short interval of time τ, angular momentum $G\tau$ about that axis will at that rate have grown up. But it cannot be affirmed in a strict sense that this same increase of angular momentum will have been produced about the line OA in the body, which at the beginning of the time τ coincided with the axis OX. For this line OA has at the end of the short time τ separated from OX in consequence of the motion of the body.

4. Another principle made use of is that of energy. The sum of the kinetic and potential energies remains constant.

III. Dynamical Theory—Top Spinning about a Fixed Point.

Now, and this is the chief thing to be remembered, there are two ways in which rate of change of angular momentum of a body about a given axis (not necessarily continually fixed, but regarded as occupying at each instant a definite known position in space) may be caused by the action of the forces—(1) rate of change of the angular velocity about the axis may be produced; (2) *moment of momentum about the axis may be growing in consequence of change of position of the already rotating body.* Failure to notice this second point explicitly is the cause, I think, of most of the difficulty in apprehending this subject.

As an example, consider the diagram of the motion of a top, spinning with its point O fixed as in Fig. 13. OC, which is inclined to the vertical through the point O, at an angle which may be denoted by the usual symbol θ, is the axis of figure of the top. Then other two axes, O D, O E, at right angles to one another and to O C, are taken to which to refer the motion. O E is in the plane Z O C, and O D at right angles to that plane, and of course turn as that plane moves with the body. Now, suppose the motion (its changes will be analysed presently) to consist of a spin of angular velocity ω about the axis O C relatively to the plane Z O C, a turning of the top about the axis O D, by which the angle θ is increased, and finally a turning of the plane Z O C about O Z. This last is the conical motion or precession of the axis O C, which gives the familiar swaying motion of the top when it is rising slowly towards the vertical or falling away from it. Let the angular velocity of the turning about O Z, which might be called the precessional motion, be denoted by Ω.

Now, by the process of compounding angular velocities to which I have referred, Ω may be regarded as the resultant of two angular velocities about the axes O E and O C, which are in the same plane with O Z. These are $\Omega\cos\theta$ about OC, and $\Omega\sin\theta$ about OE.

But the top has been supposed to be spinning relatively to the plane Z O C, with angular velocity ω, and in consequence of the turning of that plane it has in addition the angular velocity $\Omega\cos\theta$. The total angular velocity of the top about its axis is thus $\omega + \Omega\cos\theta$. This I shall frequently denote by n, for presently it will be seen that it remains constant for a top not retarded by the friction of the air, and spinning about a fixed point in its axis.

I shall use in what follows Newton's mode of denoting the time rate of growth of a quantity by the symbol of the quantity with a dot placed above it, and the rate of growth of a rate of growth by the symbol of the quantity with two dots above it placed side by side.

Now, as the top spins, gravity is acting on it with a force through the centre of gravity of the top, so that there is a moment of external force about the line O D. The top tends to turn about O D, and if m be the mass of the top, h the distance of the centre of gravity from O, and g the force of gravity on unit of mass, the couple G due to gravity is $mgh\sin\theta$.

The rate of production of angular momentum about O D is thus $mgh\sin\theta$.

Let now the moment of inertia about O D or O E be A (the moments of inertia about these axes are the same, since the top is symmetrical about O C), and that about O C be C. The angular momentum of the top about O C is thus Cn, that about O D is $A\dot{\theta}$, where $\dot{\theta}$ is the angular velocity about O D, and the angular momentum about O E is $A\Omega\sin\theta$, all for a given instant of time. The direction of the turning in each case is shown by the small circles in Fig. 13.

Now, let a short interval of time τ, beginning with the instant under consideration, elapse. During this interval the body changes its position, and the moving axes to which its motion is referred change also into new positions, according to the specification imposed on their motion. Then resolve along the line, O D′ say, which marks the position that O D had at the beginning of τ, the angular momenta of the body about the three new positions of O D, O C, and O E. The excess of the total angular momentum about O D′ thus obtained over that existing at the beginning of τ, is the gain of angular momentum in that time; and this excess, divided by τ, is the average rate of gain during τ for the direction O D′. This average I can, by taking τ sufficiently small, make as nearly as I please the rate of gain about O D, at the instant under consideration.

Calculate, then, first, the angular momentum about O D in its new position after time τ has just elapsed. If $\dot{\theta}$ was the angular velocity for the axis O D at the first instant of τ, that is for the position O D′, that about O D in its new position at the end of τ will be $\dot{\theta}+\ddot{\theta}\tau$, if $\ddot{\theta}$ be the average rate during τ at which $\dot{\theta}$ is changing. [Observe that $\dot{\theta}$ denotes the rate of turning about O D, when O D is in a definite specified position, but that $\ddot{\theta}$ is the rate at which this rate of turning, thus specified, is found to grow, as O D is followed in its change of position with lapse of time]. The angular momentum about O D is now $A(\dot{\theta}+\ddot{\theta}\tau)$. For the angle through which O D has turned away from O D′ is a small angle α, proportional to τ. The component of angular momentum about O D′, due to the angular momentum about O D, is thus $A(\dot{\theta}+\ddot{\theta}\tau)\cos\alpha$. But by making τ sufficiently small, $\cos\alpha$ can be made as nearly 1 as may be desired, and hence, in the limit, the component of angular momentum about O D′, is $A(\dot{\theta}+\ddot{\theta}\tau)$. The gain of angular momentum about O D can thus be made in the limit $A\ddot{\theta}\tau$, where $\ddot{\theta}$ has the meaning explained above with respect to O D.

The first part of the rate at which angular momentum is growing about O D in its position at the instant considered is, therefore, $A\ddot{\theta}$.

There is next the part due to the turning about O E with angular velocity $\Omega\sin\theta$. The direction of this turning is shown by the arrow-head on the small circle at E in the diagram, Fig. 13. It will be seen that this turning round OE is bringing the top, with its spin about its axis, so as to face more towards the instantaneous position of O D. Let a small interval of time τ elapse, and think again of the axis, OD′, remaining fixed in the position which OD has at the beginning of τ. The angle through which the top has turned about O E in τ is $\Omega\tau\sin\theta$, and the angle which O C now makes with OD′ is $\pi/2 - \omega\tau\sin\theta$. The angular momentum which the spinning motion has now round OD′ is $Cn\cos(\pi/2 - \Omega\tau\sin\theta)$ or $Cn\sin(\Omega\tau\sin\theta)$. But the angle $\omega\tau\sin\theta$ is small, and therefore, as it is measured in radians, may be taken as equal to its sine. Thus, there has been produced, by this change of position of the body, angular momentum about O D′ of amount $Cn\Omega\tau\sin\theta$. [Note that if θ were $\pi/2$, that is, if OC were horizontal, this would be $Cn\Omega\tau$]. The direction of this angular momentum is that shown by the small circle at D. The rate of production of angular momentum from this cause is, therefore, $Cn\Omega\sin\theta$.

Again, in consequence of the turning of the axis O E about O C with angular velocity $\Omega\cos\theta$, O E is made to face round towards the direction opposite to O D′ through the angle $\Omega\tau\cos\theta$. Hence, as the angular momentum about O E in the direction of the arrow is $A\Omega\sin\theta$, this change of position gives a component of angular momentum about O D′ in the opposite direction to the arrow at D, of amount $A\Omega\sin\theta\sin(\Omega\tau\cos\theta)$, or, since $\Omega\tau\cos\theta$ is small, of amount $A\Omega^2\tau\sin\theta\cos\theta$. Thus the rate of production of angular momentum from this cause, since the direction of the arrow at D is here taken as the positive one, is $-A\Omega^2\sin\theta\cos\theta$.

Besides the changes which have been taken into account there is a change of the angular momentum about O E, arising from the alteration which takes place in time in τ in $\Omega\sin\theta$ in consequence of growth $d\Omega$ of Ω or $d\theta$ of θ, or both. Let $\Omega\sin\theta$ become for the new position of O E $(\Omega+d\Omega)\sin(\theta+d\theta)$. This, if terms in which the products of small quantities appear be neglected in comparison with the other terms, becomes $\Omega\sin\theta+\Omega\cos\theta d\theta+d\Omega\sin\theta$. Thus the change in $A\Omega\sin\theta$ is $A(\Omega\cos\theta d\theta+d\Omega\sin\theta)$. The component of this about O D′ is this quantity multiplied into the cosine of the angle which O E now makes with O D′, which obviously can be taken as nearly a right angle as may be desired by taking τ small enough. Since the cosine of a right angle is zero, this product is zero in the limit, and does not influence the result.

Hence, summed up, the total rate of production of angular momentum in the positive direction about the fixed direction coinciding at the instant with O D, is

$$A\ddot{\theta}+Cn\Omega\sin\theta-A\Omega^2\sin\theta\cos\theta,$$

and this must be equal to the moment G of the forces about O D that is to $mgh\sin\theta$. Hence the equation :—

$$A\ddot{\theta}-(A\Omega\cos\theta-Cn)\Omega\sin\theta=mgh\sin\theta, \quad - \quad (1).$$

This is an important *equation of motion*, as it is called, of the top. It is applicable also to the gyrostat if A and m are supposed to refer to the whole body, case and fly-wheel, C to the fly-wheel alone, and for $A\Omega\cos\theta$ on the left is substituted $(A-C')\Omega\cos\theta$, where C′ is the moment of inertia of the case about the axis of figure.

Two other results are easily obtained which hold along with equation (1). One is the constancy of the angular momentum and angular velocity about O C. There is no change of this due to change of position of the body, and since there are no forces which have moment about O C, there can be no change of angular velocity about C. Hence n and Cn both remain constant. Therefore

$$Cn=0, \quad - \quad - \quad - \quad - \quad - \quad (2).$$

Another is the constancy of the angular momentum about the vertical O Z. The amount of this (for the *top* only) at any instant is $Cn\cos\theta+A\Omega\sin\theta\sin\theta$, or $Cn\cos\theta+A\Omega\sin^2\theta$. Now, there are no forces that have moment about the vertical, and, therefore, this must remain constant. Since n is constant, the changes in this due to rate of change of Ω, and to the change in position due to change of θ, must compensate one another. Hence another expression is obtained which may be stated as :—

$$\left.\begin{aligned}&\frac{d}{dt}(Cn\cos\theta+A\Omega\sin^2\theta)=0, \quad - \quad -\\ \text{or,}\quad &Cn\cos\theta+A\Omega\sin^2\theta=H, \quad - \quad - \quad -\end{aligned}\right\}\ (3),$$

where H is a constant. This expresses that the rate of growth of angular momentum about O Z is zero.

These equations, with the equation (1) already obtained, are sufficient to give the whole motion of the top, and the fact can be deduced with ease that the centre of gravity alternately rises and falls as the top spins and the plane Z O C turns round.

Equation (1) shows that the value of $\ddot{\theta}$ depends on that of Ω, and that the condition that $\ddot{\theta}$ should be zero is that the equation

$$(A\Omega\cos\theta - Cn)\Omega\sin\theta + mgh\sin\theta = 0, \quad - \quad - \quad (1'),$$

should hold. But from equation (3)

$$\Omega = \frac{H - Cn\cos\theta}{A\sin^2\theta}, \quad - \quad - \quad - \quad (4),$$

and this value of Ω used in (1′) gives an equation in θ for the condition that $\ddot{\theta}$ should be zero. Again, the expression for the kinetic energy, which is obtained at once by simply summing the kinetic energies for the rotations about the axes O C, O D, O E, added to the potential energy of the top, and equated to a constant gives an equation which is called a first integral of the equations of motion. The kinetic energy is:—

$$\tfrac{1}{2}Cn^2 + \tfrac{1}{2}A\dot{\theta}^2 + \tfrac{1}{2}A\Omega^2\sin^2\theta + mgh\cos\theta = K, \quad - \quad (5),$$

where K is a constant. This is easily obtained also from the equations of motion. If in this be put $\dot{\theta} = 0$, and the value of Ω given by (4), then an equation is obtained which gives two possible values of $\cos\theta$, and therefore of θ, for which $\dot{\theta}$, the angular velocity about O D, is zero. Thus the top rises and falls between these limits of θ. The path of the upper end of the axis C of the top, photographed on a horizontal plate, could be similar to the succession of curves meeting at their cusps shown in Fig. 14.

Equation (5) is applicable to the gyrostat, provided m and A be taken for the whole instrument, case and fly-wheel together, and C for the fly-wheel alone, and provided that a term $\tfrac{1}{2}C'\Omega^2\cos^2\theta$ (see page 285) is added on the left for the energy of rotation of the case about the axis of figure. When the gyrostat rests, with the plane of the fly-wheel inclined to the vertical, on its projecting edge on the glass plate as in the experiment I now show, in which steady precessional motion is taking place, some modifications of the quantities involved in the derivation of the equations are necessary, since the gyrostat is not supported at a point in its axis of rotation, but a similar argument is applicable.

IV. Euler's Equations of the Motion of a Rigid Body, One Point of which is Fixed.

It may be remarked here that the process used above can be applied in other cases of moving axes, for example, when the axes are *fixed in the body* and, therefore, move with it. In the case just considered the axes move, but (except OC) they are not fixed *relatively to the body*, but relatively to the moving vertical plane ZOC, Fig. 13. An important case of axes fixed in the body is that in which the body is turning about a fixed point, and the axes are chosen coincident with the principal axes of moment of inertia for that point. If A, B, C, be the principal moments of inertia of the body about these axes, OA, OB, OC, say, ω_1, ω_2, ω_3 the angular velocities of the body, and L, M, N, the moments of the externally applied forces about OA, OB, OC, respectively at the instant under consideration, the equations of motion of the body are:—

$$\left.\begin{aligned} A\dot{\omega}_1 - (B-C)\omega_2\omega_3 &= L, \\ B\dot{\omega}_2 - (C-A)\omega_3\omega_1 &= M, \\ C\dot{\omega}_3 - (A-B)\omega_1\omega_2 &= N, \end{aligned}\right\} \quad (6).$$

The reader may, as an exercise, endeavour to establish these equations, which are known as Euler's equations of the motion of a rigid body moving with one point fixed. It may be mentioned that $\dot{\omega}_1$, $\dot{\omega}_2$, $\dot{\omega}_3$, which are the rates of growth of ω_1, ω_2, ω_3, following the axes as they move, can be shown to be the same as the angular accelerations about fixed axes coinciding with AB, OB, OC, at the instant, a result which cannot be inferred from the fact that ω_1, ω_2, ω_3, are the angular velocities about these fixed axes at the instant. Euler's equations are the formal set of equations usually applied to the motions of tops, quoits, etc.

The equations here specified refer to a particular set of axes, OA, OB, OC, which move with the body. In the case of the symmetrical top, these may be taken as coinciding at a given instant with OD, OE, OC, which move with the vertical plane ZOC. But the rate of change of the angular velocity about OA or OB must not be confused with the quite different acceleration about OD or OE. For after a short interval of time τ, the axes OA, OB, will have moved away from OD, OE, because OA, OB, turn about OC with angular velocity n, and OD, DE, turn about OC with angular velocity $\Omega\cos\theta$, that is $n-\omega$. OC alone in the two sets of axes is fixed in the body. Thus, after time τ, the angular velocities about the new positions of OA, OB, are not the same as those at the same instant about OD, OE. I shall exhibit the difference for OA and OD, and hence find the accelerations for these axes.

For this purpose it will be convenient to use the idea of a cone fixed in the body rolling on a cone fixed in space, referred to above and illustrated in Fig. 13. The reader is asked here to indicate on Fig. 13 a circle through I with its centre on, and its plane at right angles to, OZ, so that a cone with its apex at O, OZ as its axis, OI a straight line on its surface, and IOZ as semi-vertical angle, is represented. Then a second circle through I, with its centre on, and its plane at right angles to, OC, is to be added. Thus a second cone with its apex at O, OC as its axis, OI on its surface, and IOC as semi-vertical angle, is represented. OI is a generating line common to the two cones. By the specification now to be given of the position of OI, the former cone is a cone fixed in space on which the second cone fixed on the body rolls, in the direction indicated by the arrow on the top, as the body moves. For the line OI in Fig. 13 is so chosen that it is the direction of the axis of resultant angular velocity, and therefore makes an angle a with OC, the tangent of which is $\Omega\sin\theta/n$. The angular velocity about OC is n, and that about OB (or OE) is $\Omega\sin\theta$. Hence the resultant is $\sqrt{n^2+\Omega^2\sin^2\theta}$, and the direction of OI is as stated, since, clearly, the amounts and directions of the angular velocities, about OC and OZ, cause each point of OI to be instantaneously at rest. Now, OI always lies in the vertical plane ZOC, which turns round OZ with angular velocity Ω. Hence, if θ does not vary neither does α, and OI moves round OZ in the cone of semi-vertical angle $\mathrm{IOZ} = \theta - \alpha$ which is the cone fixed in space. (I shall suppose θ to remain invariable, and allow afterwards for any change in $\dot{\theta}$, which, as will be seen, is all that can sensibly affect the angular velocity about OA, besides the changes involved in the conical motion). The cone fixed in the body, which rolls on the cone fixed in space, is the cone of axis OC, and semi-vertical angle $\mathrm{IOC} = \alpha$.

Now, starting at the instant at which OA and OB coincide with OD and OE (the latter in, the former at right angles to, the vertical plane ZOC), let a short interval τ of time elapse. The moving cone has rolled forward along the fixed cone, and the instantaneous axis of turning of the body is now OI′. The change of direction IOI′ on the surface of the cone is towards the position OA′ say (coinciding with OD′, as specified above) occupied by OA at the beginning of the time τ. The magnitude of the angle IOI′ is $\Omega\tau\sin(\theta - \alpha)$. For if $\mathrm{OI} = r$, then since I and I′ lie on the horizontal circle through I of axis OZ, the distance II′ is $\Omega\tau\mathrm{IZ} = \Omega\tau r\sin(\theta - \alpha)$ and the angle IOI′, as stated, has the value $\Omega\tau\sin(\theta - \alpha)$. By this turning of OI towards OA′ the angular velocity about OA′ has been increased by $\sqrt{n^2 + \Omega^2\sin^2\theta}.\cos\{\pi/2 - \Omega\tau\sin(\theta - \alpha)\}$, that is by $\sqrt{n^2 + \Omega^2\sin^2\theta}.\Omega\tau\sin(\theta - \alpha)$. (The semi-vertical angle of the cone has in the time τ been increased by $\dot{\theta}\tau$, but this has only moved the instantaneous axis parallel to the instantaneous position of the plane ZOC, and therefore can have produced no effect on the angular velocity about OA′). Now, the geometry of the figure gives $\sin(\theta - \alpha)/\sin\theta = (n - \Omega\cos\theta)/\sqrt{n^2 + \Omega^2\sin^2\theta}$, so that the change of angular velocity just calculated is $\Omega\tau(n - \Omega\cos\theta)\sin\theta$. To this falls to be added any change $\ddot{\theta}\tau$, which has grown up in the rate of increase $\dot{\theta}$ of the angle θ. The total rate of production of angular velocity about OA′ is therefore $\ddot{\theta} + \Omega(n - \Omega\cos\theta)\sin\theta$, and this, as remarked above, can be shown to be also the rate of change of the angular velocity which is associated with the axis OA as it moves with the body.

The angular acceleration about the axis OD, which remains in the plane ZOC, is uninfluenced by the rotation of the body with angular velocity $\omega = n - \Omega\cos\theta$ relatively to the plane ZOC, and is simply $\ddot{\theta}$.

For examples of equations (6), the reader may refer to any of the treatises on Rigid Dynamics, such as Routh's or Besant's. Their application to the rotational motion of a symmetrical body, such as a circular disc or ring (*e.g.*, a quoit), or an elongated cylinder (*e.g.*, a stick), thrown into the air, will be found in Tait's *Dynamics*, Sec. 264. It is easy to show that in each case the instantaneous axis describes a right cone fixed in the body, the axis of which is the axis of figure, and that this cone rolls on a cone fixed in space. In the case of the quoit, the rolling is on the *outside* of the space-cone, in the other case the rolling is on the *inside* of the space-cone.

V. Steady Precessional Motion of Top or Gyrostat.

Consider what may be called the steady motion of the top or gyrostat supported at a point in its axis of rotation. This is the motion given by equation (1) when $\dot{\theta}$ and $\ddot{\theta}$ are zero, and therefore θ is constant. Then also Ω must be constant. The equation then gives, if θ be not zero or π,

$$Cn\Omega - A\Omega^2\cos\theta = mgh, \quad - \quad - \quad - \quad (7)$$

For θ less than $\pi/2$, this motion is only possible if C^2n^2 be greater than $4Amgh\cos\theta$, and it is important to notice that the equation gives then *two* real values of Ω. If n be sufficiently great these may be taken as

$$\Omega = Cn/A\cos\theta, \quad \Omega = mgh/Cn. \quad - \quad - \quad (7')$$

The first of these is great (infinite for $\theta = \pi/2$, and negative for $\theta > \pi/2$), the second is small. Either (infinity excluded) can be realised by properly starting the top. In ordinary cases θ and Ω are initially zero, and the second is the proper value of Ω, for the steady state about which the motion oscillates.

This gives the precessional angular velocity in terms of the moment about OD of the forces due to gravity and the angular momentum. For a symmetrical *gyrostat* A must be understood to mean here the difference $A-C'$ specified on page 285.

As a numerical example of equation (7'), take an actual gyrostat for which masses in grammes and distances in centimetres are known. For this, $m=2200$, $C=1500\times 4^2$, $h=5$, and speed of rotation 200 revolutions per second. Then, since in centimetre-second units $g=981$, $\Omega=\cdot 358$ in radians per second, if C' be neglected. Thus the precessional motion is about 20° per second, or one revolution in 18 seconds.

But because of the light which I think it throws on the mode of production of the precessional motion, which is the chief difficulty felt by most people, I shall consider specially the case of $\theta=90°$. This is the case of the gyrostat hung up as in this experiment here (see diagram Fig. 8) by a string attached at the part of the case surrounding the axis. You see that the gyrostat, as I stated in the introductory part of this paper, does not fall down, but turns steadily round in azimuth with its axis approximately horizontal.

If mg here be the force of gravity on the mass of the whole gyrostat, and h the distance of its centre of gravity from the attachment of the cord, the moment of the forces is mgh tending to turn the gyrostat about a horizontal axis at right angles to the axis of rotation, and passing through the axis where the cord is attached. This produces in time τ an angular momentum of amount mgh. Now if the motion is steady, this is entirely accounted for by the turning of the gyrostat about the cord. For let O A represent the position of the axis at any instant, then the length of the line O A may be taken to represent the angular momentum Cn of the fly-wheel round it. Let O B represent the angular momentum produced in time τ by the moment of forces $mgh\tau$. Then O A, remaining horizontal, turns towards the position O B' which O B had at the beginning of the interval τ, through the angle $\Omega\tau$, to a position OA_1, and therefore Cn gives in that time a component $Cn\sin(\Omega\tau)$, or $Cn\Omega\tau$, round O B'. The rate of production of angular momentum about O B by the turning round of Cn

is thus $Cn\Omega$, and if the motion is steady, this must be equal to mgh. Thus I obtain the relation

$$Cn\Omega = mgh$$

as before. Here however the equation is exact, because of the vanishing of the term $A\Omega^2\cos\theta$.

The process it will be seen is briefly this. As the gyrostat turns about the vertical axis, there is a constant rate of production of angular momentum about the horizontal axis, which is perpendicular both to the cord and to the axis of rotation. This rate of production of angular momentum is $Cn\Omega$.

The reader may argue that there can be no such production of angular momentum, since if there were such turning, the axis should, he might think, tilt downward. But he must remember that a rate of growth of angular momentum is not angular momentum itself, any more than acceleration is velocity, or speed of motion is distance travelled. An acceleration towards the centre exists for a particle describing a circular path, though the particle never acquires velocity along any radius. The reason is that though there is acceleration towards the centre along any radius at the extremity of which the particle finds itself at the instant, it is in the act of passing on to the extremity of a radius a little further round. The velocity is growing at each instant at a constant rate in the direction at right angles to itself; but the particle does not remain at the extremity of a particular radius for any *interval* of time *however short*. Now in order that a velocity however small along a particular radius (and in no other direction) may be generated, the particle would have to remain at the extremity of that radius for an interval of time, and not be there merely at what I may call a *point* of time.

It is the same in the case here considered. Let O A be the direction at a certain instant of the axis of the fly-wheel, and represent by its length the magnitude of the angular momentum about it. The positions of the axis after successive intervals τ_1, τ_2, are indicated by O A_1, O A_2. O A by its length and direction together, therefore represents the angular momentum of the fly-wheel about $O A_2$ in direction and magnitude. Now $O A_1$ is not the same angular momentum as O A. It is the same in magnitude, but the direction is changed. The angular momentum is that obtained by compounding with $O A_1$ the angular momentum represented by $A A_1$, which is perpendicular to $O A_1$; $O A_2$ is got by compounding with $O A_1$ the angular momentum represented by $A_1 A_2$, which is perpendicular to $O A_1$, and so on. There is continual *addition* (in the sense of addition of directed quantities) of components of momentum. Yet the actual magnitude of the angular momentum about the axis is not altered; the direction is continually changed.

The rate of addition of angular momentum is always of angular momentum at right angles to that already existing, and thus the precessional motion of the axis continues at a steady rate. The angular momentum is, in point of fact, continually changing by additions at right angles to itself, just as the velocity of the particle in the circle is always growing at right angles to its own direction. In neither case is the numerical amount altered, though in both the directed quantity changes. The same hodographic construction which gives the acceleration for the particle can be applied to give the rate of growth of angular momentum in the gyrostat. This, in point of fact, is what this elementary discussion amounts to.

VI. Elementary Explanation of Origin of Precession.

I may demonstrate how the precession takes place also by elementary considerations which are presented in the following way by Mr Worthington in his book. Let A C B D Fig. 15, represent the fly-wheel as seen from one side, A B a horizontal diameter. Let an angular velocity be suddenly impressed about the horizontal diameter A B, while the wheel is rotating with angular velocity n about its axis, both rotations being in the direction represented by the arrows on the large circle and at B. A particle M of the wheel in the quadrant as it moves in its circle in the wheel is just rising above A B. Now the angular momentum of the particle about A B is proportional to the square of its distance from, and its angular velocity about, A B, and it tends to retain that angular momentum without change. Hence as it rises higher above A B it tends to move more slowly in its motion about A B, that is, it resists being carried on with the wheel about A B. This holds for all particles in the quadrant A O C (O is the centre), and hence this quadrant is on the whole acted on by resisting forces tending to turn it about C D, in the direction of the arrow shown at the top of the diagram.

Consider now the quadrant A O D. A particle M in that is approaching the axis A B, and hence as regards its motion about A B tends to move quickly. Hence it urges that quadrant in the direction to turn it about O D in the direction through the paper, and the same thing holds for all the particles in this compartment at the instant. Hence the right-hand half of the wheel tends to turn about C D in the direction shown by the arrow at the top.

In the same way it can be shown that the other half of the wheel tends to move in the opposite direction, that is the whole wheel tends to turn about C D in the direction shown by the arrow at the top.

If now a turning about C D is impressed on the fly-wheel of amount just enough to produce, by change of position of the wheel, angular momentum about the axis A B, at the rate given by the couple applied to the gyrostat by gravity or otherwise, there will be no tilting down of the axis, but the rotation about the axis of the fly-wheel and the precessional motion will continue without change except in so far as frictional resistances interfere with them.

Another way of picturing the mode of production of precession to the mind is to think of a rigid hollow ring, Fig. 16, at rest in a vertical plane, while a set of balls closely fitting the hollow space, are circulating without friction round the ring. Let a sudden turning about a horizontal diameter, A B, be given to the ring:

the balls which are above A B, will be made to move one way at right angles to the former position of the plane of the ring; those below A B will be made to move the other way. Let the motion about A B of the first set to an observer looking at one side of the ring be towards him, that of the other set be from him, and let the circulating motion be to him in the opposite direction to that of the hands of a watch. Consider a ball on the right side near the horizontal diameter, and above it. Its angular momentum about A B is proportional to its linear velocity towards the observer, and to its distance from A B. But in the circulating motion it is increasing its distance from A B, and its linear velocity at right angles to the plane diminishes, since the ball tends to preserve the angular momentum suddenly given to it. The ball therefore presses against the further side of the ring, and tends to impede the forward motion of that part. Again a particle below A B is moving nearer to A B, and as it also tends to keep the angular momentum about A B which was given to it, it moves more quickly as the distance diminishes. Hence as it is moving from the observer it also presses against the further side of the ring. Thus the whole right half of the ring is pressed from the observer.

In the same way it can be shown that the whole left half is pressed towards the observer, with forces corresponding to those exerted on the left half. Thus the ring tends to turn about its vertical diameter C D, that is to take up a precessional motion. This it will do unless acted on by a constraining framework which prevents it. In the latter case the ring will apply a turning motive to the framework, which will be balanced by the torque, by which the framework prevents the precession. This torque will be computed presently.

VII. Oscillations of Gyrostat about State of Steady Motion.

I may now complete this elementary theoretical proof that ho gyrostat can turn in azimuth steadily in the manner just described, by showing that if it is slightly displaced from this mode of motion it will perform vibrations about the steady motion, that is the axis will alternately rise and fall through a small range on each side of the horizontal position. For this go back to equation (1) which was established by the elementary considerations I have explained, and for simplicity neglect C′ (see page 285).

Let $\theta=\pi/2+\alpha$, and $\Omega=\Omega_1+\omega$, where Ω_1 is the steady value of the precessional angular velocity, and α and ω are small variations from the steady values $\pi/2$ of θ and Ω_1 of Ω. Then, put in (1) these values of θ and Ω, notice that $\sin(\pi/2+\alpha)=\cos\alpha$, $\cos(\pi/2+\alpha)=-\sin\alpha$, strike out the common factor $\cos\alpha$ from both sides, and neglect terms involving squares or products of the small quantities ω,α. Equation (1) becomes

$$A\ddot{\alpha}+Cn(\Omega_1+\omega)+A\Omega_1{}^2\alpha=mgh. \quad - \quad - \quad (8),$$

But by the condition of steady motion

$$Cn\Omega_1=mgh \quad - \quad - \quad - \quad (9),$$

so that the last equation becomes

$$A\ddot{\alpha}+Cn\omega+A\Omega_1{}^2\alpha=0 \quad - \quad - \quad - \quad (10).$$

Since there is constancy of angular momentum about the vertical suspension cord,

$$A\Omega_1=A(\Omega_1+\omega)\sin^2\left(\frac{\pi}{2}+\alpha\right)+Cn\cos\left(\frac{\pi}{2}+\alpha\right)$$

or,

$$A\Omega_1=A(\Omega_1+\omega)\cos^2\alpha-Cn\sin\alpha.$$

This (if on account of the smallness of α, $\cos^2\alpha$ be put $=1$, $\sin\alpha=\alpha$) becomes, after reduction,

$$\omega=\frac{Cn}{A}\alpha, \quad - \quad - \quad - \quad - \quad - \quad - \quad (11).$$

If this value of ω be substituted in (10), and terms involving α^2 be neglected, that equation becomes

$$\ddot{\alpha}+m_1^2\alpha=0 \quad - \quad - \quad - \quad - \quad (12),$$

where by (9)

$$m_1^2=\frac{C^2n^2+A^2\Omega_1^2}{A^2}=\frac{m^2g^2h^2+A^2\Omega_1^4}{A^2\Omega_1{}^2}$$

Equation (12) shows that the angular acceleration $\ddot{a}$ is towards the steady motion configuration, and is proportional to a. This is the well-known characteristic of angular oscillations in period $2\pi/m$, that is the period

$$T = 2\pi \frac{. A\Omega_1}{\sqrt{A\Omega_1^4 + m^2 g^2 h^2}}, \quad - \quad - \quad (13).$$

Thus as the gyrostat revolves in azimuth the outer end of the axis alternately rises above and falls below the horizontal position in the period stated. It will be observed that if Ω_1 is very small, that is, if n be very great, the period is approximately $2\pi A\Omega_1/mgh$. Thus the more rapid the rotation n, the shorter is the period, that is the greater is the return action brought into play by any deviation from the steady motion, in other words the more stable is the motion.

In the same way the more general case of oscillations about a steady value of θ not equal to $\pi/2$, could be treated by the reader. If C′ is neglected the period is

$$2\pi \frac{A\Omega_1}{\{A^2\Omega_1^4 + m^2 g^2 h^2 - 2A\Omega_1{}^2 mgh\cos\theta\}^{\frac{1}{2}}}.$$

VIII. Effect of Hurrying or Retarding Precession—Rising and Falling of Ordinary Top—Stability or Instability of Gyrostat Made Dependent on Direction of Precession.

Consider now the effect of applying to this gyrostat a couple about the vertical axis tending to quicken or to retard the precession. Let the couple be applied so as to aid the precession produced by gravity acting on the gyrostat supported as in Fig. 8. It will be seen that faster precession would increase the rate of production of angular momentum about the horizontal axis through the point of attachment of the cord, beyond the rate mgh due to the precessional turning arising from moment of the gravity forces, which is the only moment of forces acting about this axis. Since the rate must stand at this value the excess must be compensated by upward motion of the outer end of the axis of the gyrostat; that is the action of the forces tending to increase the precession is to raise the gyrostat. In the same way the forces retarding the gyrostat makes the outer extremity of the gyrostat drop, the gyrostat falls.

This is also illustrated by the diagram of a balanced gyrostat in Fig. 17. Precession impressed in one direction makes the gyrostat rise, in the other direction causes it to fall.

Another way to look at the matter is to notice that just as the gravity couple gives turning about the vertical axis, which is at right angles to the axis round which the gravity couple acts and also to the axis of rotation, so the new couple applied about the vertical gives turning about an axis which is perpendicular at once to the vertical axis and to the axis of rotation. Also just as the gyrostat turns its axis to point so as to give, by the rotation of its fly-wheel, a component of angular momentum in the direction of that which gravity tends to produce, so when the couple about the vertical axis is applied the gyrostat turns its axis of rotation towards pointing upward or downward according to the sign of the angular momentum which the couple applied produces.

In this way, as stated above, is explained the rising and falling of a top, spinning on a rounded peg on a hard stone slab, as indicated in the diagram, Fig. 11. If the spin is fast enough the point of contact with the slab is not at rest, though the top rolls forward with the hoop-motion of the circle of contact of the peg with which the precessional motion is associated, but is moving backward relatively to the plane. The action of friction on the peg is then to hurry up the precession and the top rises; on the other hand, when the spin has fallen off, the point of contact is moving forward and the friction delays the precession, with the result that the top falls.

As another illustration let me take the experiment represented in the adjoining diagram, Fig. 12. The gyrostat is supported by two trunnions screwed to the projecting edge in the plane of the fly-wheel on a wooden tray as shown. The axis of the fly-wheel is very nearly vertical, and the wheel is spinning rapidly in the direction of the arrow shown on the upper side of the case.

The centre of gravity of the whole instrument is nearly on the level of the trunnions, so that there is no stability due to gravity.

If now I carry the tray round horizontally with angular velocity Ω in the direction of spin, the gyrostat remains quite stable. If, however, I carry the tray round in the opposite direction the gyrostat immediately turns on its trunnions and capsizes so that the other end of the axis is uppermost, and if the motion Ω is continued in the same direction the gyrostat is now stable. It will be observed that the fly-wheel is now spinning in the direction of the azimuthal motion. Hence the gyrostat is in stable equilibrium when the azimuthal motion is in the same direction as the rotational motion.

This result follows from equation (1) adapted to fit this particular case. It will be seen that the terms $mgh\sin\theta$ and $A\Omega^2\sin\theta\cos\theta$ are small in comparison with $Cn\Omega\sin\theta$, the former because h is practically zero, and the latter because Ω is small in comparison with n.

Hence the equation is (since θ being small $\sin\theta = \theta$)

$$A\ddot{\theta} + Cn\Omega\theta = 0 \qquad - \quad - \quad - \qquad (14).$$

The solution of this differential equation, if n and Ω be in the same direction so that $n\Omega$ is positive, is oscillatory motion of period $2\pi\sqrt{A/Cn\Omega}$ about the vertical position, so that this position is stable.

On the other hand, if n and Ω have opposite signs the solution of the differential equation is of another form, curiously connected with the former, but representing a different state of things. It shows that if the gyrostat is disturbed from the vertical position of its axis it tends to pass further away from it; as you have seen, the instrument capsizes.

These results are indeed indicated by the differential equation. The moment $Cn\Omega\theta$, producing rate of change $A\ddot{\theta}$ of angular momentum, is in the first case in the direction to check motion away from the vertical position and to bring the gyrostat back to that position, while in the other case $Cn\Omega\theta$, having the opposite sign, produces moment of momentum in the direction away from the vertical.

This illustration is of interest in connection with Sir Henry Bessemer's proposal to obtain a steady platform at sea by means of a rapidly spinning fly-wheel on board ship, and shows that the scheme was doomed to failure. (See page 306).

The same process is applicable directly to the theory of the method proposed by Foucault long ago to use a properly mounted gyrostat to show the rotation of the earth. Let the gyrostat be supported on an axis, as on the tray in the experiment just described, passing through the centre of gravity, and let the axis of rotation be made to point in or nearly in the direction of the earth's axis. I shall suppose the trunnion axis to be fixed horizontally east and west. Then the slow turning motion of the earth supplies the angular velocity Ω. If the gyrostat be so placed that the direction of spin of the fly-wheel is in the direction of the rotation of the earth — then I have precisely the same equation as before—

$$A\ddot{\theta} + Cn\Omega\theta = 0$$

if θ be small. The gyrostat then turns on its trunnions, so that its axis moves in the meridian, and oscillates about the direction of the earth's axis in the period $2\pi\sqrt{A/Cn\Omega}$, where n is the angular velocity of spin of the gyrostat, and Ω the angular velocity of the earth's rotation.

The same simple considerations give the complete solutions in nearly every other case, for example for Foucault's gyrostat constrained to move in a horizontal plane, and for Gilbert's Barygyroscope, another arrangement for demonstrating by a gyrostat the earth's rotation.

In this a gyrostat is supported on trunnions, as in Foucault's experiment, fixed horizontally east and west; but it is given a certain adjustable amount of gravitational stability through the centre of gravity being beneath the line of trunnions.

Let l be the (north) latitude of the place, and the axis of rotation of the fly-wheel be inclined at an angle θ (lower end, say, towards the south) to the vertical at the place. The angular velocity, ω say, of the earth's rotation can be resolved into two components, one

$\omega\sin(l+\theta)$, about the axis of the fly-wheel, the other $\omega\cos(l+\theta)$, about a line at right angles to this axis, and drawn towards the north. If n and ω be in the same direction, the component $\omega\cos(l+\theta)$ gives a precessional motion which, for a proper value of θ, will equal $mgh\sin\theta$. At this inclination there will be equilibrium, and then, as in the cases considered above, $Cn\cos(l+\theta)=mgh\sin\theta$. Hence

$$\tan\theta=\frac{Cn\omega\cos l}{Cn\omega\sin l+mgh}.$$

If the spin be reversed the inclination is to the other side of the vertical, and of amount θ' given by

$$\tan\theta'=\frac{Cn\omega\cos l}{Cn\omega\sin l-mgh}.$$

This deviation θ or θ' must be taken into account when a gyrostat is used as a clinometer, or to give an artificial horizon.

IX. Gyrostatic Pendulum.—Analogue of Zeeman Effect in Electromagnetism.

I shall consider as another example of the results obtained, the motion of a pendulum, which has for bob a gyrostat with its axis along the line of suspension (see Fig. 18). This problem is of great interest because of its bearing on many physical problems, for example, the rotation of the plane of polarisation of a beam of plane polarised light transmitted along the lines of force in a transparent diamagnetic medium, such as bisulphide of carbon, or a magnetic medium, such as a thin transparent film of one of the magnetisable metals. It also gives a perfect analogue of the motions of the electrons in a source of light between the poles of a magnet, which produce the optical effect discovered a few years ago by Zeeman. As is now well known, when a source of light in a magnetic field is viewed through a spectroscope in the direction at right angles to the lines of force, the otherwise single line spectrum is found to be converted into a multilinear one, for example, into a triplet of lines, of which the two side-lines are formed by light polarised in the planes parallel to the field, while the middle line, which is due to the unmodified component of motion in the direction of the field, is formed by light plane polarised at right angles to the field.

For simplicity, I shall suppose the mass of the case and supporting rod of the pendulum to have practically no moment of inertia about the line joining the centre of gravity to the point of suspension, so that the only moment of inertia about this line is that of the fly-wheel. This will obviate the necessity for considering whether the suspension at the top is a perfectly flexible and untwistable arrangement, such as a Hooke's joint, the upper member of which does not swivel about a vertical axis, or a perfectly flexible, and at the same time, swivelling joint.

Let A be the moment of inertia of the whole arrangement about a horizontal axis through the point of support; let also C be the moment of inertia of the fly-wheel, and n its angular velocity of rotation at any instant. Since it is supposed that there is no moment of forces about the axis, both n and Cn remain constant throughout the motion.

Now let the pendulum bob be supposed to move in a circle of radius a about the vertical through the point of support as axis. The motion is just that which has been discussed above for a top, and is a possible one. The gyrostat has a spin n about its axis, which is inclined at an angle θ, the sine of which is a/h, to the downward drawn vertical. The relation fulfilled is that given in equation (7) with the changes involved in making the θ there specified greater than $\pi/2$, since the centre of gravity is now below the point of support, and in changing the sign of the term $Cn\Omega$. Hence, as the angle θ is now taken as that made by the axis with the downward drawn vertical, the sign of $\cos\theta$ in that equation is to be changed. The reader may also, by considering the matter from first principles, verify that the other change of sign is required, when, as supposed here, the directions of n and Ω are those seen by an observer looking from beyond the fly-wheel along the axis of the gyrostat towards the point of suspension, and from below at the precession. Hence

$$A\Omega^2\cos\theta - Cn\Omega = mgh. \qquad (15)$$

This considered as an equation in Ω has two real roots, one positive the other negative. Let k be written for $Cn/A\cos\theta$ and p^2 for $mgh/A\cos\theta$, and the equation becomes

$$\Omega^2 - k\Omega - p^2 = 0$$

of which the solution is

$$\Omega = \frac{k}{2} \pm \sqrt{\frac{1}{4}k^2 + p^2}. \qquad (16)$$

There are thus two values of Ω, namely $\sqrt{\frac{1}{4}k^2+p^2}+\frac{1}{2}k$ and $-\sqrt{\frac{1}{4}k^2+p^2}+\frac{1}{2}k$. The former of these is positive, that is Ω has the same sign as n, the latter is negative and Ω has the opposite sign to n. The former is numerically the greater, and consequently the angular velocity of precession is greater when it is in the direction of rotation than when it is in the contrary direction.

Unless n is great the value of p^2 is in practical cases great in comparison with that of k^2, so that the approximate values of Ω are $\frac{1}{2}(k+2p)$ and $\frac{1}{2}(k-2p)$. A numerical example will be given below.

The approximate periods of the precessional revolution are $4\pi/(2p+k)$ and $4\pi/(2p-k)$. If the fly-wheel is without rotation each of these periods becomes (if we take $A=mh^2$) numerically $2\pi/p$, that is, $2\pi\sqrt{h\cos\theta/g}$, which is the period of a simple conical pendulum.

As a numerical example I calculate from the following data for an actual case. The mass of the gyrostat is 2200 grammes, that of the fly-wheel 1500 grammes, its radius of gyration 4 cms., and its speed 100 revolutions per second. The distance h is 100 cms., and θ is 10°. Then $C=1500\times16$, $A=2200\times100^2$, $p=\sqrt{981/100\cos10°}=3{\cdot}366$, $k=\cdot7915$, so that the approximate periods are 1·67 seconds and 2·12 seconds respectively.

So far I have considered only circular motion of the bob in one direction or the other; in the general case the motion is one compounded of two circular motions in opposite directions with unequal periods, and the resultant path is a kind of star figure with curved rays as shown being traced in Fig. 18.

Consider a small negative charge of electricity, an electron revolving in a circular orbit in a magnetic field, and at right angles to the lines of force, under an attractive force towards the centre of the circle, say, given by a positive charge there situated: it will be acted on by a force due to the magnetic field, which will be toward or from the centre according to the direction of revolution of the electron. Thus for relative equilibrium the period of revolution will be less or greater according as the magnetic action aids the attraction or opposes it, so that the motion of the electron and that of the gyrostatic bob are quite analogous.

The reader may easily prove from the elementary consideration given above that, if the displacement of the pendulum from the vertical is small, the equations of motion relative to horizontal rectangular axes along which the bob is displaced distances x, y at any instant, are

$$\left.\begin{aligned} \ddot{x} + k\dot{y} + p^2 x &= 0 \\ \ddot{y} - k\dot{x} + p^2 y &= 0 \end{aligned}\right\} \quad (17)$$

where $k = Cn/mh^2$, and $p^2 = g/h$, and except as regards the moment of inertia of the fly-wheel the bob is regarded as a particle.

These equations, with the proper analogues for k and p^2, are precisely the approximate equations of the electron.

In the electromagnetic case the value of k is, if the magnetic inductive capacity of the medium be taken as unity, $\epsilon H/m$, where ϵ is the charge and m the effective inertia of the electron, and H is the magnetic field intensity. The equations can be solved by assuming that the motions are oscillatory in period $2\pi/c$, and supposing, therefore, x and y to be each proportional to e^{ict}, where i denotes $\sqrt{-1}$. The substitution of these values of x and y will lead to the conditional equations

$$(p^2 - c^2)x + ikcy = 0, \quad (p^2 - c^2)y - ikcx = 0$$

which by elimination give the single condition

$$p^2 - c^2 \pm kc = 0.$$

Thus there are two values of c and two modes of vibration, the periods of which are $4\pi/(2p+k)$ and $4\pi/(2p-k)$, as I found above by considering the circular motions.

X. Gyrostatic Reaction against Constrained Precession—Gyrostatic Reaction of Dynamo in Rolling or Pitching Ship.

It will now be evident that if the gyrostat is so fixed on bearings that the motion, which the change of direction to which its axis is subjected tends to bring about, is made impossible, a couple preventing the motion will be brought into play and applied to the bearings by the framework to which they are attached. The magnitude of this couple is $Cn\Omega$, where n is the angular velocity of the fly-wheel and Ω is the angular velocity with which its axis is changing direction. A good example is a dynamo armature of large moment of inertia, rotating with velocity n about its axis placed athwartships, while the ship rolls with angular velocity Ω. The armature tends to turn about a vertical axis, but is prevented by fore and aft forces applied to the ends of the axle by the front and back of the bearings. This couple thus tends to shear the bearings off the deck, and is reversed when the ship rolls back, and varies in amount as the angular velocity of rolling varies. If the bearings are in the fore and aft direction the rolling of the ship has no effect, but the pitching causes equal and opposite forces to be applied to the two bearings. These forces are again in the plane of the deck, but are in this case across the ship. If the bearings are at all loose, this alternating action upon them may have serious effects.

The following numerical example may be taken of a dynamo, the armature of which weighs half a ton, has a radius of gyration of 2 feet and is revolving at 240 revolutions a minute. If the axis is athwartships, and the ship rolls through a total range of 30° in a period of 10 seconds (what is commonly reckoned two periods of rolling). In ton-foot units the moment of inertia is 2. The maximum angular velocity of rolling, that at the middle of the roll, is in radians $2\pi \times 15 / (10 \times 57{\cdot}3) = 3\pi / 57{\cdot}3 = {\cdot}165$. The angular velocity of the fly-wheel is in radians 8π. Hence the couple in a plane parallel to the deck which is called into play is in engineers units $2 \times 8\pi \times {\cdot}165 / 32$ or ·26. If the length of the axis between the centre of the bearings is 2 feet, each bearing will be acted on by a force of $\frac{1}{8}$ of a ton.

It is to be carefully observed that this force is alternately forward and backward on one bearing and backward and forward on the other; and is not, as I have seen it stated to be for a similarly placed dynamo, alternately upward and downward on each bearing. Such action on the top and bottom of the bearing could only be produced by changing the direction of the ship's head.

By a dynamo so placed no gyrostatic action on the bearings is produced by pitching. If, however, the dynamo have its axis fore and aft, pitching will produce, as stated above, force on the bearings alternately to port and starboard on one, and to starboard and port on the other.

XI. Large Gyrostat with Axis Vertical on Board Ship.

I take here one other illustration, the case I have already referred to as of some interest for its marine application. Let a gyrostat be placed with its axis at right angles to the line about which the ship rolls, say in the vertical position for the ship upright, and for simplicity suppose the centre of the gyrostat to be on that line. The bearings of the gyrostat may be supposed supported on a framework, the tilting of which about an axis athwartships is resisted by springs. Any turning, then, of the axis of rotation relatively to the ship will be in the longitudinal plane of symmetry of the vessel, and will be resisted by the springs with a couple proportional to the angle turned through. I shall deal only with small *free* oscillations.

Let then the ship be rolling with angular velocity ϕ, say over to starboard, while the fly-wheel is turning in the direction against the hands of a watch to a person looking down upon it. I shall suppose the angle θ of tilt positive when it is round to the left (against the hands of a watch) to a person looking at it from beyond the starboard side of the vessel. The couple producing tilting in the longitudinal plane of symmetry which is resisted by the springs is $Cn\phi$, if C and n be, as before, the moment of inertia and angular velocity of the fly-wheel. If, then, μ be a coefficient, and θ be the angle of tilt, which will be to the right (*with* the hands of a watch) for a roll to starboard, the couple resisting tilting is $\mu\,\theta$. Therefore,

$$Cn\,\dot{\phi} = -\mu\,\theta, \qquad (18),$$

the negative sign being prefixed, since θ is now negative.

Now, as the ship rolls, this tilt changes with angular velocity $\dot{\theta}$; and hence the angular momentum about the longitudinal axis of the ship taken positively towards the bow will for a positive $\dot{\theta}$ be diminishing. There will, therefore, be a couple, $Cn\dot{\theta}$, called into play, and applied by the framework to the ship, tending to change its velocity of rolling. Hence the equation of motion of the rolling of the ship is, if C′ be the moment of inertia of the ship about the longitudinal axis,

$$C'\,\ddot{\phi} = -p^2\phi + Cn\,\dot{\theta}$$

or

$$C'\,\ddot{\phi} - Cn\,\dot{\theta} = -p^2\phi, \qquad (19)$$

where p^2 is the constant coefficient which multiplied into the angle of the roll gives the righting couple on the ship. But, taking the time-rate of variation of the equal quantities in equation (15), I get:—

$$Cn\,\ddot{\phi} = -\mu\,\dot{\theta}, \text{ or } \dot{\theta} = -Cn\,\ddot{\phi}/\mu.$$

Substituted in the equation of motion (19), this gives

$$\left(C' + \frac{C^2 n^2}{\mu}\right)\ddot{\phi} + p^2\phi = 0, \qquad (20).$$

This is the equation of rolling, and shows that the moment of inertia of the ship for rolling has been virtually increased in the ratio of $C' + C^2n^2/\mu$ to C'; and that, therefore, the period of free rolling has been increased in the square root of this ratio, that is the period has been increased from $2\pi\sqrt{C'/p}$ to $2\pi\sqrt{C' + C^2n^2/\mu}/p$.

It is to be observed that the equations show that θ varies periodically in the same period; but these oscillations differ in phase from those of ϕ by a quarter period.

Of course, in obtaining this result, I have taken no account of frictional resistances, but the result shows clearly enough the kind of change effected, in the supposed circumstances, by having such a gyrostat. This problem for a ship has been suggested to me by Sir Henry Bessemer's well-known proposal to obtain a steady cabin for a cross-channel steamer by supporting a gyrostat with its axis as imagined here directed; but with the supporting framework carried on fore and aft trunnions.

A similar problem was dealt with by Lord Kelvin at the Montreal meeting of the British Association in 1884. A long vertical torsion wire was supposed to have a gyrostat, with its axis horizontal, hung on its lower end; and a twist was given to the wire. The system performed torsional oscillations about the wire and the moment of inertia of the gyrostat about the vertical was virtually increased by the rotation of the fly-wheel in the manner here explained. Lord Kelvin's mode of dealing with the matter, I find, is similar to that adopted above.

It is to be observed that the effect of pitching with this arrangement would be very considerable, and could, of course, be dealt with in a similar way. The reader will understand that this problem is only taken here by way of illustration, and not as suggesting a practical application.

The various gyrostatic devices which have been used on board ship as clinometers, and the well-known arrangement of a rapidly driven gyrostat for actuating the rudder of a torpedo to enable it to keep its course, are applications depending on the couple called into play when a rapidly rotating fly-wheel is caused to alter the direction of its axis. If the gyrostat, as in Professor Piazzi Smyth's clinometer, be hung in well made smoothly acting gimbal rings, there will be little moment tending to alter the direction of its axis as the ship rocks or pitches, and if it is set with the axis initially vertical, it may be taken as remaining so very nearly. The difficulty in such arrangements is to know when they are adjusted to verticality, and as a rule all that can be safely observed is the whole range of motion relatively to the gyrostat. (See page 300).

Another gyrostatic device I might be expected to refer to, Mr Otto Schlick's gyrostatic brake for reducing rolling. But that is described by the author in the last volume of the "Transactions of the Institution of Naval Architects," and a mathematical discussion of its action is there given by Herr Föppl.

XII. Gyrostatic Action of Turbine Rotors on Board Ship.

I come now to the consideration of the gyrostatic action in steamers in which the main propelling engines are of the steam turbine type. The interest in this subject, which was excited at the time of the "Cobra" disaster, showed itself by the long series of letters from engineers and others, to the technical journals, to which I have already referred. These letters were informing in very varying degree, but the general conclusion come to was no doubt correct, that the gyrostatic action could not produce any breaking moment so great as to affect a ship's safety. For example, to break the ship, as the "Cobra" apparently was broken, by a breaking moment applied to it in a vertical plane, the ship's head would have had to turn round at an impossible rate. Rolling could bring no gyrostatic action into play, the axes of the turbines being fore and aft; pitching would produce a moment no doubt, as will be seen, much greater than the former, tending to bend the vessel in a *horizontal* plane, that is, about vertical lines.

I have been furnished with estimates of the data necessary for calculating the gyrostatic moments applied in possible circumstances to the hull, (1) of a large Atlantic liner (the "Carmania"), (2) of a torpedo-boat destroyer, and (3) of a cross-channel steamer.

The mode of calculation will be clear from the preceding theoretical discussion. When the ship's head turns round, the direction of the axis of the rapidly revolving turbines is changed at a rate Ω, which is the Ω of my equations. But to correct the generation of angular momentum about an athwartship axis, which this produces, the turbines make an effort to turn about that axis, and so a couple is applied to the ship.

A corresponding action takes place when the ship pitches with angular velocity Ω. In each case the couple is $Cn\,\Omega$.

For the data in the first case, I am indebted to the kindness of Mr Luke, of Clydebank.

The total weight of the rotors may be taken as 200 tons, and the radius of gyration 4 feet, so that in ton-foot units the moment of inertia of the rotor on each wing-shaft is 1280, on the supposition that the weight of the rotor on each wing-shaft is $\frac{2}{5}$ of the whole, and the weight of that on the centre shaft $\frac{1}{5}$ of the whole. The number of revolutions may be taken as 200, so that in radians per second the angular velocity is $20\pi/3$. The ship's head can be turned through about $\frac{3}{4}$ of a degree, or say $\frac{1}{75}$ of a radian, in a second. Hence the gyrostatic couple $Cn\Omega$, which must be applied to each wing-rotor by the ship to give it the precessional motion which the turning of the ship involves, and therefore the reacting couple on the ship, is in what I have called engineers' units.

$$1280 \times 20\pi \times \tfrac{1}{3} \times \tfrac{1}{75} \times \tfrac{1}{32} = 11 \cdot 2.$$

Thus the couple is only 11·2 tons acting at an arm of a foot, or a couple of ·28 ton acting at an arm of 40 feet; a couple which I should think would produce no perceptible effect.

For the case of pitching I may take the range 12°, and the (double) period 6 seconds. The maximum angular velocity of pitching is in this case $2\pi \times 6/(6 \times 57 \cdot 3) = 1/9$, nearly, in radians per second, and this must be substituted for the 1/75 in the above calculation. This gives a couple 8·3 times as much as before, that is, of moment 93 tons acting at an arm of 1 foot, or 2·3 tons acting at an arm of 40 feet. This, though much greater, is a small couple, when regarded from the point of view of breaking a ship, though the ship were relatively as lightly built as was the "Cobra." The engines of the "Cobra" were, of course, small in comparison with those here considered. The couple is, however, reversed twice in each (double) period of pitching. For a range of pitching half as much again, and a period of 9 seconds, the gyrostatic action would just be the same. If there were only two shafts, one right-handed the other left-handed, the moments applied to the ship would be equal and in opposite directions. Of course, internal stresses of a kind easily analysed would be set up in the structure. These would tend to produce alternately compression and extension at the bow, and extension and compression at the stern, athwartships in each case; but they would be, I think, quite negligible.

If there be three shafts, two turning one way, the third the other way, and the weight of the turbines be supposed distributed among them in the ratio of two parts to each wing-shaft and one part to the centre shaft, the resultant gyrostatic couple will be much less than $\frac{1}{2}$ of that calculated above, inasmuch as the radius of gyration of the centre rotor is only 3 feet. The couple may be taken as 9/32 of that due to each wing-shaft. The couples due to the wing-rotors being oppositely directed at each instant, will produce internal stresses, which can only be of importance in the event of their coinciding in period with a free oscillation of the ship as an elastic structure, an event which, I think, is very unlikely.

If, however, one wing-shaft be driven ahead, the other astern at full speed, and the centre shaft be stopped, the gyrostat couple (due to pitching) applied to the ship will be twice that due to each wing-shaft, or 186 tons at an arm of 1 foot. If the centre shaft be at the same time driven full speed ahead, the couple will be that just stated with 9/32 of its amount added or subtracted according as the centre shaft runs in the same direction as the wing-shafts or in the contrary direction. If the centre shaft is run at diminished speed the latter couple must be diminished in proportion.

I am told that for a destroyer the weight of each rotor may may be taken as 6 tons, the radius of gyration as 2 feet, and the revolutions 900. This gives moment of inertia, in ton-foot units, 24 for each rotor on wing-shafts. The angular velocity is 30π in radians per second, and the angular velocity with which the ship can be turned round is 3° per second or $\frac{1}{19}$ of a radian per second. The gyrostatic couple for the two rotors running in the same direction would be $48 \times 30\pi \times \frac{1}{19} \times \frac{1}{32} = 7\cdot4$, that is, 7·4 tons at an arm of 1 foot.

I do not know what to take as the period and range of pitching for a destroyer, but the same values as have been already used would give about twice this couple.

Here, again, to get the true values of the resultant couple, take one-half, or, if the vessel has triple screws, some other fraction of the values just found.

For a cross-channel steamer, Mr Parsons has given me the following data:—Weight of each L.P. rotor 7 tons, radius of gyration 21 inches, speed 700 revolutions. The moment of inertia of each rotor is thus $7 \times 1\cdot75^2$, or 21·4 in ton-foot units, and the speed is $70\pi/3$, in radians per second. The maximum gyrostatic couple of each rotor, for the same amplitudes and periods of pitching as those supposed above, is thus about 1·8 tons acting at an arm of 1 foot.

If the turbine on the centre shaft has, as Mr Parsons tells me it has, less than half the mass of the others, the resultant couple on the ship will be less than one-half of that just calculated.

The stresses seem to me to be quite insignificant. Their only importance, if they have any, must be in their rapid reversal and the consequent forced vibration of the structure. Danger arising from near agreement of the period of this forced vibration with that of some natural free period of the structure is not, I think, to be feared, but this is a question for naval architects. Coincidence of natural vibrations in the rotor itself with those due to gyrostatic action, has been shown by Dr Henderson in his note on a previous paper to be practically impossible.

Discussion on the Two Preceding Papers.

Professor G. A. Gibson, LL.D., said that he felt in a company of engineers and shipbuilders like a fish out of water. When he listened to their thoroughly practical remarks he felt that one who occupied the position that he did had simply no right at all in appearing before such an audience. Professor Gray's paper so far as he could gather was considered to be one of some difficulty, but to him such a paper appeared to be so simple that he did not understand where the difficulty came in. When he listened to the gentlemen who spoke from the results of experience in actual work, he felt as if he were transported into a totally different world—a world he should like to be living in; but as far as the paper before them was concerned, he did not think there was very much to add, and certainly he had nothing in the way of criticism to make. Nearly all that he knew regarding the mathematics of gyrostats he had learned from Professor Gray himself, and the line Professor Gray had taken up in that paper had been familiar to him from frequent conversations with him, so that possibly he thought it perhaps a little easier to read than the gentlemen who were less acquainted with his mode of treatment. When he first took up this question of gyrostats he tried to follow out the mathematical development, and the only place he knew in which to study that development was Thomson & Tait's "Natural Philosophy." He had seen the gyrostats spinning in the Natural Philosophy class-room, and he admired the beautiful properties of matter in motion that were there exhibited, but for his own part he did not in the least degree see how such apparently extraordinary action should take place. In trying to follow it out from the mathematical point of view, which to him was the only satisfactory one, he found exceeding difficulty in the development given in Thomson & Tait; because, in order to get at the gyrostatic principles there given, one had first of all to master practically the whole theory of the Lagrangian solutions, and the various simplifications they made rather seemed to increase than to simplify the solution of the problem. As it was given in another

Prof. G. A. Gibson, LL.D.

work of Professor Gray there seemed to be no appeal except to the most simple dynamical principles. The whole discussion from page 279 to page 286 was a very simple and an exceedingly clear illustration of two principles, first, as far as he could gather, the principle of the neglect of certain quantities in comparison with others that were retained, and next the principle of the superposition of small motions. Given these two, the whole came out with absolute simplicity, and he thought that any engineer who had possibly forgotten a little bit of his mathematics would find, if he followed out thoroughly and spent just an hour on Section III., that he had really mastered the fundamental principles that lay at the root of the dynamics of rigid bodies so far as the small movements were concerned. He thought that almost every element that entered into the solution of the problem was there discussed. At the foot of page 284 there was an element referred to that might also have been noticed at another stage. That was not the only part where certain quantities seemed to have been neglected. As a matter of fact there was a similar neglect in the discussion of the rotation towards the top of the page. But all through the discussion these terms of the second order could be neglected in comparison with those of the first order that were retained, and if one thoroughly understood that principle he did not see there was the slightest trouble in following the whole discussion. It was rather interesting from a purely mathematical point of view to compare Article III. with Article IV. These latter equations of motion were of prime importance, but as a matter of fact they were not given in a form available for this discussion, and he thought it was a matter of extreme interest that, based merely on the simple explanations of Section III., one got many illustrations of a practical kind with the practical results worked out in the later sections. He was afraid that his remarks had been of an abstract kind totally away from the interests of engineers, but it was to him a great pleasure to be present to see what engineers were doing, because he hoped that he might be able to extract from their remarks something that might be of use to him afterwards—not in the way of L. s. d. so important in itself, but possibly in the way of suggesting to him methods of attacking problems that might be useful to his students when they came to the consideration of them as practical men.

Mr R. F. Muirhead, D.Sc., expressed his pleasure at having had the opportunity of listening to so much interesting discussion during the evening. He hesitated to respond to the Chairman's invitation to speak on Professor Gray's paper, as he had only had time for a hurried glance over the printed copy that he had received, but would venture two remarks suggested by that brief perusal. Professor Gray said that the rate of growth of moment of momentum was equal to the moment round the axis of the external forces exerted on the body at that instant. That implied that the absolute, not the gravitation force unit was employed. He did not know what was the prevalent opinion on the subject amongst engineers in this locality, but he knew that in some parts of this island strong attempts had been made, particularly by engineers, to banish the Gaussian units of force from the teaching of dynamics, and to go back to the use of the pound weight as the unit. There was no doubt that in an investigation such as the present one, the absolute unit was much preferable to the other. He supposed that in Glasgow (where they had so long the benefit of Lord Kelvin's tuition on the subject) there might be little danger of a decline from absolute units back to gravitation units; but elsewhere it might be different. He noticed within the last year that the Mathematical Association, whose headquarters were in London, issued a report on the teaching of dynamics, in which one of the recommendations—which he was surprised to see—was that the term *poundal* should be given up. If this implied the abandonment of absolute force-units, he hoped that the recommendation would not be accepted. He was glad that Professor Gray, in his paper, continued to use absolute units of force.

Professor Gray—Except at the end in the case of turbines.

Mr W. J. Luke, (Member) observed that he had a great admir-

Mr W. J. Luke.
ation for these two papers, although he was not able to follow one of the gentlemen who had gone before him in the debate, as to the simplicity of the action of the gyrostats. He had got on with Professor Gray's paper with more or less satisfaction, but when he arrived at the point at which recommendation was made to refer to Routh's Rigid Dynamics, he felt compelled to call a halt. He was still in the position of finding it very difficult to understand the behaviour of the gyrostat, and Why—for example—with the apparatus shown on Fig. 12 the instrument should precess, instead of allowing the weight to get into the position which the uninformed mind would expect it to do? Of course the fact was undisputable, and one admitted the mathematical accuracy of the explanations offered, but this, to him, compelled assent, rather than enabled him to understand it. In admitting that the subject was to him difficult of comprehension, he would add that it must certainly have been difficult to others, for the late Sir George Airy, for many years Astronomer Royal, and a man of high mathematical attainments had stated that the action of a gyrostat was one of the most complicated points dealt with in the subject of Mechanics. Turning to the more practical side of the two papers, he would say that the subject first came into prominence in regard to shipbuilding, at the time of the unfortunate loss of the "Cobra," when it was urged by some writers that, gyrostatic action was in some way connected with the disaster. He was never able to see that this danger existed, when he thought of the small mass of the rotors and the small angular velocity either of pitching, or turning under the action of the helm. But as it was not absolutely safe to trust to one's feelings on such a matter, he was very much gratified to find that the authors of these papers came to the conclusion that there was no danger likely to arise in such cases from this cause. It was rather surprising to find the numerical assumptions in the two papers differing so much as they did, when apparently the same case was alluded to. Considering the value of the papers, and the certainty that they would be standards of reference in the matter for years to come, he hoped that the authors would be able

to bring their figures more nearly into line than they were at present. Dealing with the question as to the possible synchronizing of the period of the gyrostatic forces with the vibrating period of the ship, he thought that there was little danger to be anticipated on that score. Dr. Henderson could have found from "Engineering" that the natural period of vertical vibration, in trial condition, was 82 per minute. This figure fell in very well with Schlick's approximate rule for frequency of first period vibrations. He had had previous opportunities of confirming the fact that this figure gave the first period vibrations, for he had been on board vessels with ill-balanced engines, and in which two nodes were very definitely defined. Hence, no doubt existed in his mind that the period found was that of the first period. Dr Henderson gave a formula which for a bar represented the frequency of vibrations of higher periods, and in this connection it might be interesting to note that Mr Arnulf Mallock had discovered in one ship on which he had experimented, that vibrations were present of the following frequencies:—125, 226, 450, 770, 1420, 1950 per minute. Comparing this with the formula for a bar, it appeared as if there were no vibration of the fifth order in this particular case. Going on to horizontal vibrations, and to the fact that these could not be traced in the "Caronia's" trials, Dr Henderson presumed that the engine balancing was very good. This was undoubtedly the case; but, in addition, it should be noted that owing to the inertia about the vertical neutral axis being substantially greater than about the horizontal neutral axis, it was practically certain that the synchronizing period was not reached.

Professor A. Jamieson (Member) said these two papers covered the whole range of the subject, from the school boy's pastime of spinning tops to the more serious investigations of the gyrostatic actions of dynamos and steam turbines on board ships. When attending the Natural Philosophy classes at Aberdeen University, thirty-eight years ago, the students were treated to a graphic demonstration on the amusing antics of the gyroscope, with but

Prof. A. Jamieson.

few conclusive reasons for its particular behaviour under certain conditions. In fact, it was not until 1876 that he had the pleasure of handling a really well designed and well made gyroscope. This occurred when Sir William Thomson asked him to exhibit and spin his latest gyroscope at the first large conversazione in London, of the Society of Telegraph Engineers. In the very early days of electric lighting on board steam ships he was consulted regarding the peculiar and serious wear and tear of the bearings of a dynamo on a steamship which had just returned to the Clyde after a long voyage. The dynamo was of the 1881 Siemens pattern for single phase alternate currents. The weight, radius of gyration, and angular velocity of its armature were great. The distance between its bearings was small, and the axis of its shaft had been placed athwartship, so that the plane of the rotation of its armature was parallel to "lubber line." The ship was a great roller, but an easy pitcher. The dynamo shaft brasses showed no particular wear on their bottom and top bearing lines, but were "worn" oval at the front and back of their mid-seam between the lower and upper halves. He consulted Sir William Thomson (now Lord Kelvin), and the latter very kindly wrote out the following formula with the result that the dynamo was turned round with its plane of rotation athwartship, and new brasses were fitted, when no further trouble was reported:—

GYROSTATIC ACTION ON DYNAMOS IN SHIPS.
(Sir William Thomson).

$$L=\frac{Wk^2\Omega\,\omega}{g} \text{ and } P=\frac{Wk^2\Omega\,\omega}{gl}.*$$

where L = moment of couple on axis.
P = pressure on each bearing.

**Note.*—On applying the above formula to dynamos, where W, k, and ω are great, it will be found advisable to place their plane of rotation athwartships, in order to avoid as far as possible wear and tear of bearings due to the gyrostatic action.

W = weight of armature.

k = radius of gyration about axis.

$\Omega = \frac{2\pi}{T} A$ = maximum angular velocity of dynamo in radians per second due to rolling of ship.

$A = \frac{\pi d}{180}$ = amplitude in radians per second.

(Radian is unit angle in circular measure).

d = degrees of roll from mean position.

T = periodic time in seconds.

$\omega = 2\pi n$ = angular velocity of armature in radians per second.

n = number of revolutions of armature per second.

l = distance between bearings.

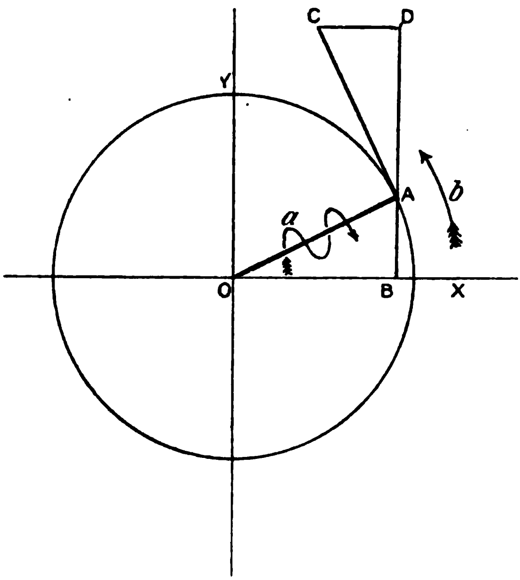
g = acceleration due to gravity.

This formula and note had appeared in seventeen successive editions of Munro & Jamieson's pocket-book, without alteration, and was discussed by several members of the Institution of Civil Engineers when it appeared in his paper on "Electric Lighting for Steamships," November, 1884. About two years thereafter he had the pleasure of drawing up a specification for the electric lighting of three steamers being built by Messrs Robert Napier & Sons, and he had to reason with the late Dr. A. C. Kirk, and show him the formula, before Dr. Kirk would agree to place the dynamos in the manner therein suggested. In *Nature* of April 27th, 1905, he observed a letter from Mr W. H. Pickering, of Harvard Observatory, Cambridge, Mass., U.S.A., drawing attention to "A Little Known Property of the Gyroscope." But Professor Gray demonstrated this very property to the members during his lecture. In fact, Professor Gray had given them a "Standard Paper" on the whole subject, whilst Dr. Henderson had provided an interesting and independent solution on "The Effects Likely to be Produced by the Gyroscopic Action of Steam Turbines on Board Vessels Pitching in a Sea." It must be pleasing to those who made, as well as to those who managed turbines in steamers, to learn from two such authorities, that no alarming or undue stresses need be expected.

Mr C. A. Matthey.

Correspondence.

Mr C. A. Matthey (Member) said there could be no doubt about the correctness of the conclusion arrived at by the authors of both these instructive papers, namely, that the gyrostatic forces due to the pitching of a turbine-driven ship were altogether insignificant. Dr Henderson went a step further to see if there might not be cumulative vibrations, due to the synchronism of the pitching with the period of longitudinal vibration of the ship; but it appeared that the former was so much slower than the latter that nothing was feared. With regard to Dr Gray's investigation of the rate of precession, while its correctness was unassailable, he thought it might be shortened and simplified to meet the case of those who were not familiar with the method of limits. In the accompanying figure the thick line OA represented the axis of the top revolving, in the direction shown by the arrow *a*, in a horizontal plane. It was supported at O, about which point it was free to move in all directions, and a couple was applied to the axis consisting of a vertical downward force at A and an equal upward reaction at O. The precession would be as shown by the arrow *b*, that was, the top moved towards that position, at right angles to its present position, in which its rotation was concurrent with the rotation produced in any body, other than a gyrostat, by the couple. Let the couple applied (consisting of the parallel forces at O and A) be of such a magnitude that it would, if applied to rotate the top about the axis OA instead of to turn that axis end-over-end, produce the observed rotation of the top in one second from a state of rest. What was the rate of precession? Describe a circle with radius OA and centre O, and choose any co-ordinate axes of reference, OX, OY, at right angles to one another. Draw AB perpendicular to OX, meeting it in B; produce BA to D, making AD equal to OB; draw DC parallel to OX, and equal to AB, and join AC. The triangle ADC was evidently equal in all respects to ABO, and AC was a tangent to the circle. Let the length OA represent the observed rotation of the top: let it also represent the couple which produced that rotation in one second. The rotation OA could be resolved into a component rotation OB about OX, and a component rotation AB about OY; and the couple OA could be resolved into a component couple OB producing rotation about OY, and a component couple AB producing rotation about OX. Inspection showed that the couple OB was in the same direction as the rotation AB, that was, AB was being increased at a rate OB, or AD per second; while the couple AB was in the contrary direction to the rotation OB, that was, OB was being diminished



at a rate AB per second. In other words, the point A was mounting in the direction OY at a rate AD per second, while it was going in the direction XO at a rate DC per second: it was, therefore, moving at the rate AC per second tangentially. That was to say, the line OA was being swung round the circle at one radian per second. It seemed almost impossible to forget this rule:—The couple which would produce the observed rotation of a gyrostat in one second, would, if applied to displace the axis, produce precession at the rate of one radian per second. For other couples, the precession was proportional.

Mr J. Bruhn, D.Sc. (Member) considered Dr Henderson's paper a very timely one, appearing as it did at the very moment when the first Atlantic turbine steamer had made her first voyage. Now that this new type of engine would probably become common in sea-going vessels, it was desirable that all possible effects both on hull and machinery, due to the changed method of propulsion, should be well considered. He did not think it detracted from the value of the paper that the results showed that, on the whole, the gyroscopic couples produced by the revolving weights and the pitching of the vessel were negligible with the present size of rotors and rates of revolution. It was well to know that it was so. The couples that were created in that way could produce no material stress on the holding-down bolts or on the shafting, even though the pitching might be somewhat more violent than assumed in the example. The couples were caused by changing the direction of the moment of momentum of the revolving rotor. In the ordinary toy gyroscope, this would throw bending moments on the shaft, due to its bearings being at a relatively large distance from the side of the fly-wheel. The rotor of the turbine engine would have bearings near the revolving mass, and no bending could take place. If the length of the rotor were represented by l, the gyroscopic couple produced by C and the force of the bearing F, then :—

$$C = F\,l.$$

At a distance x from the end of the rotor there would be a moment Fx tending to bend the part x of the rotor in one direction. The moment of momentum would be uniformly distributed through the length of the rotor. The forces causing the horizontal couple would also be uniformly distributed through the length of the rotor and the horizontal couple due to the part x would therefore be $\frac{Cx}{l}$ or Fx, which would tend to bend the part x in a direction opposite to that of the moment caused by the force F at the end of the rotor. These moments would, therefore, balance each other at every point of the length of the rotor. In other words, there were no bending moments on the rotor due to gyroscopic actions. It was a rather unique case of pure shearing through the length of a body. The shearing force would, of course, be F at any point of the length of the rotor. The main gyroscopic action on the rotor and shafting could not, therefore, be of a flexural nature. This fact made it still more unlikely that serious vibrations could be set up in the shafting from this cause. The rotor would be bent by its own weight, and the periodic reactions due to a pitching motion would cause periodic bendings to be set up, which, although possibly of little consequence, would be more important than those set up by the gyroscopic couples. Dr Henderson did not mention the gyroscopic effect of the propeller. It probably would be greater than that of the rotor, at least as far as the shafting was concerned, in spite of the fact that the moment of momentum of the propeller would be much less than that of the rotor. The effect of the gyroscopic couple of the propeller when the vessel was pitching would not be one of pure shearing, as in the case of the rotor. The horizontal couple would, in this instance, bend the tail shaft. In the discussion on Mr M'Arthur's paper on "Marine Engine Shafting," he (Dr Bruhn) drew attention to this cause of stress on the tail shafts of ordinary screw steamers. The example taken showed that the stress due to this cause was very small (about $\frac{1}{10}$th of a ton per square inch) even for a very large propeller and very violent pitching. In a turbine steamer the higher rate of revolution would increase the stresses considerably, but not to an extent to make them serious in themselves. The vibrations that this couple might give rise to in the shafting would probably also be of considerably more importance than those which the rotor might set up, but they, too, were not likely to be of practical importance, owing to the length of the period of the originating couple. And here, again, the effect of the weight of the propeller and the reactions due to pitching would be of much more import-

Mr J. Bruhn, D.Sc.

ance than the gyroscopic couple in the direct straining of the tail shaft, and the pitching reactions would also be of more importance than the gyroscopic forces in causing vibrations in the shafting. With regard to the effect of the gyroscopic couple of the rotor on the vibrations of the vessel, it was also very unlikely that the long period of the alternating couples would seriously affect the horizontal vibrations, which would have a relatively very short period. When a vessel was pitching there would be periodic forces acting on the weights carried. These vertical forces would have exactly the same period as the horizontal gyroscopic couples, although their maxima did not occur at the same instant. The former would be greatest at the extreme angles of pitching, the latter at the instantaneous horizontal position. There would be more probability of the vertical reactions, common in all vessels, causing augmentations in the longer period vertical vibrations of a ship, than there would be of the horizontal gyroscopic couples causing sensible augmentations in the shorter period horizontal vibrations. In the last sentence but one, Dr Henderson suggested that the easiest way to stop horizontal vibrations due to gyroscopic couples at sea would be to alter the speed of the vessel. He did not think this would be very effective, as a little change in the speed would not usually modify the vessel's period of pitching much.

Dr. HENDERSON, in reply, said he had enjoyed Mr Luke's kindly and humorous criticism, and was not misled by his assumed ignorance. Mr Luke's customary love of a joke was no doubt responsible for the awe inspired in him by the mention of Routh's dynamics. Since Professor Gray's paper and his (Dr. Henderson's) dealt more or less with the same subject, he thought it necessary to explain that his short paper had originated in a few remarks he made when called upon to discuss Mr Melencovich's paper on "Steam Turbines,"* and that it had been placed in the secretary's hands before he knew that Professor Gray was writing a paper on "Gyrostats" for the Institution. The two papers did not clash in any respect, but his might be considered

* See page 165.

as a supplement to Dr. Gray's, dealing more particularly with the question of synchronous vibrations. Dr. Bruhn's reminder of the gyroscopic action of the propellers was important, as synchronous vibrations might be more likely to occur there than at any other part of the shaft, but even if they did occur they could attain to no great amplitude owing to the excessive damping action exerted by the water. The direct stresses in the shaft due to pitching were, as he pointed out, of much greater importance than those due to synchronous vibrations. Whether the forces on the frame due to the gyroscopic action of the propellers, occurring as they did at the stern post, were more likely to introduce vibrations in the ship's frame than the action of the forces due to the turbines themselves, was a question which could only be settled by considering the design of the frame; but, in any case, it had been seen that the probability of synchronism between the natural period of the ship and the period of pitching was remote.

Professor GRAY, in reply, thanked Professor Gibson for his appreciative remarks, and said it was true that he had not in every case exhibited the quantities of the second order which were neglected in the limit; but it was not his aim to do so. He thought he had given enough examples to enable anyone, who cared to do so, to go through the whole discussion and make a list of all the first order and second order terms involved in the changes which took place in a small interval of time. When that was taken indefinitely small the latter terms disappeared and only the first order terms remained. Referring to Mr Luke's remarks, he said that his aim had been to make clear to the understanding how the parts of the precessional motion arose, and not merely to extort a reluctant assent that they had the values stated. Any reader who had the patience to go carefully through Sections III. and IV. above, would, he thought, obtain some real notion of how the motion of the axis of rotation was brought about, which was the crux of the whole matter. It was easy to compound the angular momentum existing at a particular instant of time with that

Professor Gray.

generated by the applied forces in a short interval of time succeeding the instant in question, and so finding the resultant angular momentum and the axis about which that had place. But the corresponding motion of the axis of figure of a gyrostat or top was not so easy to understand, and of this he tried to give a clear account from as many points of view as possible. The reference to Routh and Besant, which seemed to have had such a dire effect on Mr Luke, was not made for the purpose of enabling him to obtain information to be used in understanding the methods of the paper or any problem with which it dealt, but merely for some special problems which could not be included without unduly trespassing on space. The data for the large Atlantic liner were obtained from no less an authority than Mr Luke himself! No doubt they were practically correct. It was to be noticed that the periods of pitching might very likely be inaccurate, but the calculations were given as examples, and the maximum reaction couples for any other periods could be obtained from those given in the paper by remembering that the maximum angular velocities were for the same amplitudes inversely proportional to periods and calculated by simple proportion. He regretted that in the course of discussion he had stated that the plane of the gyrostatic couple, with which the dynamo armature reacted on its bearings, was wrongly given in *Munro and Jamieson's Pocketbook of Electrical Tables.* He had found that, while the magnitude of the couple was correctly given in the work in question, its plane of action was not specified. Mr Matthey's graphical discussion, as given, applied only to the particular case limited by the conditions that the motion was steady and the axis of the top at right angles to the axis about which precession was taking place, while a constant couple about a third axis perpendicular to the two axes, just specified, was kept applied. To his (Professor Gray's) mind it failed to demonstrate, even for that case, how the precessional motion arose, which was the chief difficulty to one approaching the study of this kind of motion. It was quite easy to indicate, by the parallelogram or triangle law of composition of angular momenta, how the axis of resultant angular momentum of the top changed its position. At each instant angular momentum was being generated in the case supposed at rate mgh, about a horizontal axis perpendicular to the axis of rotation, and as the angular momentum due to the rotation was Cn, it was practically self-evident that the *axis of resultant angular momentum* was turning round at rate mgh/Cn. It was, however, quite another thing to make clear to the understanding why the *axis of figure* of the top turned round as it did. This could be understood when it was seen that if the axis of figure did turn round at constant rate mgh/Cn, there would be a constant rate of growth of angular momentum of amount mgh about the axis round which the applied couple moment mgh acted. But that the precessional motion of rate mgh/Cn gave this growth required proof, and this it was one purpose of the paper to supply. Further, the object of the paper was to treat the general case in which the axis of the top was inclined at *any* angle to that about which the top was turning in precession and, moreover, when that angle was varying. The solution in the particular case in which that angle was, and remained ninety degrees, was to be found at once from the general discussion. The main point which did not seem to have been grasped, was that the precessional motion in the general case was given by the simple considerations of Section III.: the whole affair was really summed up in equation (1) of that Section. It was not possible, he (Professor Gray) thought, to treat fully this, the most frequently occurring case—or the more restricted case, also very common and very important in its applications, *e.g.*, to astronomy—of vibrations of a top about a state of steady motion (see Section VII.) otherwise than by the method of limits. It was to be noticed also, in view of Mr Matthey's remarks that, even in the case of steady precessional motion, unless the angle between the axis of rotation and that of precession was ninety degrees, the precessional motion was not proportional to the applied couple. As shown in equation 7 of Section V., the relation of the angular velocity Ω of precession to the applied couple involved, besides the first power term $Cn\,\Omega$,

Professor Gray.
also the second power term $-A\Omega^2\cos\theta$, and it was the sum of these multiplied by $\sin\theta$ which was equal to the applied couple. In general, therefore, there was no relation of simple proportionality between the angular velocity Ω and the applied couple, unless (and then only as a matter of approximation) the initial circumstances were such as to render the term in Ω^2 negligible. Speaking generally (and without reference to Mr Matthey's remarks), he (Professor Gray) thought it exceedingly important that the method of limits should be cultivated by engineers. The motions of the parts of a machine were, as a rule, motions that varied with the time; stresses in structures and pressures in fluids varied from point to point. For such cases, the method of limits, the principle of the neglect of quantities small in comparison with others which must be retained for a first approximation, which could be made as near the truth as was required by making the small variation of time or space, or other variable, sufficiently small, was absolutely essential. It was one which, instead of being put aside or "dodged" whenever possible, should be sedulously studied and applied to practical examples. The method was applied in a rough way, and unconsciously, by every workman in his estimation of quantities that might be neglected; and what was to be aimed at in the teaching of mathematics and dynamics to engineers was the cultivation of a scientific understanding of, and power of using it. For this it was not necessary to have any large command of formal equations or power of manipulation of mathematical symbols. The effort to acquire the method, once for all, would be found to be much less than that involved in endeavouring to understand the varions ingenious devices for representing or expressing (rarely for proving) the results to which it led. For the method was merely sublimated common sense. The paper above was an attempt to exemplify the derivation in the simplest manner of exact results from first principles by this method, and to show that there was no need to have recourse to formal equations of motion, a process, which, as Mr Luke had suggested, sometimes constrained assent, but did not fully satisfy the understanding.

The solution of dynamical problems from first principles was a discipline which both trained the mind and afforded keen mental delight; and if he had been able to help some to deal with problems of rotational motion by a general principle, applicable in a large number of cases, he would have been repaid for any trouble in putting together his paper.

BOARD OF TRADE REGULATIONS FOR CERTIFICATED MARINE ENGINEERS.

Discussion.

Mr George Macfarlane (Member) said that at the October meeting of the Board of Trade Consultative Committee in London, a communication was received from Mr Barrowman of West Hartlepool drawing attention to the inconsistencies of the Board of Trade regulations regarding the training of apprentices who might become certificated marine engineers. A sub-committee had been appointed, consisting of Mr D. B. Morison and Mr Tweedy for the North-East Coast and Mr David Dunlop and himself for the Clyde district, and it had been decided to lay the matter before the Engineering Institutions in order to obtain an expression of opinion from their members. The meeting that night had been called for the purpose of obtaining the views of the Members of the Institution, and a *précis* of the discussion would be considered by the Council of the Institution, and after approval would be forwarded to the Consultative Committee who would adopt a report to be submitted to the President of the Board of Trade by deputation. The qualifications at present required by the Board of Trade for a Second Class Certificate were :—

> "That the candidate must be 21 years of age, and that he must have served as an apprentice engineer for four years at least, and prove that during the period of his apprenticeship he has been employed on the making or repairing of steam engines, boilers, &c. Three years of the apprentice time must have been passed in the fitting or erecting shops, or in both. In calculating the four years of artisan service which are to constitute the required apprenticeship, which should not begin at an earlier date than 15, time spent at a

technical school (recognised by the Board of Trade as suitable) where there is an engineering laboratory, may be taken into account and accepted as equivalent to artisan service at the ratio of three years in the technical school to two in artisan service, provided that the applicant was over 15 years of age and can produce the Principal's certificate for regular attendance and satisfactory progress, and provided also that in such case the other portion of the time was spent in the fitting or erecting shops of an engineer, as indicated above."

A committee appointed by the North-East Coast Institution arrived at the following conclusions :—"That in view of the practical experience and general engineering knowledge now required by engineers for the efficient performance of their duties at sea, it was desirable that the term of apprenticeship should be raised from a minimum of four years to a minimum of five years. The regulation which required an apprentice to have served three-fourths of his apprenticeship in the fitting and erecting of steam engines, thus allowing only one-fourth for the turning and machine departments, as well as other important branches, both technical and practical, was equivalent to penalising an apprentice who might have opportunities for obtaining more varied engineering experience, and therefore lowered the possible standard of marine engineers. Of an apprenticeship of five years, three years might be employed in any department or departments for the manufacture of steam engines and boilers, or any of the auxiliary steam engines used on shipboard, and of these three years one year might be employed in the drawing office, and one year at the day classes of an approved technical college, and the remaining two years should be employed in the fitting and erecting of marine steam engines, either in process of manufacture, or during fitting on board ship, or in repairing when in the dockyard. It should be particularly noted that the subject for discussion was 'apprentices who were to become certified marine engineers,' including the length of apprenticeship and the manner in which the term of apprenticeship should be employed, and it was not intended that any reference should be made to the career subsequent to the completion of the period of apprenticeship. Those responsible for the Board of Trade regulations appeared to have failed to differentiate between a skilled mechanic and a marine engineer. All marine engineers should be capable mechanics, but all mechanics were not marine engineers. The question was: Could a youth become a capable mechanic and receive the basis training necessary for a marine engineer during a period of four years? The reply by all competent authorities would be in the negative. The recognised term of apprenticeship for each of the trades connected with engineering was five years, and by advocating, or at least accepting, a term of four years, the Board of Trade not only lowered the accepted standard, but by interference assumed that a marine engineer required less training than a journeyman of any one particular trade. The regulation determining how an apprentice should be employed was also difficult to understand, as it provided that the more experienced was the apprentice the less eligible was he to become a marine engineer. An apt illustration of the folly of this regulation could be had at various engineering works both in Scotland and England, where, by a scheme for the advancement of apprentices, the boys who displayed the greatest diligence and aptitude had an opportunity of entering the drawing office, or were entitled at the end of each year to serve in any department they pleased. If, however, they intended to become marine engineers, they could not take advantage of the prize they had won, as by Board of Trade regulations they were compelled to remain in the fitting and erecting shops for the greater portion of their apprenticeship. This regulation also debarred apprentices from obtaining any knowledge of manufacture by machine tools, although this branch offered facilities for an appreciation of accuracy, a knowledge of details, and a sense of proportion greater than any other department in an engine works. Service in a repairing dockyard should also be considered as equivalent to service in a fitting or erecting shop, as it was difficult to overestimate the value of the experience gained in executing repairs by reason of the variety of the work and the intimate association with the constructive details of the machinery. Broadly, what was necessary was a course of training for marine engineers, which would enable them to perform their duties as skilled mechanics, to understand the working of the machinery under their charge, and to appreciate the technical responsibilities of their position," and he was strongly of opinion that the proposals set forth would enable that to be accomplished to a far greater degree than the Board of Trade regulations now in force.

Mr David J. Dunlop (Member) supported throughout what had been said by Mr Macfarlane, but in the matter of marine engineering they must go a good deal further, because it was perfectly impossible to call on a master to do more than turn out a well-trained mechanic. Nowadays there were so many combinations and so many complications in the engine-room that it was a wonder to him the Board of Trade could have committed itself to such a rule as had been read by Mr Macfarlane,—that, to take it shortly, an education in repairing or erecting shops for three years would justify a man in claiming to be qualified as a marine engineer. According to that rule a knowledge of boilers again was almost an essential part of the education of a man who was going to be a marine engineer. It would certainly be an advantage to him to be in a boiler shop, but under existing trade rules the double apprenticeship was not possible. No doubt those present would agree with him that this education was secondary to many other branches, as the caulking that might be required to make good a bciler and to put it into proper condition was a piece of work that could be done by any ordinary man who had been trained as a mechanic. To leave out electricity, to leave out refrigerating appliances, to leave out all the other combinations that they knew were included in the outfit of a first-class steamer, he thought could only emanate from the Board of Trade on the assumption that these rules were framed without full considera-

Mr David J. Dunlop.

tion. As he said to begin with, the only thing that an engine builder could do was to turn out a good mechanic, and he would say from his own experience that the best mechanics according to the regulations laid down were excluded from ever becoming marine engineers. The fitting shop apprentice of to-day was little better than a lowly paid labourer. In the best organised shops and in all their works the use of a file or hammer and chisel was almost unnecessary. Everything was done by a machine, and the boy who was there to learn his trade was only educated to put things together. He thought there was a great deal more in putting a lad at a turning lathe and starting him on the smaller tools and advancing him as he improved till he became an accurate and good workman. A good machine hand was a much better man to raise and educate than the lad who had only had the opportunity of working superficially with his hands in the putting together of the pieces the machines turned out. Again, a restricted drawing office education was included in the rule that the Board of Trade had framed, but to take the discipline in his own establishment, each year as opportunities offered, the lads in the works, according to intelligence, their willingness to get on, and proficiency in education which they had acquired in their spare hours, were selected and put into the drawing office, and he thought that those who had gone through the same experience would find that they got good lads and got afterwards able draughtsmen and engineers. This class of men would be excluded from aspiring to the office of marine engineer. What he thought the Institution should do would be to formulate some basis that would embrace all apprentices and make it possible for them to become marine engineers which, of course, was the object of many workmen. It was desirable to have an expression of opinion from each of the kindred institutions interested as to what would be the best training for a marine engineer. The question was not one altogether for the Board of Trade. The Board of Trade said that, because it was the protector of life it should be able to lay down its own laws, but if one looked back on the long career of marine engineering and of marine engineers the loss of life due to marine engineers was a very small one indeed. Apart from that it would be impossible to carry out the full spirit of these laws of the Board of Trade by an employer. After long experience marine engineers had fixed upon a period of five years as the shortest time in which the ordinary apprentice could be thought to be an efficient tradesman, and this term should be taken as the standard of service for all apprentices. Any reduction would most seriously affect all engineering workshops. A full apprenticeship was wanted so that a lad if unsuccessful in becoming a marine engineer would still be a good mechanic, and be either a turner or slotter, a planer or fitter. If there was any length of time to be added to any particular period he thought, according to the class of steamer, the time that a third engineer or second engineer had to serve, should be lengthened. In a little coasting vessel that had nothing but the old-fashioned engine and its auxiliaries it was well enough; but when a man had to go into a ship where all the modern appliances were in use he should have longer than twelve months to serve in the lower grades, or perhaps there might be three classes of certificates instead of two as at present. This matter was one that appealed to the shipowner, shipbuilder, and marine engineer, and it should be considered with all the intelligence that could be brought to bear upon it.

Mr D. C. Hamilton (Member of Council) remarked that a great many of the best marine engineers had served a portion of their time in the pattern shop, and he quite admitted that five years was little enough for a young lad to serve as an apprenticeship, which should include experience in the pattern shop, drawing office, boiler shop, and fitting shop. As for Board of Trade surveyors: Where were they to be got in after years if experience in the pattern shop or drawing office was not encouraged? He presumed that the best Board of Trade surveyors were those who had gone through the different branches in the shops, and if three years in the fitting or erecting shop was to be the law, there was no chance of a boy who might show, as Mr Macfarlane and Mr Dunlop had

Mr D. C. Hamilton.

said, any ambition in getting on in the profession, if he passed the drawing office altogether, or any other department. He would be very glad to support anything that was proposed to alter the three years' service in fitting shops.

Mr David Johnston (Member) said it would appear that the consensus of opinion was that five years' apprenticeship for an engineer was not too long, and should not be reduced. In his experience he found that quite 75 per cent. of the young men he came into contact with, who had served an apprenticeship of five years in the engineering establishments of Glasgow and neighbourhood, and some of whom possessed second-class Board of Trade certificates, to be very indifferent practical tradesmen. This was a serious matter, which urgently required to be improved, and he did not think the present term of four years apprenticeship for a prospective marine engineer, as in force by the Board of Trade, a step in the right direction, for if any branch of engineering required what was usually known in the trade as an all-round, handy, and resourceful tradesman, it was certainly the marine engineer. He would propose that more care should be taken in the large establishments with apprentices, and that during their five years' apprenticeship they should be allowed to work some time at fitting, erecting, and repairing machinery and boilers, and one year in the pattern shop. He did not say this was necessary for all apprentices, but for prospective marine engineers he considered it absolutely necessary, and it would be well for the Board of Trade to make a rule that none but those who had had such a training, and had had one year's experience working as a journeyman, should be allowed to pass for a second-class certificate. It ought also to be made a rule that engineers should serve two years at sea with a second-class certificate, not necessarily as a second engineer, but in charge of a watch, before being allowed to pass for a first-class certificate. There were a great many men in seafaring life at present who were barely fit to be what by their certificate they were certified to be. Whether that was the fault of the Board of Trade or the fault of the people who employed them he did not know, but it was a matter that ought to be remedied. This subject required deep consideration, and should be earnestly discussed to see what really could be done. He could remember the time when engineers went to sea without a Board of Trade certificate. He went himself for a good many years without one, and he believed that the men who went to sea in those days as chief engineers were, as a whole, better fitted for their duties than the men who were sailing at the present day.

Mr R. T. Napier (Member) said that though some men might be made capable fitters in less than five years, that period was all too short to obtain a knowledge of the various matters necessary for a sea-going engineer. Some knowledge of boiler making evidently was necessary, and a year spent in that department should be a requirement.

Mr A. E. Shute (Member) observed that what Mr Dunlop had stated represented very accurately the position of matters at the present time, and anyone who had any sea experience, or association with marine engineers, could not but agree with him. Although the conditions under which an apprenticeship was served to-day were vastly different to what they were twenty-five years ago, the apprentices were far better off with respect to facilities for gaining technical knowledge now than they were then. It was not to be expected that every apprentice could get drawing office experience, but during the time he was serving his apprenticeship he could get a good, perhaps better, equivalent by attending technical classes. That men with some drawing office or pattern shop training made better marine engineers than those who had only a fitting shop training, was invariably true, and he (Mr Shute) had sailed with men of that class, and found them good shipmates in the engine room—they acquired the drift of things quicker, and when a breakdown occurred they were the best men. These men went to sea with technical knowledge, while the purely shop-trained men, in many cases, began to get it only when they had to prepare for the examination for a second-

Mr A. E. Shute.

class certificate. If all applicants for a post as junior engineer had to pass a preliminary examination, and thereby obtain a certificate showing that they were fit technically as well as practically for the job, superintending engineers would be assured of getting a better class of men, and chief engineers would also know that the men they had under them had what a good many who start a sea-going life lacked almost entirely.

Mr W. C. M'Gibbon (Member) said that in preparing candidates for the Board of Trade examinations, this matter came closely into contact with his everyday work. He would like to emphasise and follow up some of the remarks made by previous speakers in reference to the advisability of time spent in turning, patternmaking, boilermaking, etc., being allowed to count as service in lieu of fitting or erecting. He found that boilermakers, for example, had a very clear grasp of the internal construction of the engine, in many cases more so than when the entire service had been spent in the fitting shop. He thought two years might be spent in the fitting shop, two years either in the turning, patternmaking, boilermaking, or blacksmith's shops, and one year in the drawing office. Another matter for consideration was the question of allowing men to pass the Board of Trade examination who had never served any apprenticeship. At present a man could serve four years at sea in lieu of apprenticeship, and in that way they had what was commonly called a "shovel engineer." At page 11 of the Board of Trade regulations, in the second paragraph, it was stated that "journeymen's time will be considered as equivalent to apprenticeship," so that in the event of a young man serving in a department not considered as suitable for full service, he could work for a further period as a journeyman fitter, or else put in an equivalent period at sea, as might be most suitable for him. Another paragraph, page 17, read as follows:—"When the workshop service has been performed in a place where engines are made, and the department in which the applicant has been principally engaged is not fitting or erecting, the case must be referred to the Board of Trade, with a report upon the service performed. If the service be such as is useful training for an engineer the Board may accept the service, but in every such case the applicant must prove additional engine-room or marine engine workshop service." This rule allowed the local surveyor to advise the Board of Trade regarding any service not laid down in the regulations, and it was the present practice to use this option to the advantage of the candidates. He might state that many such cases had been taken up and permission granted in his personal experience. The principal point in this favour which the Board of Trade granted was that the applicant's references must be first-class.

Mr J. Foster King (Member) thought it might be accepted as a starting point that classification societies (of which the Board of Trade might, in this connection, be regarded as one) had even stronger practical reasons than this and kindred Institutions to do what they could to raise the standard of training demanded from the men who were to take charge of the machinery for which the classification societies incurred responsibility, and he had the feeling that a fair comparison of the present with the past regulations showed that, the Board had been animated by, and had tried to give effect to, a desire for an improvement in the status of sea-going engineers, and that the isolation of the first paragraph of clause (a) from its sub-paragraph, and from the succeeding clauses (b) to (m) in the official opening of the present discussion, was scarcely fair to the Board. Assuming, as he trusted he was right in assuming, that this Institution did not desire to become sponsor to any proposals which might savour of protection for a particular class, it appeared to him that the tone of the discussion would have been somewhat altered if it had been emphasised at the beginning that the regulations were framed to admit as qualified, other engineers than those who had served a regular apprenticeship; that the period of four years' apprenticeship ran concurrently with the rule that a journeyman's time would be taken as equivalent to apprentice's time; and particularly that, apart altogether from period of service, the actual examination must disclose a more comprehensive knowledge of marine engines than was obtainable within the limits of any ordinary apprenticeship to one or two branches of engineering. Having regard to the fact that the Board of Trade had raised the period of practical probationship as apprentice or journeyman from three to four years, that was 33 per cent., it was probable that, on consideration, this Institution would not care to influence a further increase of that period to five years on account of the probable hardship of such an extension to many deserving men, in which event the discussion would be narrowed down to the character of the employment specified for the four years' period. In this connection it might be that the Board of Trade had had in mind a more liberal interpretation than was attributed to it of the character of the shop service which qualified, because, under clause 29 of the regulations, candidates might be accepted who have had five years' service, which "can be regarded as useful training of an engineer," without ever having been in either erecting or fitting shops. If this were accepted as sufficient to meet special cases, the discussion was further narrowed down to the expression of an objection to training in the fitting and erecting shops being by inference regarded as the best for an engineer, and to the exclusion of any direct reference to drawing office service in clause (a) of paragraph 22. The Board of Trade expressly recognised the advantage of technical education in the new regulations, but it appeared to him that, it had taken a backward step in leaving drawing office service to be judged under clause 29 instead of directly placing it upon a higher footing than that which obtained in the old regulations. He would suggest that instead of, or in addition to, a *precis* of the discussion, the business-like course for this and other Institutions interested, would be to agree upon such definite amendments to the wording as would give practical effect to the views of the members with the least possible disturbance to the existing form of the regulations. As a basis for discussion, he would submit that the second sentence of clause (a), paragraph 22, be amended to read as follows:—"One year of the apprentice's time must have been spent in the fitting, erecting, or repair shops, or have been divided amongst them; two more years may be spent in these shops or in the turning, machine, or pattern shops; one year in the drawing office, subsequent to shop training, will be considered equivalent to shop service," and that the words "fitting or erecting" be deleted from the second last line of the clause.

Mr James Barr (Member) said that Mr King's argument seemed to be this, that having extended the period of workshop service from three to four years, and having recognised in a practical way the value of technical education, the Board of Trade had perhaps made as great a step forward as could reasonably be expected of it, and that, while the Board had in paragraph 22 laid down seemingly hard and fast rules as to the kind of workshop service that would be accepted, it had by means of paragraph 29 left itself free to accept any other service that might be considered useful training for an engineer. Paragraph 29 stipulated, "When the workshop service has been performed in a place where engines are made and the department in which the applicant has been principally engaged is not 'fitting or erecting,' the case must be referred to the Board of Trade with a report upon the services performed. If the service be such as is useful training for an engineer, the Board may accept the service, but in every such case the applicant must prove additional engine-room or marine engine workshop service." The latter paragraph considerably modified the terms of the former, and if the Board was at all reasonable in its view of what was useful training it might be quite possible, in a five-years' apprenticeship, to satisfy the Board of Trade requirements by serving one or one and a half years in the fitting shop. As a matter of fact he understood that the Board of Trade did in practice make considerable allowance for time spent in the drawing office, pattern shop, or other department of an engineering establishment. Three years' service in the fitting or erecting shops must be taken, however, to be that which, in the opinion of the Board of Trade, was the most suitable training for a marine engineer, and while he thought that every engineer, and especially every marine engineer,

Mr James Barr.
should serve a portion of his time in these departments, because there was a good deal of experience to be got there that could be got nowhere else, he agreed with those who had already spoken on the subject that a considerable part of that time might be more profitably spent in gaining a more general experience in some of the other departments. The suggestion that all junior engineers before being allowed to sign on as such should have to pass an examination indicated the direction in which any real improvement in the standard of marine engineers was to be looked for.

Professor ANDREW JAMIESON (Member) observed that there was a clear and united consensus of opinion that, those who aimed at becoming marine engineers should serve a practical apprenticeship of not less than five years. He entirely agreed with this opinion. The chief difficulty, however, would be to get masters to adhere to any proposed differentiation of the five years' apprenticeship. Having had over a quarter of a century of experience in teaching engineering students, of whom a great many were serving their apprenticeship in marine engineering shops, with the ultimate object of going to sea, he took the liberty of submitting the following Table. He believed that it sub-divided the five years' workshop training very fairly; but he most certainly meant it to be so elastic, that the time spent in any one department could be longer or shorter, according to circumstances. He would insist upon young men attending one or two—but not more than two—evening or correspondence classes during each winter, and, as far as possible, joining the Engineer or Artillery Volunteers during the summer months. Finally, he believed that each candidate for a "sea job" should work as a journeyman for one year after his time was out at the fitting-up of machinery on board ship, and take, at the same time, advantage of classes, so as to prepare for the preliminary engineers' examination, which should be held and passed before a man was appointed as a third, fourth, or fifth engineer, to any first-class steamer.

Mr JAMES GILCHRIST (Chairman of Council) said it occurred to him that the Board of Trade was assuming a great deal when it

PROPOSED APPRENTICESHIP OF FIVE YEARS, WITH NOT LESS THAN ONE YEAR AS A JOURNEYMAN,

For those aiming at becoming Sea-going Marine Engineers.
By Professor Andrew Jamieson.

YEARS.	DEPARTMENTS.	DETAILS.	EVENING OR CORRESPONDENCE CLASSES.
1st	Machine Shops,	Working with Shaping, Planing, Milling, and Turning Machines.	Practical Mathematics; Boiler and Engine Drawing.
2nd.			Applied Mechanics; Boiler and Engine Drawing.
3rd.	Fitting and Erecting Shops,	Boring, Tapping, Fixing Bolts, Chipping, Filing, Fitting, and Finishing Details.	Practical Mathematics; Theoretical Mechanics.
4th.		Erecting Engines, and Fixing Boiler Mountings.	Higher Applied Mechanics; Elementary Steam.
5th.	Pattern Making or Drawing Office,	Preference to be given to Pattern and Millwright Work.	Higher Steam, Refrigerating Machines, Strength and Elasticity of Material.
6th.	Journeyman.	Erecting and Fixing Engines and Boilers on Steamers.	Electricity and Electrical Engineering, *e.g.*, Wiring, Lamps, Dynamos, and Motors, &c.

Mr James Gilchrist.

was willing to accept young men who had only served an apprenticeship of four years. Engineers not only on the Clyde and in Scotland generally, but also in England, had set their faces against anything in the shape of a four years' apprenticeship. Five years was quite short enough for practical purposes, and it was quite a mistake for the Board of Trade to think that efficient young men could be got after a four years' apprenticeship. Employers would not accept any young man as an engineer who could not produce a certificate of apprenticeship. That was a *sine qua non*, and they had made up their minds that they would not grant a certificate to any who had served for a less period than five years. The idea of considering a young man efficient who had served three years of his apprenticeship in a fitting or erecting shop was one which he thought perfectly absurd. The superintendent engineers in this country, in all companies that he knew of, were men of very considerable intelligence and ability, and they would not give ship room to a young man who had served his apprenticeship in this flimsy manner in a fitting or erecting shop. To his mind, fitting and erecting were exactly synonymous. It was only within the last few years that a fitting shop was known as an erecting shop. It was called a fitting shop in Scotland and an erecting shop in England. What he affirmed was this, that those who were training apprentices every day were making a point, as far as possible, to give their young men the best opportunities of working in the different shops. As Prof. Jamieson had said, it was very difficult to promise young men that they should serve so long in one shop and so long in another. Employers, as a rule, tried to give them "a turn" of all the different shops except the drawing office, which was only entered by sheer merit after an examination. This arrangement of the Board of Trade entirely ignored the pattern shop as well as the drawing office, and his own experience was that the best apprentices he had trained, and the best men that he had ever known in the engineering profession, were those who had served a very large portion of their apprenticeship in the pattern shop. There was

Mr James Gilchrist.

more to be learned in that department than in any other. A young man could not be a good pattern maker unless he understood drawing, and he must understand the one before he could make the other. He considered the Board of Trade was standing in its own light if it did not recognise in a very high manner those young men who had during the five years of their apprenticeship served a considerable amount of their time both in the drawing office and in the pattern shop. To follow out the scheme, as propounded in the paragraph dealing with the qualifications required by the Board of Trade for a second-class certificate, would simply bring the matter back to what was giving so very much dissatisfaction in the navy, where good engineers were named artificers. In the mercantile marine, engineers were not plain artificers. They wanted them to be men of brains, who could not only handle an engine properly, but who could do hard work, not like the highly-mathematical, college-bred students of the royal navy, who were afraid to soil their fingers, and left the real work to be done by the handy artificers. He would, therefore, suggest that they should strongly uphold the idea which possessed Mr Borrowman and other gentlemen on the north-east coast, that the engineers who were eligible for certificates of the Board of Trade should be of a higher class than what was indicated in the regulation under discussion, and that the term of apprenticeship should not be less than five years. He did not object to a man acting for the sixth year as a journeyman (as Professor Jamieson said), but he would certainly say that this regulation was worthy of condemnation, and ought to be rectified as quickly as possible.

Mr John W. Sothern (Member) said that very few men presented themselves for the Board of Trade examinations who had not completed five, six, or seven years' service. He strongly advocated some scientific training conjointly with practical work; for he had known men, after having served as engineers on watch in a large steamer for some time, come forward for examination, who had not the least idea of the principles lying behind moving machinery. The course drawn up by Professor Jamieson

Mr John W. Sothern.

appeared to be very satisfactory, in fact, ideal. The trouble was to get young men to attend classes, unless it was made in some way compulsory. One year in the drawing office was desirable, in order to give young men some idea of the scientific side of their work. Two years, he thought, was quite sufficient in the fitting or erecting shop, and two in the pattern making or turning departments.

Mr James Mollison (Member of Council) remarked that, like Mr Gilchrist and Professor Jamieson, he had gone through the mill, and had served a five years' apprenticeship. In fact, he was an indentured apprentice. Going back to indentures at this time of day could not be thought of, but he concurred in what had been said by previous speakers, that five years was quite short enough to gain a knowledge of their business and become proficient mechanics. Mr Gilchrist had referred to artificers in the navy. These men, he believed, underwent a certain examination to ascertain their fitness as mechanics before they were accepted for service, and a great deal depended on them for the efficient working of the complicated machinery on board ships of the Navy. Professor Jamieson remarked that in high-class passenger steamers, which carried electrical and refrigerating apparatus, apprentices who had only served four years should not be considered eligible as engineers, but in an ordinary cargo or coasting steamer it did not matter so much. He felt that in the cargo or coasting steamer it was quite as necessary to have well-trained mechanics in charge of the machinery as in the high-class steamer, because when anything did go wrong they had not the same resources to fall back upon, and were, therefore, more dependent on individual skill and mechanical ability. He had endeavoured, so far as was in his power, to keep up the status of the marine engineer, and an apprenticeship of five years was quite short enough to gain the knowledge necessary for the duties required. It was difficult to understand why the Board of Trade had in recent years put such a restriction on the time to be spent by an apprentice at pattern making or turning, two of the most skilled and useful branches in mechanical training. He was sure that everyone would be pleased to see the restriction modified, and due recognition given to time in those branches when spent in conjunction with fitting shop, drawing office, or other recognised practice.

Mr Thomas Burt (Member) suggested that five years should be accepted as the term of apprenticeship, so as to restrict the discussion. He thought that a five years' apprenticeship should be proposed by the Institution, and other relative matters could be discussed afterwards.

The Chairman (Mr E. Hall-Brown, Vice-President), said it had not been decided to put forward any recommendation from the Institution, but the idea rather was to give a summary of the views of Members. He thought they would all agree that a five years' apprenticeship was necessary ; it certainly should not be less.

Mr Gilchrist—The simplest thing was for the Board of Trade to go back to its old *regimé*, and accept the certificate of the employer who trained the individual. Up till recently the Board of Trade was perfectly satisfied if a young engineer could produce a certificate stating that he had served five years, and had worked to the entire satisfaction of his employer. It was absurd that employers should be ignored, the inference being that they did not know their business sufficiently well to train engineers capable of taking charge of machinery on board ship.

Mr D. C. Hamilton—There must have been a time when the Board of Trade did not insist on apprenticeship lines at all.

Mr Gilchrist moved that a report of the discussion be put into correct form, and remitted to their representatives on the Board of Trade Consultative Committee. Mr Hall-Brown, their Chairman that evening, was a member of that Committee, and he felt quite sure that he and his other three colleagues would see that the views of the Institution were represented at the proper quarter.

The Chairman observed that, before putting the motion to the meeting, he presumed that the opinion of the members was that

The Chairman.
the Board of Trade should not make any hard and fast limit as to the number of years spent in the fitting shop provided that the apprentice had spent five years in a marine engineering shop to the satisfaction of his employers. He also thought that if that were agreed to they should also emphasize the very valuable suggestion, that, before any engineer was allowed to go to sea in a junior capacity, he ought to show some knowledge of the theoretical side of engineering. It was very desirable that there should be an examination before a junior went to sea; and he thought if the Board of Trade could see its way to institute such an examination a better class of young men would be found going to sea, and there would be fewer engineers who had obtained Chief Engineers' certificates without having any real scientific knowledge, beyond what could be "crammed" in the few weeks usually set apart for preparation for the examinations. He was strongly of opinion that if every engineer who proposed to go to sea was required to have served an apprenticeship of five years to the satisfaction of his employers (but without further restriction), and was required to pass such an examination as would show a satisfactory knowledge of the scientific side of engineering, a much better class of marine engineers would obtain than under the present system.

The motion, on being put to the meeting, was carried unanimously.

The Chairman said that that closed the discussion and the work of the Session.

THE "JAMES WATT" ANNIVERSARY DINNER.

THE "JAMES WATT" ANNIVERSARY DINNER, under the auspices of the Institution, was held in the Grosvenor Restaurant, Gordon Street, Glasgow, on Thursday evening, 19th January, 1905. Professor J. Harvard Biles, LL.D., Vice-President of the Institution, presided, and the croupiers were Messrs W. M. Alston, W. A. Chamen, and John Ward. The company numbered upwards of 360 gentlemen. The Chairman was supported by the Hon. Lord Provost Sir John Ure Primrose, Bart.; The Most Hon. The Marquis of Graham; The Right Hon. Lord Inverclyde; The Right Hon. The Earl of Glasgow; Mr E. G. Pretyman, M.P.; Sir William H. White, K.C.B.; Sir William Arrol, LL.D., M.P.; Mr John Inglis, LL.D.; Col. J. M. Denny, M.P.; Mr James Gilchrist, Chairman of Council of the Institution; Admiral W. Wilson, R.N.; Mr John A. F. Aspinall; Mr Alexander Gracie; Professor A. Gray, LL.D., F.R.S; Mr A. D. Wedgwood; Provost Bell, Paisley; Mr David Murray, LL.D., President, Royal Philosophical Society, Glasgow; Mr David M'Gee; Captain J. G. Heugh, D.S.O., R.N.; Mr James Bain; Mr Laurence MacBrayne; Mr John Steven; Mr Andrew Lamberton, President, West of Scotland Iron and Steel Institute; Mr John S. Costigane; Provost Denholm, Greenock; Mr James Mollison; Mr Robert Robertson, B.Sc., President, Glasgow Section, Institution of Electrical Engineers; Professor A. Barr, D.Sc.; Mr Alexander W. Sampson; Professor John W. Gregory, D.Sc.; Captain H. Mowatt; Mr J. E. Harrison, President, Glasgow Association of Students' Inst. C.E.; Mr Thomas Kennedy; Mr R. T. Moore, D.Sc.; Mr James M'Kechnie; Dr. Freeland Fergus; and Mr James M. Blair.

Letters of apology were intimated from the Duke of Argyll, the Marquis of Linlithgow, Lord Rosebery, Lord Brassey, Lord Blythswood, Lord Armstrong, Sir John Fisher, Sir David Richmond, and others.

Lord Inverclyde.

The loyal toasts having been honoured,

Lord INVERCLYDE proposed "The Imperial Forces." He said that there were few in that company who were not directly or indirectly connected with the Navy, and he might safely add that all felt at the present time that the Admiralty was progressive, up-to-date, and it was looking ahead in connection with the Navy. The men who were associated with the control of the Navy were men of whom the country had every reason to be proud. During the past year the West of Scotland had been visited by three branches of His Majesty's Navy—the Channel Squadron, the Home Squadron, and the Cruiser Squadron, as well as a number of flotillas of torpedo-boat destroyers. Those who saw the magnificent Cruiser Squadron, which lay in Rothesay Bay, could not help having a feeling of pride that Britain possessed a Cruiser Squadron the equal of which did not exist in any other country in the world. He could not say they looked forward with pleasure to that other squadron which report said was shortly to be "dumped" down in the neighbourhood of the Clyde. The only way in which the Admiralty could provide recompense for doing that was by giving orders to the Clyde shipyards for the building of new vessels.

Admiral Wilson replied.

The EARL of GLASGOW proposed "The Corporation of Glasgow." He referred to the work it had accomplished not only in regard to the city, but in the development of the river, and in the latter connection paid a tribute also to the Clyde Trust.

Lord-Provost Sir JOHN URE PRIMROSE, Bart., alluding to the reference by Lord Glasgow to the Clyde Trust, said that mention of that body necessarily involved the consideration of the question of the constitution of the Trust, which was at present agitating the community. He claimed that the Corporation had developed the river till there was seventeen feet of water for every keel that was floated, and he claimed for the citizens that whatever Parliament might do in reconstituting the Clyde Trust, that the City of Glasgow should have a very prominent, if not a paramount, vote in the administration of the Trust. The claim could be absolutely justified, because at the root of the well-being of Glasgow lay the river. He could conceive of no situation of embarrassment or commercial stress in which the city would not act on behalf of the Clyde Trust, and give of its vast resources to land the Trust on the bed rock of solid ground if ever such help was needed. The Trades' House, the Merchants' House, and the Chamber of Commerce, sent men to the Clyde Trust whose value to that body could not be surpassed. Such men had run the whole gamut of public experience, and they had discrimination and judgment, which gave practical force to the administration of the Clyde Trust. He thought those who sought to give a few a dominant vote in the Trust failed to appreciate the situation. He deprecated any sectional tinkering with the constitution of the Trust, which could not be permanent, and which could not be in the best interests of the city.

The toast of "James Watt" was afterwards pledged in solemn silence.

Mr E. G. Pretyman, M.P., proposed "The Shipbuilding and Engineering Trades." He referred to the statement made by Lord Brassey the other day, at which he was surprised. Lord Brassey complained that the cost of battleships constructed in this country was unduly high, and he compared them to our disadvantage with ships built in other countries, and particularly in the United States. His Lordship quoted the names of the following ships built in America:—The United States, "Connecticut," "Kansas," "Louisiana," "Minnesota," and "Vermont," and he gave the total cost of these vessels at something over £800,000 each. He contrasted that with the following four ships built in this country—the "Commonwealth," "Dominion," "Hindustan," and "New Zealand," and he stated that the total cost of these ships approximated £1,400,000 each. But Lord Brassey had failed to take into account that the cost of armour and armament, in the case of the American ships, amounting to £680,000 had to be added to the total which he had given, while the cost of the armament was included in the case

Mr E. G. Pretyman, M.P.

of the British ships. The latter had, therefore, cost £1,400,000, against £1,500,000 for the American ships—a difference of £100,000 in favour of the former. Mr Pretyman went on to speak of visits he had made that day to shipbuilding yards on the Clyde, and stated that he was very pleased to see the indications of progress shown in these establishments, which he had often heard of, and the magnificent work that was being done by the combined brains and enterprise of the representatives of the navy and shipbuilding and engineering trades. Referring to the putting out of commission of a number of warships, he was pleased to see that under the new policy the country was now left with ships that would be ready to take their place in active service if required, and that no obsolete ships were on the active list. They would be ready for instant and effective action, and could be concentrated at whatever point might be required. Moreover, obsolete dockyards in distant parts of the world had been abolished, whereby very considerable expense had been saved. These changes had been carried out in the course of a very few weeks, and that seemed to show him that the system of administration at the Board of Admiralty was good, seeing that it enabled such changes to be effected in so short a time. It was only the loyal co-operation of the Navy and the splendid work of the heads of departments at the Admiralty that had contributed to make so effective a system. Sometimes such alterations involved added expense to the ratepayers, but in the present case he believed there would be a considerable reduction in that respect, and the saving thus effected would provide financial resources and reserves which could be called upon if occasion ever arose. He referred also to the new scheme of training and education of officers in the Navy, whereby a naval officer must be largely an engineer. Mr Pretyman afterwards referred to the assistance the Navy received from members of the shipbuilding and engineering trades such as were represented there that night, and said that one of the greatest pleasures in serving at the Admiralty was to have the feeling that it could rely upon the assistance and experience of such professional men.

Sir WILLIAM WHITE, K.C.B., LL.D., who acknowledged the toast, referred to the value of private shipyards, remarking that had it not been for the shipbuilding and engineering industries of the country, established and maintained by private enterprise, the work of the Navy could never have been accomplished. It was worth mentioning that of the £22,500,000 which had been spent on the great scheme of naval defence sixteen years ago, £2,000,000 represented wages spent in the dockyards, and the rest had been spent in private establishments. He thought therefore that Mr Pretyman, as representing the Admiralty, in acknowledging the assistance rendered by the engineering and shipbuilding industries of the country, was simply acknowledging what every man in these industries knew. While he called attention to the value of the private shipyards in doing work for the Navy, he did not wish as an old dockyard apprentice to reflect on or say anything against the Royal Dockyards. He thought a great deal of unfair criticism had been passed upon them, but they must never forget that the Royal Dockyards were essentially arsenals, provided for the repair and maintenance of the fleet, and for having it ready for action in time of war. It might be right to carry on in the dockyards a certain amount of new construction; but was it not a fact that if the new vessels of the Navy were to be maintained in an absolutely efficient condition the Dockyards would be very fully employed in doing that work. Without shipbuilding he thought the British Empire would not exist. Referring to Lloyd's shipbuilding returns for 1904, he pointed out that the tonnage produced in Great Britain was greater than in all the rest of the world; and the Tyne had produced as much as Germany—a country of which we heard a great deal. Glasgow alone, not taking the Greenock district into account, had built 255,000 tons, and Greenock 157,000, so that the Clyde district surpassed the United States, which had built 409,000 tons, including warships, and it did not seem to him that there was very much the matter with British shipbuilding.

The Marquis of GRAHAM proposed "The Houses of Parliament." They were, he said, sometimes told that the influence of Parlia-

The Marquis of Graham.
ment was waning, and that more men of business were required in the House of Commons. If they were to judge by the members who were present—Sir Wm. Arrol and Colonel Denny—that could not be said. There might be a Scotsman who did not take an interest in Scotland or read the newspapers, but there could hardly be one who had never heard the name of Arrol or Denny—names that were famous all over the world.

Col. DENNY, M.P., in replying, said it was not devolution the House of Commons required to enable it to do more work, it was the better oiling of its works. If a Scotch measure was sent to a Grand Committee, it showed the acme of perfection of Parliamentary procedure. If they could only have a Parliament without opposition, where there would be nothing to clog the wheels of progress, there would be no reason to complain of delay. All that was needed was a little of the oil of goodwill in order to pass as much by legislation as they wished for, and perhaps more than was good for them.

Sir WILLIAM ARROL, LL.D., M.P., who also replied, said the House of Lords fulfilled a very useful function in preventing rash legislation. Even in the decision in the Church case the public, he believed, were now coming round to the opinion that the House of Lords did quite right. Its decision would, perhaps, make the Churches leave politics alone and attend to their own work. He hoped the Government would stick to its guns in spite of all criticism, and continue to carry on the work of the country.

Mr J. A. ASPINALL, manager of the Lancashire and Yorkshire Railway, proposed "The Institution of Engineers and Shipbuilders in Scotland," to which the Chairman replied.

During the evening an interesting programme of vocal and instrumental music was submitted.

SMOKING CONCERT.

THE Members of the Institution and their friends met at a "smoker" in the Banqueting Hall of the Grosvenor Restaurant, Gordon Street, Glasgow, on the evening of Saturday, 7th March, 1905. Mr John Ward, Vice-President, occupied the chair. Mr Ward was supported by Mr James Gilchrist, Chairman of Council, Mr W. A. Chamen, Mr E. Hall-Brown, Mr D. A. Matheson, Mr C. P. Hogg, Mr H. Mechan, Mr J. W. Young, and Mr Leslie Denny. Previous to the concert an informal reception was held in an adjoining room, set apart for the purpose. The toast of "The King" was followed by an excellent programme, well rendered by local artistes. The company numbered upwards of 360.

MINUTES OF PROCEEDINGS.

FORTY-EIGHTH SESSION.

THE FIRST GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 25th October, 1904, at 8 p.m.

Mr JOHN WARD (Vice-President) occupied the chair.

The Minutes of the Extraordinary General Meeting, held on 3rd May, 1904, 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 Treasurer's Statement, and called upon Mr F. J. ROWAN to move their adoption.

Mr F. J. ROWAN, in moving the adoption of the Report of the Council, said he felt sure that all the Members would echo the hopes of the Council that their President would soon be able to be amongst them again, and take his place in the chair. They would notice that in the Report statements were included concerning various bodies to which the Council had appointed delegates; and while some might feel that these statements dealt with matters a little outside of the Institution, at the same time he thought it was a good sign that the Institution should be to the front in connection with the educational and scientific interests in the country. His own feeling was that the Report might well be enlarged with profit, and that it might be made a hand-book of information with regard to the Institution and those other scientific societies and educational institutions with which the Institution was identified, through its delegates, so that it might, with credit, be put into the hands of those whom they wished to attract as Members of the Institution.

Mr WILLIAM M'WHIRTER, with reference to the housing of the Institution, said there were matters in connection with the Library and Finance which should be carefully considered by the Institution in connection with the proposed dissolution of joint ownership with the Royal Philosophical Society, and he hoped that the Council would take the Members of the Institution into its confidence before making any final arrangements. He was very glad to see that considerable additions had been made to the books in the Library, and the progress made in that direction was gratifying.

Mr WILLIAM BROWN, in seconding the motion for the adoption of the Report of the Council, said he would like to congratulate the Institution on the fact that the Report showed a larger balance in its favour than had been reached in his time. He thanked Mr M'Whirter for his reference to the Library, he having had the honour of being the Honorary Librarian and Convener of the Library Committee for the last three years. As affecting the Library, he would not like the opportunity to pass without saying that in Mr Hall-Brown, who had succeeded him, they had one who would look very carefully after the Library and its interests. The Housing Accommodation Committee was looking after the interests of the Institution pretty well, and there was not the slightest doubt that the affairs with which the Committee had been dealing would be brought before the Institution in a practical way. The men who were serving the Institution on the Housing Accommodation Committee were men who had the interests of the Institution at heart.

The motion for the adoption of the Report, on being put to the Meeting, was unanimously agreed to.

The new Members elected at the previous Meeting were duly admitted.

PREMIUM OF BOOKS.

A letter from Dr BRUHN was read expressing inability to attend the Meeting to receive the award of books for his paper on "Some

Points in Connection with the "Riveted Attachments in Ships,' read during Session 1902-03.

Thereafter the Chairman gave a short address.

A paper was read by Mr F. J. Rowan on "The Smoke Problem"; and a paper by Mr Hector MacColl, on "The Breakage and Renewal of a Large Cylinder," was held as read.

The following candidates were duly elected;—

AS MEMBERS.

Ballantyne, John Hutchison, Electrical Engineer, 212 Bath Street, Glasgow.

Jones, Arthur Llewelyn, Engineer Surveyor, Lloyd's Register, 342 Argyle Street, Glasgow.

Kinloch, James, Naval Architect, Messrs Henderson Bros., Ltd., Stobcross, Glasgow.

Miller, George McEwan, Shipbuilder, 3 Clydeview, Partick.

Periton, William John, Shipbuilder, 41 Malone Avenue, Belfast.

From Associate Members.

Burns, William J. L., Assistant Manager, Bangkok Dock Coy., Bangkok, Siam.

From Students.

Dobson, James, Chief Draughtsman, Messrs H. Pooley & Son, Albion Foundry, Kidsgrove, Staffordshire.

Galloway, Andrew, Civil Engineer, The Grand Hotel, Heidelberg, Transvaal, S.A.

Mackay, W. Norris, Chief Engineering Draughtsman, c/o Stenhouse, 87 St George Mansions, Glasgow.

Portch, Ernest C., Engineer, 37 Vicar's Hill, Ladywell, London, S.E.

Watson, John, Foundry Manager, 9 Woodside Crescent, Glasgow, W.

AS ASSOCIATE MEMBERS.

Cook, Robert Templeton, Marine Engineer, 16 Abbotsford Place, Glasgow.

Findlay, Edwyn Alfred, Engineering Draughtsman, 10 Glebe Road, Kilmarnock.

Meek, William M'Carter, Ship Draughtsman New Parish Manse, Rothesay.

Stirling, William, Mechanical Engineer, 236 Dumbarton Road, Glasgow.

From Students.

Sloan, John Alexander, Draughtsman, 37 Annette Street, Crosshill, Glasgow.

STEVENSON, GEORGE, Chief Electrical Engineer, Wellpark, Larbert.

AS ASSOCIATES.

BOWLES, GEOFFREY TATTON, Lieutenant, R.N., 25 Lowndes Square, London, S.W.

CRAIGIE, JOHN, Engineering Agent, Bankhead, Pollokshaws, Glasgow.

AS STUDENTS.

ALEXANDER, WILLIAM, Apprentice Engineer, 13 Laurence Street, Partick.

CAMERON, CHARLES, Engineering Draughtsman, 126 Paisley Road, West, Glasgow.

HOWIE, JOHN, Engineering Draughtsman, 5 Fairlie Park Drive, Partick.

LOCHHEAD, JAMES M'CULLOCH, Apprentice Engineer, 10 Hamilton Crescent, Partick.

M'GREGOR, ROBERT, Engineering Draughtsman, 22 Westminster Terrace, Sauchiehall Street, Glasgow.

MITCHELL, JOHN MACFARLAN, Apprentice Draughtsman, 37 West Princes Street, Glasgow.

VICK, HENRY HAMPTON, Ship Draughtsman, 23 Broomhill Terrace, Partick.

WILSON, ROWAND, Engineering Draughtsman, 3 Cecil Street, Ibrox, Glasgow.

THE SECOND GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 22nd November, 1904, at 8 p.m.

Mr W. M. ALSTON (Vice-President) occupied the chair.

The Minutes of the First General Meeting, held on 25th October, 1904, 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.

Thereafter the discussion on Mr F. J. ROWAN'S paper on "The Smoke Problem" was resumed and adjourned.

The discussion on Mr H. MACCOLL'S paper on "The Breakage and Renewal of a Large Cylinder" was postponed.

A paper, by Mr EDWIN KENYON, on "The Transmission of Power by Ropes," was read.

The following candidates were duly elected :—

AS MEMBERS.

BROEKMAN, LOUIS, Electrical Engineer, 5 University Avenue, Glasgow.

HARRIS, WILLIAM, Engineer, Principal Officer to the Board of Trade, Western District of Scotland, 73 Robertson Street, Glasgow.

From Students.

MACKAY, LEWIS CHALMERS, Locomotive Engineer, 20 Glasgow Street, Hillhead, Glasgow.

AS AN ASSOCIATE MEMBER.

From Students.

MELENCOVICH, ALEXANDER, Engineer, 21 Peel Street, Partick.

AS A STUDENT.

HARVEY, WILLIAM BARNETT, B.Sc., Engineer, 7 Marchmont Terrace, Kelvinside, Glasgow.

THE THIRD GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 20th December, 1904, at 8 p.m.

Mr W. M. ALSTON (Vice-President) occupied the chair.

The Minutes of the Second General Meeting, held on 22nd November, 1904, 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 Mr F. J. ROWAN's paper on "The Smoke Problem" was resumed and concluded.

On the motion of the Chairman, Mr ROWAN was awarded a vote of thanks for his paper.

The discussion on Mr H. MACCOLL's paper on "The Breakage and Renewal of a Large Cylinder" was postponed.

Thereafter the discussion on Mr EDWIN KENYON's paper on "The Transmission of Power by Ropes" was begun and adjourned.

The following candidates were duly elected :—

AS MEMBERS.

ANDERSON, JOHN, Consulting Engineer, 40 West Nile Street, Glasgow.

BARR, JAMES, Engineer Surveyor, 67 Durward Avenue, Shawlands, Glasgow.

BRUCE, CHARLES ROSS, Engineer, 47 Brougham Street, Greenock.

BUDD, EDWARD R., Engineer, Manager, Messrs G. & A. Harvey, Ltd., Albion Works, Govan.

FINNIE, WILLIAM, Engineer, Manager, Messrs Howarth Erskine Ltd., Singapore, Straits Settlements.

LAW, DAVID, Engineer, Manager, Ibrox Iron Works, Ibrox, Glasgow.

MCARTHUR, DUNCAN, Engineer Surveyor, 6 Bank Street, Greenock.

MCONIE, PETER SMITH, Engineer, 9 Grant Street, Greenock.

MARRIOTT, ALFRED, Engineer, Manager, 44 Kelburn Avenue, Dumbreck.

ROYDS, ROBERT, B.Sc., Assistant Lecturer of Engineering, 5 Wilton Mansions, Kelvinside, Glasgow.

From Students.

BROOKFIELD, JOHN WAITES, Shipbuilder, Assistant Manager, Brookhurst, Halifax, Nova Scotia.

ASSOCIATE MEMBERS.

ANDERSON, DAVID, B.Sc., Engineering Draughtsman, 5 Great George Street, Hillhead, Glasgow.

DICKIE, JAMES BLACK, B.Sc., Ship Draughtsman, Sorrento, Terregles Avenue, Pollokshields, Glasgow.

HUTCHESON, ALEXANDER, Engineer, 5 Belmont Street, Hillhead, Glasgow.

HAY, JAMES, Engineering Draughtsman, Devon Bank, High Crosshill, Rutherglen.

MARTIN, JAMES, Engineering Draughtsman, 7 Woodend Drive, Jordanhill, Glasgow.

From Students.

WILLIAMSON, ALEXANDER, B.Sc., Engineer, Craigbarnet, Greenock.

AS STUDENTS.

APPLETON, EVELYN, Apprentice Engineer, Rosevale, Windsor Road, Renfrew.

BROOM, WILLIAM A., M.A., Student of Naval Architecture, Rothmar, Campbeltown.

CLARK, WILLIAM W., Apprentice Engineer, 32 Grafton Square, Glasgow.

FERGUSON, JOHN, Apprentice Engineer, Bellevue, Clydesdale Street, Hamilton.

FLEMING, ARCHIBALD L., Student of Naval Architecture, c/o Rankin, 280 Bath Street, Glasgow.

HOLLAND, JOHN C., Student of Engineering, 50 Gibson Street, Hillhead. Glasgow.

LEMON, ERNEST J. H., Apprentice Engineer, c/o Rutherford, 49 Barcaple Street, Springburn, Glasgow.

LIEPKE-RÖED, CARL, Student of Naval Architecture, 9 Grosvenor Terrace, Glasgow.

LOW, ARCHIBALD N., Apprentice Engineer, Dunlea, Partickhill, Glasgow.

MCAULAY, ALEXANDER, Apprentice Engineer, 1 Leven Grove Terrace, Dumbarton.

MCCLURE, WILLIAM, Engineering Draughtsman, 48 Claremont Street, Glasgow.

MCFARLANE, JOHN K., Apprentice Engineer, 20 Kelvinside Gardens N., Glasgow.

MAY, ANDREW, Engineering Draughtsman, Woodbourne, Minard Avenue, Partickhill, Glasgow.

ROSS, FRANCIS CECIL, Student of Naval Architecture, c/o Mackay, 29 Park Road, Glasgow, W.

SHEARDOWN, HAROLD E., Student of Engineering, c/o Murchison, 17 Montague Street, Glasgow, W.

SPENCE, JAMES, Jun., Student of Engineering, 21 West Princes Street, Glasgow, W.

SPIERS, ERNEST I., Student of Engineering, 76 Stepney Green, London, E.

THOMSON, JOHN A., Student of Engineering, c/o Ferguson, 59 North Park Street, Glasgow.

WADDELL, ROBERT, Engineer, 19 Kelvinside Terrace, S., Glasgow.

THE FOURTH GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 24th January, 1905, at 8 p.m.

Prof. J. H. BILES, LL.D. (Vice-President) occupied the chair.

The Minutes of the Third General Meeting, held on 20th December, 1904, having been printed in the billet calling the Meeting, was held as read, and signed by the Chairman.

The new Members elected at the previous Meeting were duly admitted..

The discussion on Mr H. MACCOLL's paper on "The Breakage and Renewal of a Large Cylinder" was begun and concluded.

On the motion of the Chairman, Mr MacColl was awarded a vote of thanks for his paper.

Thereafter the discussion on Mr Edwin Kenyon's paper on "The Transmission of Power by Ropes" was resumed and adjourned.

A paper on "Multiple Steam Turbines" by Mr Alexander Melencovich was read by the Secretary.

The following candidates were duly elected :—

AS MEMBERS.

Ballantine, Thomas, Assistant Consulting Engineer, 7 Royal Bank Place, Glasgow.

Boyd, John White, Consulting Engineer, 7 Royal Bank Place, Glasgow.

Cobb, Francis Hills, Engineer, Public Works Department, Pretoria, Transvaal.

Hunt, Wilfred, Patent Agent, 121 West George Street, Glasgow.

McDonald, Alexander, Engineer Surveyor, 9 Sutherland Street, Hillhead, Glasgow.

AS ASSOCIATE MEMBERS.

Atchley, Charles Atherton, Engineer, 50 Wellington Street, Glasgow.

Little, Simon Mure, Ship Draughtsman, 32 Sutherland Terrace, Glasgow, W.

AS STUDENTS.

Cameron, Ivan Johnstone, Apprentice Engineer, 5 Osborne Place, Copland Road, Govan.

More, Thomas, Apprentice Engineer, 593 Cathcart Road, Glasgow.

Munro, George W., Engineer, 5 Osborne Place, Copland Road, Govan.

Paterson, A. Stanley, Apprentice Engineer, Maryville, Bearsden.

Sutherland, Alexander, Student of Engineering, 12 Regent Park Terrace, Strathbungo, Glasgow.

The Fifth General Meeting was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 21st February, 1905, at 8 p.m.

Mr E. Hall-Brown (Vice-President) occupied the chair.

The Minutes of the Fourth General Meeting, held on 24th January, 1905, 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 Chairman called upon Mr C. P. Hogg to make a statement regarding the work that had been done by the Improved Accommodation Committee.

On behalf of that Committee, Mr C. P. HOGG reported that after protracted negotiations with the Royal Philosophical Society a definite recommendation had been agreed to. From the first the Committee had realised that they had either to acquire the existing building or sell their share in it and look out for new premises. The Royal Philosophical Society was now, subject to the approval of its members, willing to give the Institution £4000 for their share, and the Council had decided to recommend that the offer be accepted. At the close of the session the Institution would have about £3000 in hand; so that altogether there would be £7000 available towards the cost of providing the new Accommodation.

The discussion on Mr EDWIN KENYON'S paper on "The Transmission of Power by Ropes" was resumed and concluded.

On the motion of the Chairman, Mr KENYON was awarded a vote of thanks for his paper.

Thereafter the discussion on Mr ALEXANDER MELENCOVICH'S paper on "Multiple Steam Turbines" was begun and adjourned.

A paper on "Methods of Estimating the Strength of Ships," by Dr J. BRUHN was read by the Secretary.

A paper on "The Compounding of Locomotive Engines," by Mr JOHN RIEKIE was held as read.

The following candidates were duly elected:—

AS MEMBERS.

APPLEBY, JOHN R., Engineer, Manager, 133 Balshagray Avenue, Partick.

GARNETT, SYDNEY HAROLD, Engineer, 144 St. Vincent Street, Glasgow.

MALCOLM, WILLIAM GEORGE, Electrical Engineer, Boyack House, Pollokshields, Glasgow.

MUIR, JAMES, Engineer, Manager, Messrs John King & Co., Ltd., Engineers, Calcutta.

SMITH, ROBERT, Engineer, Burnlea Place, Milton of Campsie.
WELCH, ARCHIBALD, Shipbuilder, Clune Bank, Port-Glasgow.

AS ASSOCIATE MEMBERS

McKENZIE, WILLIAM JOHN, Ship Draughtsman, 14 Stephen Drive, Govan.
RUSSELL, JOHN, Engineer, Orchard Street, Motherwell.

AS ASSOCIATES.

BRECKNELL, GEORGE W., Engineering Agent, 79 West George St, Glasgow.
FARNELL, JOHN A., Engineering Agent, 11 Charing Cross Mansions, Glasgow.
GOVAN, WILLIAM, Engineering Agent, Maylea, Radnor Park, near Glasgow.

THE SIXTH GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 21st March, 1905, at 8 p.m.

Mr JAMES GILCHRIST (Chairman of Council) occupied the chair.

The Minutes of the Fifth General Meeting, held on 21st February, 1905, 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 following Nominations for Office-Bearers (Sessions 1905-08) were then made :—

President, Mr JAMES GILCHRIST. *Vice-Presidents*, Messrs ANDREW LAING, WILLIAM MELVILLE, JOHN STEVEN, and A. D. WEDGWOOD. *Ordinary Members of Council*, Messrs WILLIAM M. ALSTON, J. E. HARRISON, W. W. LACKIE, DAVID McGEE, MAGNUS MACLEAN, M.A., D.Sc., WILLIAM SHANKS, JOHN THOMSON, PETER WALLACE, and ALEXANDER WILSON. *Members of Council from Associate Class*, Messrs JAMES DONALD and J. B. HENDERSON.

A paper by Dr J. BLACKLOCK HENDERSON on "Some Notes on the Effects likely to be produced by the Gyroscopic Action of Steam Turbines on board Vessels pitching in a Sea," was held as read.

A paper by Professor ANDREW GRAY, LL.D., F.R.S., on "Gyrostats and Gyrostatic Action" was read.

Thereafter the discussion on Mr ALEXANDER MELENCOVICH'S paper on "Multiple Steam Turbines" was begun and concluded.

On the motion of the Chairman, Mr MELENCOVICH was awarded a vote of thanks for his paper.

The discussion on Dr J. BRUHN'S paper on "Methods of Estimating the Strength of Ships" was postponed.

The discussion on Mr JOHN RIEKIE'S paper on "The Compounding of Locomotive Engines" was postponed.

The following candidates were duly elected :—

AS MEMBERS

AULD, JOHN, Mechanical Engineer, Pollok Buildings, Corkerhill, Glasgow.

GILLIES, JAMES, Naval Architect, 14 Walmer Terrace, Glasgow.

GROUNDWATER, CHARLES LAMONT, Engineer, 13 Dryden Place, Edinburgh.

M'KILLOP, PETER ALEXANDER, Engineer, 45 Hope Street, Glasgow.

MARSHALL, ALEXANDER, Engineer, Manager, Glenmavis, Melrose Avenue, Rutherglen.

AS AN ASSOCIATE.

WILLOCK, FREDERICK GEORGE, Machinery Merchant, 109 Hope Street, Glasgow.

AS STUDENTS.

CRIGHTON, ARTHUR EDWARD, Apprentice Engineer, 119 Rue von Schoonbeke, Antwerp, Belgium.

DEWAR, ROBERT D., Engineering Draughtsman, 4 Battlefield Avenue, Langside, Glasgow.

DUNLOP, JOHN, Apprentice Engineer, 9 Oakfield Terrace, Hillhead, Glasgow.

M'GENN, HENRY HAMILTON, Engineer, 46 Claremont Street, Glasgow, W.

AN EXTRAORDINARY GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 18th April, 1905, at 8 p.m.

Mr JAMES GILCHRIST (Chairman of Council) occupied the chair.

The minutes of the Sixth General Meeting, held on 21st March, 1905, 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.

A discussion on "The Board of Trade Regulations for Certificated Marine Engineers" was begun and adjourned.

The discussion on Dr Bruhn's paper on "Methods of Estimating the Strength of Ships" was begun and adjourned.

The following Candidates were duly elected:—

AS MEMBERS.

Hislop, Jr., George Robertson, Engineer, 13 St James Place, Paisley.

Lage, Renaud, Engineer, Ilha do Vianna, Rio de Janeiro, P.O., Box 1032.

Robertson, Robert, Engineer, Manager, Messrs Watson, Gow & Co., Ltd., Etna Foundry, Lilybank Road, Glasgow.

AS AN ASSOCIATE MEMBER.

Norman, Myles Garnet, Engineering Draughtsman, Bracken Brae Road, Bishopbriggs.

AS ASSOCIATES.

Christie, William, Machinery Merchant, 4 Westminster Gardens, Hillhead, Glasgow.

Paul, Robert, Iron and Steel Merchant, 82 Gordon Street, Glasgow.

The Annual General Meeting was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 2nd May, 1905, at 8 p.m.

Mr John Ward (Vice-President) occupied the Chair.

The Minutes of the Extraordinary General Meeting, held on 18th April, 1905, having been printed in the billet calling the Meeting, were held as read, and signed by the Chairman.

Messrs Thomas Burt and William Harris were nominated to Scrutinise the Ballot for the appointment of Office-Bearers; and Messrs James Richmond and J. T. G. Leslie were appointed Assistant Scrutineers.

The new Members elected at the previous Meeting were duly admitted.

Mr John G. Johnstone, B.Sc., was awarded a premium of books for his paper on "The Uses of the Integraph in Ship Calculations," read during Session 1903-04.

Discussions on the following papers took place, viz.:—

On "Methods of Estimating the Strength of Ships," by Dr J. BRUHN.

On "The Compounding of Locomotive Engines," by Mr JOHN RIEKIE.

On "Some Notes on the Effects likely to be produced by the Gyroscopic Action of Steam Turbines on board Vessels pitching in a Sea," by Dr J. BLACKLOCK HENDERSON.

On "Gyrostats and Gyrostatic Action," by Professor ANDREW GRAY, LL.D., F.R.S.

The authors were awarded votes of thanks for their papers.

The Scrutineers submitted their Report, and the Chairman announced that the following gentlemen had been duly elected:—

President, Mr JAMES GILCHRIST; *Vice-Presidents*, Messrs ANDREW LAING and WILLIAM MELVILLE; *Members of Council from Class of Members*, Messrs W. M. ALSTON, W. W. LACKIE, DAVID McGEE, MAGNUS MACLEAN, M.A., D.Sc., ALEXANDER WILSON and R. H. B. THOMSON; *Member of Council from Class of Associates*, Mr J. B. HENDERSON.

The following candidates were duly elected:—

AS MEMBERS.

PEARSON, THOMAS, Engineer, Manager, 31 Lygon Road, Craigmillar Park, Edinburgh.

REID, ROBERT, Chief Engineer, British India Steam Navigation Co., Ltd., Colombo, Ceylon.

WILKINS, WILLIAM OWEN, Naval Architect, 175 West George Street, Glasgow.

From Students.

HOUSTON, PERCIVAL T., Consulting Engineer, Coronation House, 4 Lloyd's Avenue, London, E.C.

KEMP, ROBERT G., Mechanical Engineer, 60 Abbey Drive, Jordanhill, Glasgow.

MILLER, JAMES, Foundry Manager, 3 Roebuck Terrace, Stenhousemuir, Larbert.

MILLER, JOHN, Engineer, Etruria Villa, South Govan.

AS ASSOCIATE MEMBERS.

LEWIS, THOMAS, Ship Draughtsman, 37 Crow Road, Partick.

From Students.

ALLAN, JAMES, Civil Engineer, 326 West Princes Street, Glasgow.

CAMERON, ANGUS J., Ship Draughtsman, c/o Granger, 5 Osborne Place, Copland Road, Govan.

GILMOUR, ANDREW, Draughtsman, 3 Allanshaw Street, Hamilton (West).

MILLER, JAMES W., Mechanical Engineer, 84 Portland Place, London, W.

POLLOCK, GILBERT F., Engineer, 10 Beechwood Drive, Tollcross, Glasgow.

ROSS, THOMAS C., Engineer, 13 Hampden Terrace, Mount Florida, Glasgow.

SANGUINETTI, W. ROGER, Engineer, Public Works Department, Selangor, Malay States.

YOUNG, JOHN, Jun., Engineer, Messrs The Wallsend Slipway and Engineering Co., Ltd., Wallsend-on-Tyne.

AS AN ASSOCIATE.

HAMILTON, DAVID JOHN, Chemist, 9 Princes Gardens, Glasgow, W.

AS STUDENTS.

ANDERSON, JOHN, Jun., Student of Naval Architecture, 3 Crow Road, Partick.

BROWN, WALTER GEORGE, Student of Engineering, 35 Burnbank Gardens, Glasgow.

M'MILLAN, DUNCAN MURRAY, Student of Engineering, Millbrae, Milngavie.

AN EXTRAORDINARY GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 23rd May, 1905, at 8 p.m.

Mr E. HALL-BROWN, Vice-President, occupied the Chair.

The Minutes of the Annual General Meeting, held on Tuesday, 2nd May, 1905, 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 "The Board of Trade Regulations for Certified Engineers," was resumed and concluded.

The following candidates were duly elected:—

AS AN ASSOCIATE MEMBER.

FLETCHER, WILLIAM DAWSON, Engineer, 11-15 East Vermont Street, Kinning Park, Glasgow.

AS STUDENTS.

ANDREW, ARCHIBALD, Engineer, 4 Thornwood Terrace, Partick.

O'SULLIVAN, ANTHONY, Engineer, 54 Daisy Street, Govanhill, Glasgow.

REPORT OF THE COUNCIL.

SESSION 1903-1904.

ON the occasion of the Opening Meeting of the Forty-eighth Session, the Council, in presenting to the Members the following report of the proceedings of the Institution during the past twelve months, regrets to state that a protracted illness prevented the President from occupying the Chair; but it hopes that he will shortly be able to carry out the duties devolving upon him. In the absence of the President, Mr Gilchrist acted as Chairman of Council, and in his hands the interests of the Institution have been carefully attended to.

THE ROLL.

The changes which have taken place in the Roll during the year ending 30th September, 1904, are shown in the following statement:—

	Session 1902-1903.	Session 1903-1904.
Honorary Members,	9	8
Members, ...	962	1,013
Associate Members,	46	100
Associates, ...	87	88
Students, ...	287	193
	1,385	1,402

The elections were Members 45, Associate Members 15, Associates 11, and Students 37, a total of 108. The deaths, resignations, and deletions amounted to 91, which, deducted from the additions leaves a nett increase of 17. The decrease in the list of Students is partly due to a considerable number having been transferred to the classes of Members and Associate Members.

The Students' Section will continue to receive every encouragement from the Council.

The Council records with regret the deaths of the following:—Honorary Member—James M. Gale, Glasgow. Members—Sir William Allan, M.P., Sunderland; Charles Collie, Glasgow; W. T. Courtier-Dutton, Glasgow; Samuel Crawford, Liverpool; Charles M. Davies, Glasgow; James Ferrier, Carnoustie; Samson Fox, Leeds; Donald King, Glasgow; James D. M'Kinnon, Glasgow; John MacTaggart, Piree; James B. Mirrlees, Glasgow; James Neilson, C.B., Bellshill; Heinrich Paasch, Antwerp; Allan Strachan, Yloilo; and John Wilson, Glasgow. Associates—John Brown, Glasgow; and William Mann, Glasgow. Students—James G. Duncan, Singapore; and Robert Lowe, Glasgow.

Meetings.

During the Session eight meetings were held, at which papers of general interest and covering a wide range in engineering practice were read. In sequence they were submitted as follows:—

"Superheated Steam," by Mr F. J. Rowan.

"Improvements in Valve-Gears," by Mr John Riekie.

"Marine Propellers with Non-Reversible Engines and Internal Combustion Engines," by Mr Rankin Kennedy.

"An Inquiry Regarding the Marine Propeller," by Mr J. Millen Adam.

"Experiments with Rapid Cutting Steel Tools," by Mr Charles Day.

"The Hewitt Mercury Vapour Lamp," by Prof. Magnus MacLean, M.A., D.Sc.

"The Uses of the Integraph in Ship Calculations," by Mr John G. Johnstone, B.Sc.

"Some Modern Appliances Connected with Railway Crossings and Points," by Mr Owen R. Williams, B.Sc.

"Motor Cars," by Mr Alexander Govan.

These papers together with a synopsis of a lecture on "Radium," by Dr John Macintyre, are embodied in Volume xlvii of the Institution's proceedings.

In respect to papers read during Session 1902-03, awards of books were granted respectively to Mr Konrad Andersson for his paper on "Steam Turbines: With special reference to the de Laval type of Turbine"; and to Dr J. Bruhn for his paper on "Some Points in connection with the Riveted Attachments in Ships."

The Council desires to emphasize the importance of Members taking part in the discussions on papers; and to express the hope that in future those conversant with the subjects brought forward will endeavour to fully express their views on the same.

A Conversazione, combined with an Exhibition of models and apparatus connected with engineering and shipbuilding, took place in the St. Andrew's Halls on the evening of Friday, 16th October.

The "James Watt" Dinner was held in the Windsor Hotel, Glasgow, on Saturday evening, 23rd January, the company present numbering upwards of 320.

The better housing of the Institution has received the careful attention of the Council. Meetings have been held with the representatives of the Royal Philosophical Society, and this matter is under active consideration.

Students' Section.

The Meetings held by the Students were seven in number. The Chairman of the Section, Mr E. Hall-Brown, opened the Session with an address; and an exhibition of electrical apparatus was given by Mr J. M. Hossack. At the subsequent meetings the undermentioned papers were read and discussed.

"Steam Turbine Machinery," by Mr A. A. W. Wynne, M.A.

"Vibrations of Ships and Balancing of Engines," by Mr A. Melencovich.

"Early Transatlantic Steamers," by Mr Angus Cameron.

"Design of Merchant Steamers," by Mr J. R. Jack.

"Economy of Fuel Combustion." by Mr N. Fish.

"Steam Turbines," by Mr A. Melencovich.

Mr A. Melencovich was awarded a premium of books for his paper on "Steam Turbines," and a similar award was given to Mr N. Fish.

Visits were paid to the following works during the Session:—

Holm Foundry, Cathcart, Glasgow, Messrs G. & J. Weir. Ltd.

Dalmarnock Ironworks, Bridgeton, Glasgow, Messrs Sir William Arrol & Co., Ltd.

Leven Ship Yard, Dumbarton, Messrs William Denny & Brothers.

The thanks of the Institution are due to the principals and directors of these firms for the kindness extended to the Students when visiting their works.

Board of Governors of The Glasgow and West of Scotland Technical College.

Mr James Weir continued to represent the Institution on the Board of Governors of the Glasgow and West of Scotland Technical College.

The College had a very successful session, the number of students being as follows:—

Day students, ...	489
Day students, including students of county classes conducted by College lecturers,	4,212
Pupils of Allan Glen's School, ...	632
Total number of individual students, ...	5,333

The total number of class enrolments was 7,848, and the total number of "student-hours" was no less than 368,282.

During the year the Committee of the College was reorganised, and a new Committee for the superintendence of the engineering departments was established.

This Committee included such of the Governors as were engineers, and in addition the following members of the Institution accepted the invitation of the Governors to join the Committee:—

Mr Alexander Cleghorn, Messrs Barclay, Curle & Co., Ltd.
Mr Charles P. Hogg, Messrs Crouch & Hogg.
Mr John Inglis, LL.D., Messrs A. & J. Inglis.
Mr Andrew T. Reid, The North British Locomotive Co., Ltd.
Mr Robert Robertson, B. Sc., Messrs Strain & Robertson.
Mr James Rowan, Messrs David Rowan & Sons.

The immediate direction of the departments of engineering is now in the hands of the members of this Committee, on whose recommendation certain modifications have been made in the curriculum, and additional members appointed to the engineering staff.

Satisfactory progress with the new buildings has been made during the year. A few of the rooms will be occupied during the session 1904-5, and it is expected that the whole of the first section, now in course of erection, will be available for the following session.

BOARD OF GOVERNORS OF THE GLASGOW SCHOOL OF ART.

The Institution was represented on this Board by Mr James Mollison.

Since the Scotch Education Department recognised the Glasgow School of Art as a central institution for art education (which to a very large extent is applied to industrial art), the Governors have endeavoured to raise the standard by the appointment, from time to time, of professors from abroad, who give their services in the work of the school. Classes for the instruction of teachers have also been established with very good results.

The enrolments for the session numbered 626 ordinary students and 858 in teachers' classes, or a total of 1,484.

Last session the Education Department made a new arrangement, whereby it was agreed to give half the actual expenditure, less the amount required from school fees, on condition that the other half was raised locally. This is a heavy responsibility for the Governors to face, but hitherto they have contrived, with the assistance of the Corporation grant, to find the money. They are sanguine that should the increasing demand on the School require it, the citizens will support it financially, and its continued prosperity and usefulness is certainly worthy of all the interest the Institution of Engineers and Shipbuilders in Scotland can bestow upon it.

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 James Hamilton and Mr George McFarlane.

Two meetings were held during the year, on the 2nd February, and on the 5th July, when the Institution's representatives took part in the discussions on the various matters submitted by engineering and shipbuilding firms, of which the following were the most important:—

- Italian Certificates of Tonnage.
- The Use of Corticene as a Substitute for Wood for Sheathing Iron and Steel Decks.
- The Survey of Masters' and Crews' Spaces.
- The Freeboard of Hopper Barges.
- The New Regulations issued by the Board of Trade in December, 1903.
- The Measurement of Water-ballast Tanks for Tonnage.
- Freeing-ports on Shelter-deck Vessels.
- Testing of Steam Pipes on Vessels built under the Board of Trade Survey.

Lloyd's Technical Committee.

The Institution was represented on the Technical Committee of Lloyd's Register of British and Foreign Shipping by Mr Sinclair Couper, Mr John Inglis, LL.D., Mr Richard Ramage, and Mr James Rowan.

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 dealt with :—

Bilge Suction in Steam and Sailing Vessels.
Amendments of Rules regarding Engine Space.
,, ,, relating to Equipment.
,, ,, and Tables relating to Deep Framing.
,, ,, relating to Tubular Pillars and Davits.
,, ,, regarding Double-bottoms.
,, ,, ,, Wood Middle Decks.
New Rules for Turret-deck Vessels.

TWENTY-SECOND CONGRESS OF THE SANITARY INSTITUTE.

Mr C. P. Hogg and Mr F. J. Rowan, Members of the Council, acted as delegates from the Institution at the Meetings of the Congress of the Sanitary Institute which were held at the University, Glasgow, from July 25th to 30th.

The Members of the Congress were received by the Hon. Lord Provost Sir John Ure Primrose, Bart., after which the Inaugural Address was delivered by the Right Hon. Lord Blythswood, LL.D., President of the Congress. The President gave a rapid review of the progress of sanitary science in its material aspect since the year 1818, and indicated further possible steps in the improvement of the sanitary conditions of Glasgow, amongst which the purification of the atmosphere from smoke, and the removal of sewage from the river Clyde and its tributaries were mentioned. The introduction of elementary instruction in sanitation into schools was advocated by the President, and in the remainder of his address he dwelt upon the importance of what he called "the infinitesimal"—or infinitesimal forces, amongst which the ultra-violet rays of sunlight, electricity, and radio-activity were instanced.

The meetings were arranged under three Sections and eight Conferences. The Sections were :—

I. Sanitary Science and Preventive Medicine.
II. Engineering and Architecture.
III. Chemistry, Physics and Biology.

The addresses given by the Presidents of the Sections were:—

Section I., by Professor J. Glaister, M.D., on "Smallpox Infection from Hospitals; a Critical Study of the Doctrine of Aerial Convection of Smallpox, based upon the Histories of Previous Epidemics," in which, after a long and minute study of the subject, he concludes against the doctrine having been proved, and in favour of the view that aerial dissemination is problematical.

Section II., by Professor Henry Robinson, on "Sewage Outfalls and the Proper Utilization of Rainfall or Flood Water, with a few remarks on Road Sanitation."

Section III., by Professor Frank Clowes, D.Sc., on "The intimate relation between Chemistry, Physics, and Biology in Sanitary Problems." This address dealt with the following subjects:—"Sewage Treatment," "Bacterial Treatment by Intermittent Contact," "Bacterial Treatment by Continuous Contact," "Standards for Sewage Effluents," "Bacterial Contamination of Shell-fish by Sewage," "The Study of Disease and its Propagation," and "Purity of Food and Air."

These addresses and papers read at the Congress are in course of publication in "The Journal of the Sanitary Institute," and will eventually be placed in the Library of the Institution, along with a souvenir handbook of Glasgow, issued by the Corporation of Glasgow, containing a brief account of the various departments which are carried on under its management.

The Council desires to express the thanks of the Institution to all these gentlemen for their services on the various Committees.

FINANCE.

The continued financial prosperity of the Institution is a matter of congratulation. The surplus revenue for the Session ending 30th September, 1904, as shown by the Treasurer's Statement appended hereto, is £725 13s. 8d; an augmentation to the funds of the Institution which the Council hopes to utilize in providing additional accommodation to meet the growing requirements of the Institution.

TREASURER'S
INCOME AND EXPENDITURE ACCOUNT
GENERAL

ORDINARY INCOME.				1903-1904.			1902-1903.		
I. *Annual Subscriptions received—*									
Members, ...	£1748	0	0						
Associate Members, ...	83	0	0						
Associates, ...	120	0	0						
Students, ...	84	10	0						
				£2035	10	0	£1885	10	0
II. *Arrears of Subscriptions recovered, less expenses,*				43	8	6	42	1	1
III. *Sales of Transactions,*				31	8	3	11	14	3
IV. *Interests and Rents—*									
Interest on Clyde Trust Mortgages for £400, less tax, ...	£13	7	0						
Interest on Deposit Receipts, *less* Income Tax, ...	12	9	7						
Interest on Glasgow Corporation Loan, ...	3	6	0						
West of Scotland Iron and Steel Institute, for use of Library,	20	0	0						
Students, Institution C.E., for use of Library, ...	11	12	0						
				60	14	7	33	13	0
				£2176	1	4	£1980	18	4

STATEMENT.
FOR YEAR ENDING 30TH SEPTEMBER, 1904.
FUND.

ORDINARY EXPENDITURE.				1903-1904.	1902-1903.
I. *General Expenses*—					
Secretary's Salary, ...	...£400	0	0		
Clerk's Salary, ...	... 66	0	0		
Institution's proportion of net cost of maintenance of Buildings, etc.,	122	6	7		
Library Books, ...	.. 31	14	11		
Binding Periodicals and Papers,	12	15	8		
Stationery and Postages, etc.,	58	13	5		
Office Expenses, ...	.. 31	18	11		
Advertising, Insurance, etc., ...	5	7	0		
Travelling Expenses, ...	... 4	3	3		
Assistance at Meetings, ...	1	12	0		
				£731 11 9	*£808 16 10*
II. "*Transactions*" *Expenses*—					
Printing and Binding,	£396	17	4		
Lithography, ...	... 194	15	1		
Postages, ...	... 71	9	6		
Reporting, ...	... 17	7	0		
Delivery of Annual Volume, ...	17	5	0		
				697 13 11	*711 13 7*
III. *Awards*—Premiums for Papers, ...				....	*15 1 7*
EXTRAORDINARY EXPENDITURE.					*311 14 10*
Deficit on Conversazione, £18 10s 9d, less surplus on "James Watt" Dinner, 8s 9d, ...				18 2 0	...
Surplus carried to Balance Sheet, ...				725 13 8	*135 11 6*
				£2176 1 4	*£1980 18 4*

BALANCE SHEET, AS AT

LIABILITIES.				As at 30th Sept., 1904.	*As at 30th Sept., 1903.*
I. *General Capital Account—*					
As at 1st Oct., 1903, ...		£4766 19 9			
Entry money, ...		68 0 0			
Surplus from Revenue, ...		725 13 8			
				£5560 13 5	*£4766 19 9*
II. *Life Members' Subscriptions,*				150 0 0	*50 0 0*
III. *Sundry Creditors,*				0 10 0	*27 1 6*
IV. *Subscriptions paid in advance,*				65 5 0	*56 10 0*
V. *Medal Funds—*					
Marine Engineering—					
Balance as at 1st Oct., 1903,	£569 3 0				
Interest received during year, £18 8s, less Premium of Books, £5 1s 6d,	13 6 6				
		£582 9 6			
Railway Engineering—					
Balance as at 1st Oct., 1903,	£355 16 1				
Interest received during year,	11 10 0				
		367 6 1			
Students'—					
Balance as at 1st Oct., 1903,	£23 1 10				
Cost of medal, £1 7s 6d; *less* interest received during year, 14s 11d,	0 12 7				
		22 9 3		972 4 10	*948 0 11*
				£6748 13 3	*£5848 12 2*

30TH SEPTEMBER, 1904.

ASSETS.				As at 30th Sept., 1904.			*As at 30th Sept. 1903.*		
I. *Heritable Property—* Total Cost,	£7094	16	2						
Of which one-half belongs to the Institution, ...				£3547	8	1	*£3547*	*8*	*1*
II. *Furniture and Fittings—* Valued at, say				65	10	0	*65*	*10*	*0*
III. *Books in Library—* Valued at, say				500	0	0	*500*	*0*	*0*
IV. *Investments—*									
Clyde Trust Mortgages, ...	£1200	0	0						
Glasgow Corporation Loan,	200	0	0	1400	0	0	*600*	*0*	*0*
V. *Medal Funds Investments—*									
Clyde Trust Mortgage,	£903	0	0						
On Deposit Receipt and Interest,	46	5	2	949	5	2	*920*	*7*	*8*
VI. *Arrears of Subscriptions—* Session 1903-1904—									
Members, ...	£117	0	0						
Associate Members, ...	5	0	0						
Associates, ...	1	10	0						
Students, ...	12	10	0						
	£136	0	0						
Previous sessions— Members, £51 10 0; Students, 7 0 0	58	10	0						
Total,	£194	10	0						
Valued at, say				50	0	0	*50*	*0*	*0*
VII. *Sundry Debtors—*				12	12	8	*1*	*0*	*0*
VIII. *Cash—*									
In Bank, on Deposit Receipt and Interest, ...	£160	15	9						
On Current Account, ...	44	6	9						
In Secretary's hands, ...	18	14	10	223	17	4	*164*	*6*	*5*
				£6748	13	3	*£5848*	*12*	*2*

GLASGOW, *17th October, 1904.*—Audited and certified correct.

DAVID BLACK, C.A., *Auditor.*

ABSTRACT OF "HOUSE EXPENDITURE" ACCOUNT FOR SESSION 1903-1904.

Note.—The Account of the House Committee, of which the following is an abstract, is kept by Mr John Mann, C.A., Treasurer to the Committee, and is periodically audited by the Auditors appointed by the Institution and the Royal Philosophical Society.

EDWARD H. PARKER, *Secretary to the House Committee.*

INCOME.	12 months, to 30th Sep., 1904.	*12 months, to 30th Sep., 1903.*
Rents for Letting Rooms, ...	£110 16 0	*£97 8 6*
Balance, being excess Expenditure, ...	244 13 1	*426 14 6*
Payable by Institution, ... £122 6 7		
Payable by Philosophical Society, 122 6 6		
	£355 9 1	*£524 3 0*

EXPENDITURE.	12 months, to 30th Sep., 1904.	*12 months, to 30th Sep., 1903.*
Salary to Curator, ...	£154 0 0	*£135 0 0*
Salary to Attendant at Library, Cleaning, etc., ...	88 12 8	*85 3 8*
Feu-duty, Taxes, and Insurance,	50 13 3	*57 8 4*
Alterations, Repairs & Renewals,	19 19 8	*198 11 6*
Coal, Gas, and Electric Light,	38 16 11	*45 6 4*
Stationery, Postages, and Incidental Expenses, ...	3 6 7	*2 13 2*
	£355 9 1	*£524 3 0*

GLASGOW, *17th October, 1904.*—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 16 volumes and 21 Board of Trade Reports on boiler and steam-pipe explosions, by donation; 161 volumes by purchase; and 92 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, 26 were weekly and 24 monthly. Seventy-one 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.

Donations to the Library.

Brough, B. H. Mining of Non-Metallic Minerals (Cantor Lecture), 1903. Pam. From the Author.

Colby, Albert Ladd, A Comparison of Certain Physical Properties of Nickel Steel and Carbon Steel, South Bethlehem, Pa., 1903. From the Author.

Hiller, Edward G., Notes on Material, Construction and Design of Land Boilers. 8vo. Manchester, 1903. From the Author.

Incorporated Accountants' Year-Book, 1903-4. From Society of Accountants and Auditors.

Institution of Naval Architects. Vols. 1, 3, 4, 5, and 22. From Edward M. Speakman.

Jahrbuch für das Eisenhuttenwesen (Ergänzung zu Stahl und Eisen). 1901. 8vo. Düsseldorf, 1903. From Vereins Deutscher Eisenhuttenleute.

London University College, Calendar, 1903-04. From the University.

Matheson, Donald A. Notes on the Engineering Features on American Railroads. Folio, 1903. From Mr R. Millar.

Maycock, W. P. Electric Lighting and Power Distribution: An Elementary Manual of Electrical Engineering for Students. Vol. 2. 8vo. London, 1903. From the Author.

Sothern, J. W. Verbal Notes and Sketches for Marine Engineers. 4th edition, 1904. From the Author.

White, James. Altitudes in the Dominion of Canada, with 4 Sheets of Profiles, 1901. From Geological Survey of Canada.

Books added to the Library by Purchase.

Arnold, E. Armature Windings of Direct Current Dynamos. Translated by Francis B. De Gress, 1903.

Association of Municipal Engineers. International Engineering Congress (Glasgow), 1901. Proceedings of Section 7. Edited by T. Cole.

Atherton, W. H., and Mellanby, A. L. Resistance and Power of Steamships. 8vo. Manchester, 1903.

Atkinson, A. A. Electrical and Magnetical Calculations. 2nd edition; 8vo. London, 1903.

Baker, Ira Osborne. Treatise on Roads and Pavements. New York, 1903.

Barnaby, Sydney W. Marine Propellers. 4th edition, 1900.

Bedell, Fredk., and Crehore, Albert C. Alternating Currents. 2nd edition. New York, 1893.

Bell, Louis. Power Distribution for Electric Railroads. New York.

Berkeley, H. R., and Walker, W. M. Practical Receipts for the Manufacturer, the Mechanic, and for Home Use. 1902.

Björling, Philip R. Briquettes and Patent Fuels: their Manufacture and Machinery. 8vo. London, 1903.

Bodmer, G. R. Inspection of Railway Material. 1902.

Booth, William H. Liquid Fuel and its Combustion. Westminster, 1903.

Bowker, William R. Practical Construction of Electric Tramways, 1903.

Box, Thomas. Practical Treatise on Heat as applied to the Useful Arts. 9th edition; 8vo. London, 1903.

Brassey's Naval Annual. 1904.

Buchanan, John F. Brassfounders' Alloys. London, 1901.

Buchetti, J. Engine Tests and Boiler Efficiencies. 3rd edition; 8vo. Westminster, 1903.

Burton, Francis G. The Naval Engineer and the Command of the Sea. 8vo. Manchester, 1903.

Clarke, J. Wright. Practical Science for Plumbers, Engineers, Students, &c. 8vo. London, 1903.

Clowes, W. Laird, and Others. The Royal Navy: a History from the Earliest Times to the Present. Vols. 6-7; 8vo. London, 1901, 1903.

Cunningham, Brysson. Treatise on the Principles and Practice of Dock Engineering. London, 1904.

Dervoort, W. H. Van. Modern Machine Tools. 4th edition. London, 1904.

Durley, R. J. Kinematics of Machines: an Elementary Text-Book. New York, 1903.

Felskowski, G. L. Shipbuilding Industry of Germany. 4to. London, 1904.

Fletcher, William. The Steam-Jacket, Practically Considered as an Efficient Fuel Economiser. 2nd edition. London, 1895.

Foreman Pattern-Maker (J.Horner).Helical Gears. London, 1893.

Foster, G. Carey, and Porter, Alfred W. Elementary Treatise on Electricity and Magnetism. 2nd edition; 8vo. London, 1903.

Gray, Andrew. Theory and Practice of Absolute Measurements in Electricity and Magnetism. Vol. 1; 8vo. London, 1888.

Griffin, Charles & Co., Year-Book of the Scientific and Learned Societies of Great Britain and Ireland for 1902-03. 8vo. London, 1903.

Griffiths, John W. Treatise on Marine and Naval Architecture: or Theory Blended in Shipbuilding. 4to. New York, 1851.

Guy, Albert E. Experiments on the Flexure of Beams, resulting in the Discovery of New Laws of Failure by Buckling. 8vo. New York, 1903.

Halsey, Frederick A. Slide-Valve Gears. 7th edition. New York, 1901.

Hillcoat, Charles H. Notes on Stowage. London, 1894.

Holms, A. Campbell. Practical Shipbuilding: A Treatise on the Structural Design and Building of Modern Steel Vessels. 2 Vols. Text and Plates. London, 1904.

Hornby, John. Text-Book of Gas Manufacture for Students. London, 1902.

Howie, Malverd A. Design of Simple Roof Trusses in Wood and Iron. New York, 1902.

Hurst, Charles. Hints on Steam-engine Design and Construction. 8vo. London, 1901.

Jamieson, Andrew. Text-Book of Applied Mechanics. 3rd edition, vol. 2; 4th edition, vol. 1. London, 1903.

Leaf, H. M. The Internal Wiring of Buildings. 2nd edition: 8vo. Westminster, 1903.

Leeds, F. H., and Butterfield, W. J. A. Acetylene: the Principles of its Generation and Use. 8vo. London, 1903.

Lieckfeld, G. Practical Hand-Book on the Care and Management of Gas-engines. Translated by G. Richmond. 16mo. New York.

Loppé and Bouquet. Alternate Currents in Practice. London, 1898.

Lunge, George. Theoretical and Practical Treatise on Sulphuric Acid and Alkali, with the Collateral Branches. 3rd edition, Vol. I., parts 1, 2. London, 1903.

Lunge, George, and Hurter, Ferdinand. Alkali-Makers' Hand-Book. 3rd edition. London, 1902.

Lupton, Arnold, Parr, G. D. A., and Perkin, Herbert. Electricity as Applied to Mining. 8vo. London, 1903.

Lyons, T. A. Treatise on Electromagnetic Phenomena, and on the Compass and its Deviations Aboard Ship. 2 vols.; 8vo. New York, 1901, 1903.

Mahan, D. H. Treatise on Civil Engineering, edited by De Volson Wood, with a Chapter on River Improvements, by F. A. Mahan. New York, 1902.

Mechanics' Magazine. Vols. 1-68. 8vo. London, 1823-58.

Merriman, Mansfield. Text-book on the Method of Least Squares. 8th edition. 8vo. New York, 1900.

Morgan, J. James. Tables for Quantitative Metallurgical Analysis for Laboratory Use. 8vo. London, 1899.

Neilson, Robert M. The Steam Turbine. 2nd edition. London, 1903.

Oudin, Maurice A. Standard Polyphase Apparatus and Systems. 3rd edition. 12mo. New York, 1902.

Owen, Douglas. Ports and Docks, their History, Working, and National Importance. London, 1904.

Perrine, F. A. C. Conductors for Electrical Distribution, their Materials and Manufacture. New York, 1903.

Popplewell, William C. Experimental Engineering. Vol. 2—Treatise on the Methods and Machines Used in the Mechanical Testing of Materials of Construction. Manchester, 1901.

Potter, Thomas. Concrete: its Use in Building. 2 vols. 8vo. Winchester, 1891.

Rea, John T. How to Estimate: Being the Analysis of Builders Prices. 8vo. London, 1902.

Reagan, H. C. Locomotives—Simple, Compound, and Electric 4th edition. New York, 1902.

Reeve, Sidney A. Thermodynamics of Heat-Engines. New York, 1903.

Richards, H. W. Bricklaying and Brickcutting. 8vo. London, 1901.

Rider, John Hall. Electric Traction: A Practical Hand-Book on the Application of Electricity as a Locomotive Power. London, 1903.

Rose, Joshua. Slide-Valve Practically Explained. Philadelphia, 1899.

Rosenberg, E. Electrical Engineering: An Elementary Text-book. Translated by W. W. H. Gee and Carl Kinzbrunner. 8vo. London, 1903.

Rowan, Frederick J. Practical Physics of the Modern Steam Boiler. 8vo. London, 1903.

Ryan, Harris J., Norris, Henry H., and Hoxie, George L. Text-Book of Electrical Machinery, vol. 1—Electric-Magnetic and Electric-Static Circuits. New York, 1903.

Smart, R. Addison. Handbook of Engineering Laboratory Practice. 8vo. New York, 1899.

Still, Alfred. Alternating Currents of Electricity and the Theory of Transformers. London, 1898.

Suplee, Henry H. Mechanical Engineer's Reference Book. London, 1904.

Tait, P. G. Properties of Matter. 4th edition. London, 1899.

Thallner, Otto. Tool-Steel: A Concise Handbook on Tool-Steel in General. Trans. by W. T. Brannt. 8vo. Philadelphia, 1902.

Thomas, B. F., and Watt, D. A. Improvement of Rivers: A Treatise on the Methods Employed for Improving Streams for Open Navigation, and for Navigation by Means of Locks and Dams. 4to. New York, 1903.

Thompson, Silvanus P. Dynamo-Electric Machinery. 7th edition. London, 1904.

Transactions of the Institution of Naval Architects. Vols. 36-42. 4to. London.

Trautwine, John C. Civil Engineer's Pocket Book. 18th edition, revised by John C. Trautwine, Jun. New York, 1902.

Treadwell, Augustus. The Storage-Battery: A Practical Treatise on the Construction, Theory, and Use of Secondary Batteries. 8vo. New York, 1901.

Unwin, W. C. Elements of Machine Design. New edition, revised 1901, 2 vols. London, 1903.

Walmsley, R. Mullineux. Electricity in the Service of Man. 8vo. London, 1904.

Williams, Hal. Mechanical Refrigeration. London, 1903.

Wilson, Eugine B. Hydraulic and Placer Mining. 8vo. New York, 1903.

Wolff, C. E. Modern Locomotive Practice. Manchester.

Wright, A. C. Analysis of Oils and of Allied Substances. 8vo. London, 1903.

The Institution Exchanges Transactions with the following Societies, etc.:—

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.
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.
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 Polytechnic, 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.
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.
Osterreichischen Ingenieur und Architekten-Verein, Wien.
Patent Office, London.
Royal Dublin Society, Dublin.
Royal Philosophical Society, Glasgow.
Royal Scottish Society of Arts, Edinburgh.
Sanitary Institute of Great Britain, London.
Schiffbautechnischen Gesellschaft, Berlin.
Scientific Library, U.S. Patent Office, Washington.
Shipmasters' Society, London.
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 Arts, Massachusetts Institute of Technology, Boston.
Society of Engineers, London.
Society of Naval Architects and Marine Engineers, New York.
South Wales Institute of Engineers, Cardiff.
Technical Society of the Pacific Coast, San Francisco.
University of Texas Mineral Survey, Austin.
West of Scotland Iron and Steel Institute, Glasgow.
Western Society of Engineers, Chicago.

Copies of the Transactions are forwarded to the following Colleges, Libraries, etc.:—

Advocates' Library, Edinburgh.
Bodleian Library, Oxford.
British Museum, London.
Coatbridge Technical School, Coatbridge.
Cornell University, Ithaca, U.S.A.
Dumbarton Free Public Library, Dumbarton.
Glasgow and West of Scotland Technical College, Glasgow.
Glasgow University, Glasgow.
Mercantile Marine Service Association, Liverpool.
M'Gill University, Montreal.
Mitchell Library, Glasgow.
Polytechnic School of Engineering, Ghizeh, Egypt.
Royal Naval College, Greenwich.
Southampton Public Library, Southampton.
Stevens Institute of Technology, Hoboken, U.S.A.
Stirling's Library, Glasgow.
Trinity College, Dublin.
Underwriters' Rooms, Glasgow.
do. Liverpool.
University College, London.
University Library, Cambridge.
Yorkshire College, Leeds.

Publications Received periodically in Exchange for Institution Transactions:—

Weekly.

American Machinist.
American Manufacturer and Iron World.
Automobile Club Journal.
Automotor Journal.
Colliery Guardian.
Contract Journal.
Electrical Review.
Engineer.

Engineering.
Engineering Record.
Engineering Times.
Indian Engineering.
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.
Revue Industrielle.
Shipping World.
Stahl und Eisen.
Transport.

Monthly.

Cassier's Magazine.
Cold Storage and Ice Trades Review.
Electrical Magazine.
Engineering Magazine.
Engineering Press Monthly Index.
Engineering Review.
Light Railway and Tramway Journal.
Machinery.
Machinery Market.
Marine Engineer.
Marine Engineering.
Mariner.
Mechanical Review.
Mines and Minerals.
Page's Magazine.
Petroleum World.

Portefeuille Économique des Machines
Science Abstracts.
Scottish Electrician.
Steamship.
Technics.
The Indian and Eastern Engineer.
Tramway and Railway World.

The Library is closed 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 each lawful day from 9.30 A.M. till 10 P.M., except on Saturdays, when 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.

WILLIAM BROWN,
Hon. Librarian and Convener.

Annual Subscriptions are due at the commencement of each Session: viz.:—

MEMBERS, £2; ASSOCIATE MEMBERS, £1; ASSOCIATES, £1 10s; STUDENTS, 10s; LIFE MEMBERS, £25; LIFE ASSOCIATES, £20. *Membership Application Forms can be had from the Secretary or from the Sub-Librarian, at the Rooms, 207 Bath Street.*

The Council, being desirons of rendering the transactions of the Institution as complete as possible, earnestly request the co-operation of Members in the preparing of Papers for reading and discussion at the General Meetings.

Early notice of such papers should be sent to the Secretary, so that the dates of reading may be arranged.

Copies of the reprint of Vol. 7 containing a paper on "The Loch Katrine Water Works," by Mr J. M. Gale, C.E., may be had from the Secretary; price to Members, 7/6.

Members of this Institution, who may be temporarily resident in Edinburgh, will, on application to the Secretary of the Royal Scottish Society of Arts, at his office, 117 George Street, be furnished with billets for attending the meetings of that Society.

The Meetings of the Royal Scottish Society of Arts are held on the 2nd and 4th Mondays of each month, from November till April, with the exception of the 4th Monday of December.

OBITUARY.

Members.

James Foster was born at Sunderland on 2nd October, 1845, and came of an old and well-known North of England Quaker family. His apprenticeship was served with Messrs Thompson, Boyd & Co., Newcastle-on-Tyne, and George Clark, Sunderland. In 1867 he went out to the East, remaining there six years and living at Hong Kong, Saigon, and Bankok respectively. In 1877 he proceeded to Java as the representative of Messrs George Fletcher & Co., Derby and London, and remained there until 1884, when he came home, only to return again in the following year on his own account.

He left Java finally in 1888, and shortly after entered the service of Messrs Duncan Stewart & Co., Ltd., Glasgow, in whose interests he visited Nicaragua, Antigua, and Bahia, Brazil. He joined Messrs Fullerton, Hodgart & Barclay, Ltd., Paisley, in 1895, and remained with them till his death, which took place at Glasgow very suddenly on Friday, 10th March, 1905. He made a special study of sugar machinery and evaporating plant of all kinds, and was the inventor of numerous patents connected therewith. In 1890 he compiled and published "Evaporation by the Multiple System," which has run to several editions.

Mr Foster joined the Institution as a Member in 1897.

James Gray was born in the Barony Parish of Glasgow, in August, 1823, and died at his residence, Riverside, Old Cumnock, on the 25th day of April, 1904.

When quite a young man he went to New Cumnock, and in company with the late Mr Robert Brown, started a coal-pit at Muirfoot, being at the same time a contractor on an extensive scale in connection with the Lugar Ironworks. For many years, too, he worked the coal on the Mansefield estate, and later he joined hands with the late Mr James Angus to open up a coalfield on the Auchincruive estate, near Ayr. Removing to Old Cumnock, he became a Councillor and a Magistrate of that burgh, and for a length of time was Chairman of the School Board there. He also filled the office of County Councillor, and at the time of his death was Chairman of the Parish Council.

As a master he was not only highly respected, but greatly beloved by his workmen.

Mr Gray became a Member of the Institution in 1862.

Edmund Hunt died at Whitehall, Bothwell, on 2nd December, 1904, in his seventy-sixth year. He was a son of Mr Richard Thomas Hunt, surgeon, of Manchester, one of the founders of the British Medical Association, and was born in that city on 22nd January, 1829. He received his early education at the Manchester Grammar School, and after leaving that establishment he spent some years at Bahia, Brazil. On returning to this country he entered a patent agency in Glasgow, leaving it in 1857 to start a business on his own account, which is still carried on under the title of Edmund Hunt & Co. His great experience as a patent agent, and his knowledge of patent law, made him greatly in demand as an expert witness, and he figured in many of the most notable patent cases. He retired from business in 1900.

Mr Hunt took a keen interest in mathematical subjects, and studied deeply the action of the gyroscope. His mathematical labours led him into friendship with Professor Macquorn Rankine and Sir Henry Bessemer, and to a large acquaintance with engineers in Glasgow, in the fifties. He was also interested in colour vision, and published a book on the subject in 1897.

He was the first secretary of the Institution, retaining office for a period of seven years, and was for three sessions a Member of Council.

Mr Hunt joined the Institution as a Member, at its foundation, in 1857.

David M'Call, of the firm of Formans & M'Call, Glasgow, died at his residence, Kelvinside, Glasgow, on the 14th November, 1904, in his 77th year.

He was a native of Glasgow, and his earliest associations were with the Forth and Clyde Canal, of which his father was manager. He was trained as a civil engineer under the late Mr Neil Robson, the originator of the present firm of Formans & M'Call, and later was assumed as a partner in that firm. As the firm included an active practice from an early period of the last century, Mr M'Call's personal reminiscences in connection with the history of railway and other enterprises, which played so important a part in the development of the city, were very interesting. Being naturally of an unassuming disposition, he aspired to no prominent part in public affairs, but those who had the privilege of his acquaintance never failed to recognise his sterling qualities.

Mr M'Call was elected a Member of the Institution in 1858.

John F. Miller died at his residence, Greenoakhill, Broomhouse, Glasgow, on the 18th November, 1904. He was born at Crossmyloof in 1848, and was educated at the High School. Electing to become an engineer, he served an apprenticeship with Messrs J. & G. Thomson, in the old Clydebank Engineering Works, and the Govan shipyard of that firm. He acquired considerable theoretical knowledge at Glasgow University, where he studied under the late Professor Macquorn Rankine.

In 1870 he became a partner in his father's firm of James Miller & Co., and on that firm being converted into the Rivet, Bolt & Nut Company (Limited), in 1895, with its headquarters at Coatbridge, he was appointed Chairman, a position which he continued to hold until his death. He was also senior partner of George Miller & Sons, coalmasters, and for ten years previous to

1892 he was managing partner of the engineering works of Miller & Co., Coatbridge.

Mr Miller took a prominent part in the affairs of the Trades' House of Glasgow, and was especially interested in his own incorporations of Hammermen, Bakers, and Wrights. In the year 1897 he was elected Deacon-Convener of the ancient House, and as such sat for the prescribed period in the Glasgow Town Council. Subsequently he represented the Blythswood Ward in that Council, retiring shortly before his death after having held the office of Magistrate. He was a Justice of the Peace for the City of Glasgow and for Lanarkshire.

A man of deeds rather than of words, Mr Miller was a quiet kindly gentleman, who was highly esteemed alike for his personal worth and for the services which he rendered to his native city.

Mr Miller joined the Institution as a Graduate in 1873 and became a Member in 1881.

Edmund Mott was born at Newcastle-on-Tyne. Owing to the death of his father he was compelled to leave school at the early age of eleven years, when he commenced the battle of life. He served a seven years' apprenticeship with Messrs R. Stephenson & Co., Newcastle-on-Tyne, and also worked with that firm as a journeyman until he went to sea, on board the s.s. "Democrat," which belonged to Messrs Day & Farlane, of North Shields, eventually becoming chief-engineer of that steamer. In the same capacity he served on board the s.s. "Peer of the Realm," and the s.s. "Cavalier," belonging to the same owners.

He entered the service of the Board of Trade as an engineer surveyor in 1881 and was appointed to the Glasgow district, where he remained upwards of twenty-one years, becoming during that period senior surveyor. In July, 1902, he removed to Cardiff on promotion, and occupied the post of chief surveyor of that important district until his death, which took place somewhat suddenly on Sunday, 5th March, 1905.

Mr Mott joined the Institution as a Member in 1885.

William Robertson was born at Strathbungo, Glasgow, on the 24th November, 1826, shortly after which his family removed to Jordanhill, where his father was interested in mines. In 1841 he was apprenticed to the late Mr Neil Robson as a civil and mining engineer, and started business for himself in 1849. In 1856 Mr Robertson constructed the Hamilton and Strathaven Railway, and acted as manager on it for a short time afterwards. Latterly he devoted himself to the mining side of his profession, and was engineer for many large estates in the coal and shale fields of Scotland. Mr Robertson, whose death took place at Clairmont Gardens, Glasgow, on the 22nd January, 1905, was active in business to the end of his life.

Mr Robertson joined the Institution as a Member in 1863.

George Lennox Watson was born in Glasgow in 1851, being the eldest son of Dr. Thomas Watson, a well-known practitioner of the city; and his maternal grandfather was Mr Timothy Burstall, an inventor of considerable note, and a rival of George Stephenson in early locomotive design. The death of his father at a comparatively early age caused a considerable change in family arrangements, Mrs Watson taking up her residence in London, while her son remained in Glasgow to complete his education, which was received at the High School and the Collegiate School. He early evinced a strong taste for inventive pursuits—especially so in connection with ships and navigation; and eventually a choice was made of shipbuilding as a profession. When sixteen years of age he was entered as an apprentice in the renowned yard of Messrs Robert Napier & Sons, Govan, which in those days was controlled by Mr William Pearce, who later became Sir William Pearce, Bart., of Fairfield, the able and world-renowned builder of ocean "greyhounds." After three years' training, in the yard and drawing office, on both the practical and theoretical sides of the shipbuilding profession, young Watson transferred his services to Messrs A. & J. Inglis, of Pointhouse Shipyard, of which firm Mr (now Dr.) John Inglis was then, as now, the ruling spirit. In the drawing office here, in association with highly experienced colleagues, and under the immediate guidance of Dr. Inglis, Mr Watson developed his designing qualities, amongst the important work intrusted to him being a series of calculations and investigations concerned with the strength of ships and their speed performances. It was clearly apparent, however, that the particular branch of design in which he was most deeply interested was that concerned with yachts and sailing craft. An enthusiastic yachtsman himself, Dr. Inglis extended to his pupil encouragement, and valuable guidance as well, in the paths of design in which he was afterwards to become so distinguished. While still employed at Pointhouse he engaged in his spare time in giving practical effect to his conceptions in yacht design, one result being the construction of the "Peg Woffington," a small craft measuring about 9 tons, according to the formulas of the day, but with unconventional features, and in a way the prototype of the shallow-bottomed deep-keeled racing yacht of the present time.

Other essays in design and construction followed, and in 1873 Mr Watson started business in Glasgow on his own account as a naval architect. Together with friends he not only designed, but helped to build, and afterwards sailed and competed with various craft, including the 5-ton "Clothilde" in 1875, and more notable still, the 5-ton "Vril" in the year following. Assisted by two carpenters, Mr Watson and his friends constructed the latter in the yard of Messrs D. & W. Henderson, Meadowside; she being the first yacht to be filled with a heavy lead keel going to form the whole of the necessary ballast. In 1879 he designed and had built for Mr James Coats, Paisley, the 10-tonner "Madge," which, after beating all of her class in home waters, was taken out to America and pitted against the centre-board sloops there, winning six out of seven matches, and never sustaining defeat. In 1880 the "Vanduara," 90-ton cutter, was produced for Mr John Clark, Paisley; this proving Mr Watson's first marked success in the large classes. Then followed in rapid succession, giving evidence of persistent industry and growing skill, an almost unbroken line of famous yachts, including "Quiraing," "Marjorie," "May," "Dora," "Doris," "Thistle," "Britannia," the three "Valkyries," the "Meteor, "Sybarita," "Rainbow," "Gleniffer," "Bona," and others less renowned. He designed four America Cup challengers—"Thistle," "Valkyrie II.," "Valkyrie III.," and "Shamrock II.;" but perhaps his greatest triumph was the designing of the "Britannia" for H.M. the King (then Prince of Wales), a production which, one yachting authority has written, "stands, and is likely long to stand, as the most phenomenally able yacht that ever sailed a race."

Concurrently with his labours and achievements in sailing yacht production, Mr Watson for a number of years prior to his decease increasingly devoted himself, and the staff of able assistants he gathered round him, to the designing, placing, and superintending the construction in Clyde yards of large, speedy, and splendidly-fitted steam yachts. Many of these were for American millionaires, and were magnificent examples of Clyde shipbuilding, including the "Nahma," the "Mayflower," the "Varuna," the "Margarita," and the "Lysistrata." During the 32 years Mr Watson was in business, the number of his productions exceeded 500, comprising sail and steam yachts, and a number of steamers for cargo and passenger services, aggregating over 33,000 tons. Mr Watson also contributed, especially in earlier years, very extensively to journals on his favourite sport, and, later, to such works as the Badminton Library and Dixon Kemp's "Manual of Yacht and Boat Sailing." He was, of course, a member of the Royal Clyde Yacht Club, and of others, and a valued member of council of the Yacht Racing Association. He was also official adviser to the Royal National Lifeboat Association; and lifeboats of his design continue to be highly approved and favoured by lifeboat men round our coasts. He was a member of the Institute of Naval Architects, but took no prominent share in the deliberations of this body. He died at Glasgow on the 12th November, 1904.

Mr Watson became a Member of the Institution in 1875.

JOHN WILSON was born in Lanark on 19th November, 1855, and received his education there; afterwards serving his time with Mr John Wilson, engineer, Carluke. For some time he occupied a trustworthy position in Young's Mineral Oil Works, and later became assistant manager of the Tradeston Gas Works, Glasgow, from which post, after nine year's service, he was promoted to manager. This position he resigned at the end of 1903. He departed this life on 23rd December, 1904.

Mr Wilson joined the Institution as a Member in 1902.

JOHN YOUNG was born in Glasgow, in April, 1822. His father Mr John Young, was a house and ship plumber, carrying on business in Argyle Street, at the head of Carrick Street. He was also the principal owner of several famous Clyde passenger steamers, among others being the "Rob Roy," the "Lady Brisbane," and the "Lady Kelburne." At an early age, the subject of this memoir was apprenticed as an engineer with Messrs Murdoch & Aitken, of Gallowgate, Glasgow, and subsequently became a draughtsman with Messrs William Penn & Sons, London. Later on he joined his brother, Mr William Young, in carrying on his father's business, under the name of J. & W. Young, plumbers and brassfounders, Stobcross, Glasgow. He was for upwards of half a century closely identified with the Clyde shipbuilding industry. Deceased was a keen yachtsman, and was one of the oldest members of the Royal Clyde Yacht Club. As far back as 1845, he built and engined a small paddle steam yacht, and from that date until shortly before his death he always kept a small steamer. He died at Tighnabruaich on the 28th August, 1905, in his 83rd year.

Mr Young joined the Institution as a Member in 1867.

Associate.

JAMES NAPIER, eldest son of Mr James S. Napier, of Messrs Napier & M'Intyre, iron merchants, Glasgow, was born in Partick on the 21st October, 1858, and received his education at the Glasgow Academy and the Glasgow University. He was a capable student, and graduated in Arts at the early age of seventeen, thereafter entering his father's office. In 1884 he was assumed as partner, and as the years advanced the weight of business rested increasingly on his shoulders. He proved an able business man, and his services were required in more fields than one. His rule in dealing with his firm's clients was to give no evasive promises, and those buying from him soon found that his promise of "delivery"—the vital matter when work was pressing—needed no letter to confirm it. Privately, he was not a man of many friends, but those who had the privilege of knowing him intimately, especially in his home at Old Kilpatrick, knew his worth. His work, "The Life of Robert Napier," published a few months before his death, was well received. He died on 1st January, 1905.

Mr Napier joined the Institution as an Associate in 1901, and, during the two following years, acted on the Council.

LIST OF HONORARY MEMBERS, MEMBERS, ASSOCIATE MEMBERS, ASSOCIATES, AND STUDENTS

AT CLOSE OF SESSION 1904-1905.

HONORARY MEMBERS.

	DATE OF ELECTION.
KELVIN, Lord, G.C.V.O., O.M., P.C., LL.D., D.C.L., Netherhall, Largs,	1859
BRASSEY, Lord, K.C.B., D.C.L., 4 Great George street, Westminster, London, S.W.,	1891
BLYTHSWOOD, Lord, Blythswood, Renfrewshire,	1891
KENNEDY, Sir A. B. W., LL.D., F.R.S., 17 Victoria street, London, S.W.,	1891
MURRAY, Sir DIGBY, Bart., Hothfield, Parkstone, Dorset,	1891
WHITE, Sir WILLIAM HENRY, K.C.B., F.R.S., LL.D., D.Sc., Cedar Croft, Putney Heath, London, S.W.,	1894
DURSTON, Sir A. J., K.C.B., Westcomlea, Park Road, Blackheath, London, S.E.,	1896
FROUDE, R. E., F.R.S., Admiralty Experiment works, Gosport,	1897

MEMBERS.

	DATE OF ELECTION.
AAMUNDSEN, JENS L., Amaliegade 6, Copenhagen, Denmark,	24 Jan., 1899
ABERCROMBIE, ROBERT GRAHAM, Broad Street Engine Works, Alloa,	21 Mar., 1899
ADAM, J. MILLEN, Ibrox Iron works, Glasgow,	G. 25 Mar., 1890 M. 22 Jan., 1895
ADAMSON, JAMES, St. Quivox, Stopford road, Upton Manor, Essex,	23 Apr., 1889
ADAMSON, PETER HOGG, 2 Thornwood terrace, Partick,	19 Mar., 1901
AILSA *(The most Honourable the Marquis of)*, Culzean castle, Maybole,	25 Jan., 1898

Names marked thus * were Members of Scottish Shipbuilders' Association at incorporation with Institution, 1865.

Names marked thus † are Life Members.

AITKEN, H. WALLACE, 147 Bath Street, Glasgow,	G. 24 Jan., 1888 M. 24 Jan., 1899
AITON, J. ARTHUR, Western Works, Hythe Road, Willesden Junction, London, N.W.,	24 Nov., 1896
ALEXANDER, JOHN, Engineer, Barrhead,	19 Mar., 1901
ALLAN, ROBERT, Demerara Foundry, Georgetown, Demerara,	30 Apr., 1895
ALLEY, STEPHEN E., 8 Woodside terrace, Glasgow,	23 Nov., 1897
†ALLIOTT, JAMES B., The Park, Nottingham,	21 Dec., 1864
ALLO, OSCAR EDWARD, 100 Bothwell street, Glasgow,	22 Mar., 1904
ALSTON, WILLIAM M., 24 Sardinia terrace, Hillhead, Glasgow,	G. 15 Feb., 1865 M. 18 Dec., 1877
†AMOS, ALEXANDER, Glen Alpine, Werris Creek, New South Wales,	21 Dec., 1886
†AMOS, ALEXANDER, Jun., Braeside, 81 Victoria Street (North), Darlinghurst, Sydney, New South Wales,	21 Dec., 1886
ANDERSON, ALEXANDER, 176 Balgray hill, Springburn, Glasgow,	24 Nov., 1903
ANDERSON, ALFRED WALTER, Blackness Foundry, Dundee,	27 Oct., 1903
†ANDERSON, E. ANDREW, c/o Clinton, 13 Holmhead street, Glasgow,	21 Feb., 1899
ANDERSON, F. CARLTON, c/o Messrs G. Harland, Bowden & Co., 196 Deansgate, Manchester,	23 Apr., 1901
ANDERSON, GEORGE C., 18 Balmoral drive, Cambuslang,	G. 24 Dec., 1895 M. 27 Oct., 1903
ANDERSON, J. GODFREY, B.Sc., c/o Messrs James Templeton & Co., Greenhead, Glasgow,	19 Mar., 1901
ANDERSON, JAMES, 5 Buckingham square, Copland road, Govan,	G. 24 Feb., 1874 M. 23 Nov., 1880
†ANDERSON, JAMES, Ravelston, Great Western Road, Glasgow,	26 Nov., 1901
ANDERSON, JAMES H., Caledonian Railway, Glasgow,	20 Dec., 1892
ANDERSON, JOHN, 40 West Nile street, Glasgow,	20 Dec., 1904
ANDERSON, ROBERT, Clyde Street, Renfrew,	26 Jan., 1897
ANDERSON, WILLIAM MARTIN, 5 Buckingham square, Copland road, Govan,	18 Dec., 1900
ANDERSON, WILLIAM SMITH, Alderwood East, Port-Glasgow,	21 Nov., 1899
ANDREWS, H. W., 128 Hope street, Glasgow,	A. 21 Dec., 1897 M. 24 Oct., 1899
ANDREWS, JAMES, Blythswood Chambers, 180 West Regent street, Glasgow,	22 Nov., 1898
ANGUS, ROBERT, Lugar, Old Cumnock, Ayrshire,	28 Nov., 1860
ANIS, MOHAMED, Pasha, Chief of the Technical Department, P.W.D., Cairo,	24 Apr., 1894

APPLEBY, JOHN R., 133 Balshgray avenue, Partick, 21 Feb., 1905

ARCHER, W. DAVID, 47 Croham road, Croyden, Surrey, 20 Dec., 1887

ARNOT, WILLIAM, 4 Hayburn crescent, Partick, 26 Apr., 1904

ARNOTT, HUGH STEELE, 99 Clarence drive, Hyndland, Glasgow, { G. 26 Oct., 1897 / M. 22 Jan., 1901 }

ARROL, THOMAS, 32 Falkland mansions, Hyndland, Glasgow, 27 Oct., 1903

ARROL, THOMAS, Oswald gardens, Scotstounhill, Glasgow, 20 Nov., 1894

†ARROL, Sir WILLIAM, LL.D., M.P., Dalmarnock Iron works, Glasgow, 27 Jan., 1885

ARROL, WILLIAM, 23 Doune terrace, Kelvinside, Glasgow, 27 Oct., 1903

AULD, JOHN, Whitevale foundry, Glasgow, 28 Apr., 1885

AULD, JOHN, Pollok buildings, Cockerhill, Glasgow, 21 Mar., 1905

AUSTIN, WILLIAM R., 61 Brisbane Street, Greenock, 23 Feb., 1897

BAILLIE, ROBERT, c/o Stirling Boiler Company, Limited, 75 Bath street, Glasgow, 20 Nov., 1900

BAIN, WILLIAM N., 40 St. Enoch square, Glasgow, 24 Feb., 1880

BAIN, WILLIAM P. C., Lochrin Iron works, Coatbridge, 28 Apr., 1891

BAIRD, ALLAN W., Romiley, Erskine avenue, Drumbreck, Glasgow, 25 Oct., 1881

BALDERSTON, JAMES, Gateside, Paisley, 25 Jan., 1898

BALDERSTON, JOHN A., Vulcan Works, Paisley, 18 Dec., 1900

BALFOUR, GEORGE, Messrs J. G. White & Co., Ltd., 22a College hill, Cannon street, London, E.C., 21 Mar., 1899

BALLANTINE, THOMAS, 7 Royal Bank place, Glasgow, 24 Jan., 1905

BALLANTYNE, JOHN HUTCHISON, 212 Bath street, Glasgow, 25 Oct., 1904

BALLINGALL, DAVID, c/o Messrs. Richard Hornsby & Son, Ltd., Spittlegate Iron Works, Grantham, 27 Oct., 1896

BAMFORD, HARRY, M.Sc., The University, Glasgow, 24 Nov., 1896

BARCLAY, GEORGE, Vulcan works, Paisley, 25 Jan., 1898

BARMAN, HARRY D. D., 21 University avenue, Glasgow, { G. 24 Apr., 1888 / M. 24 Oct., 1899 }

BARNETT, J. R., Westfield, Crookston, 22 Dec., 1896

BARNETT, MICHAEL R., Engineer's Office, Laurel Bank, Lancaster, 22 Nov., 1887

BARR, Professor ARCHIBALD, D.Sc., Royston, Dowanhill, Glasgow, 21 Mar., 1882

BARR, JAMES, 67 Durward avenue, Shawlands, Glasgow, 20 Dec., 1904

BARR, JOHN, Glenfield Company, Kilmarnock, { A. 28 Oct., 1883 / M. 25 Jan., 1898 }

BARROW, JOSEPH, Messrs Thomas Shanks & Co., Johnstone,	19 Feb., 1901
BAXTER, GEORGE H., Clyde Navigation works, Dalmuir,	22 Mar., 1881
BAXTER, P. M'L., Copland works, Govan,	G. 22 Dec., 1885 M. 15 June, 1898
BEARDMORE, JOSEPH GEORGE, Parkhead forge, Glasgow,	22 Nov., 1898
BEARDMORE, WILLIAM, Parkhead forge, Glasgow,	27 Oct., 1896
BEGBIE, WILLIAM, P.O. Box 3982, Johannesburg, South Africa,	15 June, 1898
*†BELL, DAVID, 19 Eton place, Hillhead, Glasgow.	
BELL, IMRIE, 49 Dingwall road, Croydon, Surrey,	23 Mar., 1880
BELL, STUART, 163 Hope street, Glasgow,	26 Feb., 1895
BELL, THOMAS, Messrs John Brown & Co., Ltd., Clydebank,	G. 26 Apr., 1887 M. 27 Apr., 1897
BELL, W. REID, Transvaal Department of Irrigation and Water Supply, Box 78, Potchefstroom, South Africa,	22 Jan., 1889
BENNIE, H. OSBOURNE, Clyde Engine works, Cardonald, Glasgow,	25 Jan., 1898
BERGIUS, W. C., 8 Marlborough terrace, Glasgow, W.,	23 Jan., 1900
BEVERIDGE, RICHARD JAMES, 53 Waring street, Belfast,	22 Feb., 1898
BIGGART, ANDREW S., Inchgarvie, 39 Sherbrooke avenue, Pollokshields, Glasgow,	G. 20 Mar., 1883 M. 25 Nov., 1884
BILES, Professor JOHN HARVARD, LL.D., The University, Glasgow,	25 Mar., 1884
BINNIE, R. B. JARDINE, Carntyne Works, Parkhead,	24 Dec., 1901
BIRD, JOHN R., 10 Morrison street, Glasgow,	25 Mar., 1890
BISHOP, ALEXANDER, 3 Germiston street, Glasgow,	G. 24 Mar., 1885 M. 24 Jan., 1899
BLACK, JOHN W., 108a West Regent street, Glasgow,	G. 25 Oct., 1892 M. 27 Oct., 1903
BLAIR, ARCHIBALD, 21 Havelock street, Dowanhill, Glasgow,	G. 27 Oct., 1885 M. 27 Oct., 1903
BLAIR, DAVID A., Scotland street Copper works, Glasgow	23 Mar., 1897
BLAIR, FRANK R., Ashbank, Maryfield, Dundee,	G. 22 Mar., 1892 M. 21 Apr., 1903
BLAIR, GEORGE, Jun., 38 Queen street, Glasgow,	G. 22 Jan., 1884 M. 23 Feb., 1897
BLAIR, JAMES M., Williamcraigs, Linlithgowshire,	27 Mar., 1867
BONE, WILLIAM L., Ant and Bee works, West Gorton, Manchester,	23 Oct., 1883
BOOTH, ROBERT, Glengelder, Cowey road, Durban, Natal,	26 Jan., 1904
BORROWMAN, WILLIAM C., Strathmore, West Hartlepool,	G. 27 Oct., 1887 M. 26 Oct., 1895
BOST, W. D. ASHTON, Adelphi house, Paisley,	25 Jan., 1898
BOW, WILLIAM, Thistle works, Paisley,	27 Jan., 1891

BOWMAN, WILLIAM DAVID, 21 Kersland terrace, Hillhead, Glasgow,	G. M.	22 Dec., 1891 24 Nov., 1903
BOWSER, CHARLES HOWARD, Charles street, St. Rollox, Glasgow,		21 Mar., 1899
BOYD, JOHN WHITE, 7 Royal Bank place, Glasgow,		24 Jan., 1905
BRACE, GEORGE R., 25 Water street, Liverpool,		25 Mar., 1890
BRAND, MARK, B.Sc., Barrhill cottage, Twechar, Kilsyth,	G. M.	24 Jan., 1888 21 Apr., 1903
BREINGAN, W. D., Barns place, Clydebank,		22 Jan., 1901
BREWER, J. ALFRED, 58 St Vincent street, Glasgow,		20 Nov., 1900
BRIER, HENRY, 1 Miskin road, Dartford, Kent,		22 Dec., 1891
BROADFOOT, JAMES, Lymehurst, Jordanhill,	G. M.	23 Dec., 1873 22 Jan., 1884
BROADFOOT, WILLIAM R., Inchholm works, Whiteinch,		25 Jan., 1898
BROCK, HENRY W., Engine works, Dumbarton,		30 Apr., 1895
*BROCK, WALTER, Engine works, Dumbarton,		26 Apr., 1865
BROCK, WALTER, Jun., Levenford, Dumbarton,		27 Oct., 1896
BROEKMAN, LOUIS, 5 University avenue, Glasgow,		22 Nov., 1904
BROOKFIELD, JOHN WAITES, Brookhurst, Halifax, Nova Scotia,	S. M.	18 Feb., 1902 20 Dec., 1904
BROOM, THOMAS M., 11 Union street, Greenock,		25 Apr., 1893
BROWN, ALEXANDER D., Dry Dock, St. John's, Newfoundland,		22 Dec., 1896
BROWN, ALEXANDER T., 18 Glencairn drive, Pollokshields, Glasgow,	G. M.	25 Feb., 1879 27 Oct., 1891
*†BROWN, ANDREW, London works, Renfrew,		16 Feb., 1859
BROWN, ANDREW M'N., Strathclyde, Dalkeith avenue, Dumbreck, Glasgow,	G. M.	25 Jan., 1876 24 Nov., 1885
†BROWN, DAVID A., 41 Rosslyn crescent, Edinburgh,	G. M.	23 Feb., 1897 27 Oct., 1903
BROWN, EBENEZER HALL-, Helen street Engine works, Govan,	G. M.	18 Dec., 1883 26 Feb., 1895
BROWN, GEORGE, Garvel Graving Dock, Greenock,		23 Mar., 1886
BROWN, J. POLLOCK, 1 Broomhill avenue, Partick, Glasgow,	G. M.	18 Dec., 1894 22 Dec., 1903
BROWN, JAMES, c/o Messrs. Scott & Co., Greenock,	G. M.	26 Oct., 1886 26 Jan., 1892
BROWN, JAMES M'N., 15 Falkland Mansions, Hyndland, Glasgow,		26 Jan., 1897
BROWN, MATTHEW T., B.Sc., 21 Bisham gardens, Highgate, London, N.,	G. M.	25 Jan., 1881 18 Dec., 1894
BROWN, ROBERT, 7 Church road, Ibrox, Glasgow,		18 Feb., 1902
BROWN, WALTER, Monkdyke, Renfrew,		28 Apr., 1885
BROWN, WILLIAM, Kilrene, 7 Whittinghame gardens, Glasgow, W.,	G. M.	27 Jan., 1874 22 Jan., 1884

BROWN, WILLIAM, Albion works, Woodville street, Govan, 21 Dec., 1880

BROWN, WILLIAM, Messrs Dübs & Co., Glasgow Locomotive works, Glasgow, 17 Dec., 1889

BROWN, WILLIAM DEWAR, 25 Mar., 1890

BRUCE, CHARLES ROSS, 47 Brougham street, Greenock, 20 Dec., 1904

BRUHN, JOHANNES, D.Sc., 23 Methuen park, Muswell hill, London, N., G. 24 Oct., 1893; M. 22 Feb., 1898

BRYAN, MATTHEW REID, 1 Royal terrace, Springburn, Glasgow, 24 Nov., 1903

BRYSON, WILLIAM ALEXANDER, 16 Charlotte street, Leith, 27 Oct., 1896

BUCHANAN, JOHN H., 5 Oswald street, Glasgow, 23 Jan., 1900

BUCKWELL, GEORGE W., Board of Trade Surveyor's Office, Barrow-in-Furness, 27 Apr., 1897

BUDD, EDWARD R., Messrs G. & A. Harvey, Ltd., Albion works, Govan, 20 Dec., 1904

BUDENBERG, CHRISTIAN FREDERICK, 31 Whitworth street, Manchester, 20 Dec., 1898

BULLARD, E. P., Jun., Bridgeport, Conn., U.S.A., 29 Oct., 1901

BURDEN, ALFRED GEORGE NEWKEY, c/o Messrs Harvey & Co., Box 953, Johannesburg, South Africa, 20 Feb., 1900

BURNS, WILLIAM, J. L., Bankok Dock Co., Bankok, Siam, A.M. 26 Jan. 1904; M. 25 Oct., 1904

BURNSIDE, WILLIAM, 3 Armadale street, Dennistoun, Glasgow, 27 Oct., 1903

BURT, THOMAS, 1 Royal terrace, Glasgow, 22 Mar., 1881

BUTTERS, JAMES THOMAS, Percy Crane & Engine Works, Glasgow, 19 Mar., 1901

BUTTERS, MICHAEL W., 20 Waterloo street, Glasgow, 24 Oct., 1899

CAIRD, ARTHUR, Messrs Caird & Co., Ltd., Greenock, 27 Oct., 1896

†CAIRD, EDWARD B., 777 Commercial road, Limehouse, London, 29 Oct., 1878

†CAIRD, PATRICK T., Messrs Caird & Co. Ltd., Greenock, 27 Oct., 1896

CAIRD, ROBERT, LL.D., Messrs Caird & Co., Ltd., Greenock, 20 Feb., 1894

CALDER, JOHN, 10 Prospect avenue, Ilion, New York, U.S.A., G. 24 Feb., 1891; M. 27 Oct., 1903

CALDERWOOD, WILLIAM T., Stanley villa, Cathcart, Glasgow, 25 Jan., 1898

CALDWELL, JAMES, 130 Elliot street, Glasgow, 17 Dec., 1878

CAMERON, ANGUS, Union Steamship Co. of New Zealand, 175 West George street, Glasgow, 18 Feb., 1902

CAMERON, DONALD, 7 Bedford circus, Exeter.	25 Feb., 1890
CAMERON, HUGH, 40 Camperdown road, Scotstoun, Glasgow,	G. 25 Oct., 1892 M. 27 Oct., 1903
CAMERON, JOHN B., 111 Union street, Glasgow,	24 Mar., 1885
CAMERON, WILLIAM, Arlington, Seedhill road, Paisley,	25 Mar., 1890
CAMPBELL, ANGUS, De La-Beche terrace, Sketty, Swansea,	G. 24 Jan., 1888 M. 27 Oct., 1908
CAMPBELL, DUNCAN, Carntyne foundry and engineering works, Parkhead, Glasgow,	23 Jan., 1900
CAMPBELL, HUGH, The Campbell Gas Engine Company, Halifax, Yorkshire,	18 Dec., 1900
CAMPBELL, JAMES, 104 Bath street, Glasgow,	18 Dec., 1900
CAMPBELL, JOHN,	21 Jan., 1890
†CAMPBELL, THOMAS, Maryhill Iron works, Glasgow,	20 Nov., 1900
CAMPBELL, WALTER HOPE, 42 Krestchatik, Kieff, South Russia,	25 Apr., 1899
CAREY, EVELYN G., 4 Sunnyside avenue, Uddingston,	22 Oct., 1889
CARLAW, ALEX. L., 11 Finnieston street, Glasgow,	24 Dec., 1895
CARLAW, DAVID, Jun., 11 Finnieston street, Glasgow,	24 Dec., 1895
CARLAW, JAMES W., 11 Finnieston street, Glasgow,	24 Dec., 1895
CARMICHAEL, ANGUS T., 3 Harvey street, Paisley road, W., Glasgow,	19 Mar., 1901
CARRUTHERS, JOHN H., Ashton, Queen Mary avenue, Crosshill, Glasgow,	22 Nov., 1881
CARSLAW, WILLIAM H., Jun., Parkhead boiler works, Parkhead, Glasgow,	G. 23 Dec., 1890 M. 27 Oct., 1903
CARVER, THOMAS, A. B., D.Sc., 118 Napiershall street, Glasgow,	19 Feb., 1901
CHALMERS, WALTER, Cathage, Milngavie,	23 Jan., 1900
CHAMEN, W. A., c/o Messrs Bramwell & Harris, 5 Great George street, Westminster, London,	22 Feb., 1898
CHISHOLM ROBERT, 1 Albany quadrant, Springboig, Shettleston,	29 Oct., 1901
CHRISTIE, JOHN, CorporationElectricityWorks, Brighton,	22 Nov., 1898
CHRISTIE, R. BARCLAY, Messrs M'Lay & M'Intyre, 21 Bothwell street, Glasgow,	25 Apr., 1893
CHRISTISON, GEORGE, 13 Cambridge drive, Glasgow,	22 Feb., 1898
CLARK, JOHN, British India Steam Navigation Co., 9 Throgmorton avenue, London, E.C.,	23 Jan., 1883
CLARK, WILLIAM, 208 St. Vincent street, Glasgow,	25 Apr., 1893
CLARK, WILLIAM, Companhia Carris de Ferro de Lisbon, Lisbon, Portugal,	22 Dec., 1896
CLARK, WILLIAM, 23 Royal Exchange square, Glasgow,	26 Jan., 1904
CLARK, WILLIAM GRAHAM, 29 Church road, Waterloo, Liverpool,	22 Feb., 1898

CLARKSON, CHARLES, 20 Macaulay road, Birkby, Huddersfield,	27 Oct., 1891
CLEGHORN, ALEXANDER, 10 Whittingehame drive, Kelvinside, Glasgow,	22 Nov., 1892
CLELAND, W. A., Yloilo, Philippine Islands,	G. 25 Apr., 1893 M. 25 Nov., 1902
CLYNE, JAMES, Messrs Clyne, Mitchell, & Co., Commercial road, Aberdeen,	18 Dec., 1900
COATS, ALLAN, Jun., B.Sc., Hayfield, Paisley,	23 Oct., 1900
COATS, JAMES, 362 Maxwell road, Pollokshields, Glasgow,	21 Dec., 1897
†COBB, FRANCIS HILLS, Public Works Department, Pretoria, Transvaal,	24 Jan., 1905
COCHRAN, JAMES T., 52 Woodville gardens, Langside, Glasgow,	26 Feb., 1884
COCHRANE, JAMES, Resident Engineer's Office, Harbour works, Table Bay, Capetown,	G. 27 Oct., 1891 M. 22 Dec., 1903
COCHRANE, JOHN, Grahamston foundry, Barrhead,	25 Mar., 1890
COCKBURN, GEORGE, Cardonald, near Glasgow,	25 Oct., 1881
COCKBURN, ROBERT, Cumbrae House, Dumbreck, Glasgow,	25 Jan., 1898
COLVILLE, ARCHIBALD, 51 Clifford street, Bellahouston, Govan,	23 Jan., 1900
COLVILLE, ARCHIBALD, Motherwell,	27 Oct., 1896
COLVILLE, DAVID, Jerviston house, Motherwell,	27 Oct., 1896
CONNELL, CHARLES, Whiteinch, Glasgow,	G. 19 Dec., 1876 M. 25 Mar., 1884
CONNER, ALEXANDER, 6 Grange Knowe, Irvine road, Kilmarnock,	G. 26 Feb., 1884 M. 24 Jan., 1899
CONNER, BENJAMIN, 196 St. Vincent street, Glasgow,	G. 22 Dec., 1885 M. 26 Oct., 1897
CONNER, JAMES,	G. 18 Dec., 1877 M. 24 Nov., 1885
CONNER, JAMES, English Electric Manufacturing Co., Limited, Preston,	20 Nov., 1900
CONSTANTINE, EZEKIEL GRAYSON, 17 St. Ann's square, Manchester,	26 Apr., 1904
COPELAND, JAMES,	17 Feb., 1864
COPESTAKE, S. G. G., 40 Queen Mary avenue, Glasgow, S.,	11 Mar., 1868
†COPLAND, WILLIAM R., 146 W. Regent street, Glasgow,	20 Jan., 1864
CORMACK, Prof. JOHN DEWAR, B.Sc., University College, Gower street, London, W.C.,	24 Nov., 1896
COSTIGANE, A. PATON, Lymekilns, East Kilbride,	20 Jan., 1903
COULSON, W. ARTHUR, 47 King street, Mile-end, Glasgow,	15 June, 1898
COUPER, SINCLAIR, Moore Park boiler works, Govan,	G. 21 Dec., 1880 M. 27 Oct., 1891

COUSINS, JOHN BOOTH, 75 Buchanan street, Glasgow,	22 Mar., 1904
COUTTS, FRANCIS, 280 Great Western road, Aberdeen,	G. 27 Oct., 1885 M. 24 Jan., 1899
COWAN, DAVID, Coulport house, Loch Long, Dumbartonshire,	24 Apr., 1900
COWAN, JOHN, 8 Wilton mansions, Kelvinside N., Glasgow,	27 Apr., 1897
COWAN, JOHN, Clydebridge Steel Co., Ltd., Cambuslang,	16 Dec., 1902
†COWIE, WILLIAM, 51 Endsleigh gardens, Ilford, Essex,	20 Feb., 1900
CRAIG, ALEXANDER, 163 West George street, Glasgow,	G. 26 Nov., 1895 M. 16 Dec., 1902
CRAIG, ARCHIBALD FULTON, Belmont, Paisley,	25 Jan., 1898
CRAIG, JAMES, Lloyd's Registry, 14 Cross-shore street, Greenock,	G. 20 Dec., 1892 M. 21 Dec., 1897
CRAIG, JOHN, 32 Cartside quadrant, Langside, Glasgow,	22 Jan., 1900
CRAN, JOHN, Albert Engine works, Leith,	21 Jan., 1902
CRAWFORD, JAMES, 30 Ardgowan street, Greenock,	27 Oct., 1896
CRIGHTON, JAMES, Rotterdamsche Droogdok, Maatschapij, Rotterdam, Holland,	G. 23 Nov., 1897 M. 20 Jan., 1903
CRIGHTON, JOHN, Hondiusstraat 9, Rotterdam, Holland,	G. 26 Nov., 1901 A.M. 20 Jan., 1903 M. 22 Dec., 1903
CROCKATT, WILLIAM, 179 Nithsdale road, Pollokshields, Glasgow,	22 Mar., 1881
CROSHER, WILLIAM, 74 York street, Glasgow,	24 Jan., 1899
CROW, JOHN, Trynlaw, Merrylee road, Newlands, Glasgow,	25 Jan., 1898
CUMMING, WM. J. L., Motherwell Bridge Co., Motherwell,	24 Jan., 1899
CUNNINGHAM, PETER N., Easter Kennyhill House, Cumbernauld road, Glasgow,	28 Dec., 1884
CUNNINGHAM, P. NISBET, Jun., Easter Kennyhill House, Cumbernauld road, Glasgow,	G. 22 Nov., 1898 M. 3 May, 1904
CUTHILL, WILLIAM, Beechwood, Uddingston,	24 Nov., 1896
DARROCH, JOHN, 27 South Kinning place, Paisley road, Glasgow,	24 Jan., 1899
DAVIDSON, DAVID, 17 Regent Park square, Strathbungo, Glasgow,	G. 22 Mar., 1881 M. 18 Dec., 1888
DAVIE, JAMES, Villafield, Johnstone,	19 Dec., 1899
DAVIE, WILLIAM, 50 Lennox avenue, Scotstoun, Glasgow,	22 Dec., 1903
DAVIS, CHARLES H., 25 Broad street, New York, U.S.A.,	20 Nov., 1900
DAVIS, HARRY LLEWELYN, Messrs Cochran & Co., Ltd., Newbie, Annan,	G. 18 Dec., 1888 M. 23 April, 1901
DAWSON, CHARLES E., 571 Sauchiehall street, Glasgow,	21 Jan., 1902

DAY, CHARLES, Huntly lodge. Ibroxholm, Glasgow,	24 Nov., 1903
DELACOUR, FRANK PHILIP, Baku, Russia,	24 Apr., 1900
DELMAAR, FREDERICK ANTHONY, Sourabaya, Netherlands East Indies,	G. 24 Apr., 1883 M. 24 Oct., 1899
DEMPSTER, JAMES, 7 Knowe terrace, Pollokshields, Glasgow,	24 Jan., 1899
DENHOLM, JAMES, 3 Westminster crescent, Crow road, Partick,	21 Nov., 1883
DENHOLM, WILLIAM, Meadowside Shipbuilding yard, Partick, Glasgow,	G. 18 Dec., 1883 M. 21 Nov., 1893
DENNY, ARCHIBALD, Braehead, Dumbarton,	21 Feb., 1888
DENNY, JAMES, Engine works, Dumbarton,	25 Oct., 1887
DENNY, Col. JOHN M., M.P., Helenslee, Dumbarton,	27 Oct., 1896
DENNY, LESLIE, Leven Shipyard, Dumbarton,	30 Apr., 1895
DENNY, PETER, Bellfield, Dumbarton,	21 Feb., 1888
†DEWRANCE, JOHN, 165 Great Dover street, London, S.E.,	19 Feb., 1901
DICK, FRANK W., c/o The Parkgate Steel & Iron Co., Ltd., Parkgate, Rotherham.	19 Mar., 1878
DICK, JAMES, 12 Ronald street, Coatbridge,	18 Mar., 1902
DIMMOCK, JOHN WINGRAVE, Lloyd's Register of Shipping, 342 Argyle street, Glasgow,	22 Mar., 1898
DIXON, JAMES S., 127 St. Vincent street, Glasgow,	G. 24 Dec., 1873 M. 22 Jan., 1878
DIXON, WALTER, Derwent, Kelvinside gardens, Glasgow,	26 Feb., 1895
DOBSON, JAMES, Messrs H. Pooley & Son, Albion Foundry, Kidsgrove, Staffordshire	G. 22 Dec., 1896 M. 25 Oct., 1904
DOBSON, WILLIAM, The Chesters, Jesmond, Newcastle-on-Tyne,	17 Jan., 1871
DODD, T. J., Lloyd's Register of Shipping, 342 Argyle street, Glasgow,	20 Nov., 1900
D'OLIVEIRA, RAPHAEL CHRYSOSTOME, Campos, Rio de Janeiro, Brazil,	20 Feb., 1900
DONALD, B. B., Low Balernock, Petershill, Glasgow,	G. 20 Mar., 1888 M. 24 Jan., 1899
DONALD, DAVID P., Johnstone,	21 Mar., 1899
DONALD, ROBERT HANNA, Abbey works, Paisley,	22 Nov., 1892
DONALDSON, A. FALCONER, Beechwood, Partick,	G. 27 Oct., 1896 M. 16 Dec., 1902
DONALDSON, JAMES, Almond villa, Renfrew,	25 Jan., 1876
†DOUGLAS, CHARLES STUART, B.Sc., St. Brides, 12 Dalziel drive, Pollokshields, Glasgow,	G. 24 Jan., 1899 M. 3 Mar., 1903
DOWNIE, A. MARSHALL, B.Sc., London road Iron works, Glasgow,	21 Nov., 1899
DOYLE, PATRICK, F.R.S.E., 7 Government place, Calcutta, India,	23 Nov., 1886

DREW, ALEXANDER, 154-6 Temple Chambers, Temple avenue, London, E.C.,	29 Apr., 1890
DRON, ALEXANDER, 59 Elliot street, Glasgow,	27 Oct., 1903
DRUMMOND, WALTER, The Glasgow Railway Engineering works, Govan, Glasgow,	26 Mar., 1895
DRYSDALE, JOHN W. W., 3 Whittingehame gardens, Kelvinside, Glasgow,	23 Dec., 1884
DUNCAN, GEORGE F., 12 Syriam terrace, Broomfield road, Springburn, Glasgow,	G. 23 Nov., 1886 M. 20 Mar., 1894
DUNCAN, GEORGE THOMAS, Cumledge, Uddingston,	15 Apr., 1902
DUNCAN, HUGH, 11 Hampden terrace, Mount Florida, Glasgow,	15 June, 1898
DUNCAN, JOHN, Ardenclutha, Port-Glasgow,	23 Nov., 1886
DUNCAN, ROBERT, Whitefield Engine works, Govan,	25 Jan., 1881
DUNCAN, W. LEES, Partick foundry, Partick,	18 Dec., 1900
DUNKERTON, ERNEST CHARLES, 43 Cecil street, Hillhead, Glasgow,	17 Feb., 1903
DUNLOP, DAVID JOHN, Inch works, Port-Glasgow,	23 Nov., 1869
DUNLOP, JOHN G., Clydebank, Dumbartonshire,	23 Jan., 1877
DUNLOP, THOMAS, 25 Wellington street, Glasgow,	19 Dec., 1899
DUNLOP, WILLIAM A., Harbour Office, Belfast,	23 April, 1901
DUNN, J. R., 42 Magdalen Yard road, Dundee,	16 Dec., 1902
DUNN, JAMES, Collalis, Scotstounhill, Glasgow,	23 April, 1901
†DUNN, PETER L., 815 Battery street, San Francisco, U.S.A.,	26 Oct., 1886
†DUNSMUIR, HUGH, Govan Engine works, Govan,	21 Apr., 1903
DYER, HENRY, M.A., D.Sc., 8l Highburgh terrace, Dowanhill, Glasgow,	23 Oct., 1883
EDWARDS, CHARLES, The Greenock Foundry Company, Greenock,	26 Oct., 1897
ELGAR, FRANCIS, LL.D., F.R.SS., L.& E., 34 Leadenhall street, London, E.C.,	24 Feb., 1885
ELLIOTT, ROBERT, B.Sc., Lloyd's Surveyor, Greenock,	G. 24 Mar., 1885 M. 21 Feb., 1898
EWEN, PETER, The Barrowfield Ironworks, Ltd., Craigielea, Bothwell,	21 Mar., 1899
FAICKNEY, ROBERT, 3 Thornwood terrace, Partick,	20 Nov., 1900
FAIRWEATHER, WALLACE, 62 St. Vincent st., Glasgow,	24 Apr., 1894
FERGUSON, DAVID, Glenholm, Port-Glasgow,	29 Oct., 1901
FERGUSON, JOHN JAMES, Kennard, Kirn,	24 Jan., 1899

FERGUSON, LOUIS, Newark Works, Port-Glasgow,	G. 22 Jan., 1895 M. 26 Nov., 1901
FERGUSON, PETER, Rossbank, Port-Glasgow,	22 Oct., 1889
FERGUSON, PETER J., Carlogie, Greenock, W.,	G. 22 Jan., 1895 M. 26 Nov., 1901
FERGUSON, WILFRED H., 4 Thornwood terrace, Partick,	22 Nov., 1898
FERGUSON, WILLIAM D., 3 Mount Delphi, Antrim road, Belfast,	G. 27 Jan., 1885 M. 20 Mar., 1894
FERGUSON, WILLIAM R., Messrs Barclay, Curle & Co., Ltd., Whiteinch, Glasgow,	G. 22 Feb., 1881 M. 22 Jan., 1895
FERRIER, HUGH, 48 Daisy street, Govanhill, Glasgow,	22 Dec., 1903
FIFE, WILLIAM, Messrs William Fife & Sons, Fairlie, Ayrshire,	28 Apr., 1903
FINDLAY, ALEXANDER, M.P., Parkneuk Iron works, Motherwell,	27 Jan., 1880
FINDLAY, LOUIS, 50 Wellington street, Glasgow,	G. 21 Feb., 1893 M. 27 Oct., 1903
FINLAYSON, FINLAY, Laird street, Coatbridge,	23 Dec., 1884
FINNIE, WILLIAM, Messrs Howarth Erskine, Limited, Singapore, Straits Settlements,	20 Dec., 1904
FISHER, ANDREW, St. Mirren's Engine works, Paisley,	25 Jan., 1898
FLEMING, GEORGE E., Messrs Dewrance & Co., 79 West Regent street, Glasgow,	27 Oct., 1896
FLEMING, JOHN, Dellburn works, Motherwell,	24 Jan., 1899
FLETT, GEORGE L., 5 Abercromby terrace, Ibrox, Glasgow,	22 Jan., 1895
FORRESTER, JOHN, 41 Bothwell street, Glasgow,	22 Dec., 1903
FORSYTH, LAWSON, 97 St. James road, Glasgow,	18 Dec., 1883
FRAME, JAMES, 6 Kilmailing terrace, Cathcart, Glasgow,	23 Feb., 1897
FRASER, J. IMBRIE, Clifton, Row, Dumbartonshire,	G. 27 Apr., 1886 M. 27 Oct., 1903
FRYER, TOM J., Brookdean, Hope, Sheffield,	G. 18 Dec., 1894 M. 20 Dec., 1898
FUJII, TERUGORO, Imperial Japanese Navy, 8 Nottingham place, London, W.	21 Feb., 1899
FULLERTON, ALEXANDER, Vulcan Works, Paisley,	22 Dec., 1896
FULLERTON, JAMES, Abbotsburn, Paisley,	19 Mar., 1901
FULLERTON, ROBERT A., 1 Strathmore gardens, Hillhead, Glasgow,	19 Mar., 1901
FULTON, NORMAN O., South Brae drive, Scotstounhill, Glasgow,	G. 23 Feb., 1892 M. 19 Mar., 1901
FYFE, CHARLES F. A., 2 Wellesley avenue, Belfast,	G. 18 Dec., 1894 M. 28 Apr., 1903

GALE, WILLIAM M., 18 Huntly gardens, Kelvinside, Glasgow,		24 Jan., 1893
GALLETLY, ARCHIBALD A., 10 Greenlaw avenue, Paisley,		22 Jan., 1901
GALLOWAY, ANDREW, The Grand Hotel, Heidelberg, Transvaal, S.A.	G. / M.	24 Oct., 1893 / 25 Oct., 1904
GALLOWAY, CHARLES S., Greenwood City, Vancouver, B.C.,		22 Jan., 1895
GARDNER, WALTER, 11 Kildonan terrace, Paisley road W., Glasgow,		20 Dec., 1898
GARNETT, SYDNEY HAROLD, 144 St. Vincent street, Glasgow,		21 Feb., 1905
GEARING, ERNEST, Rosehurst, Grosvenor road, Headingley, Leeds,		20 Mar., 1888
GEMMELL, E. W., 73 Robertson street, Glasgow,		18 Dec., 1888
GEMMELL, THOMAS, Electric Lighting Department, St. Enoch Station, Glasgow,		24 Oct., 1899
GIBB, ANDREW, Garthland, Westcombe Park road, Blackheath, London, S.E.,	G. / M.	23 Dec., 1873 / 21 Mar., 1882
GIFFORD, PATERSON, c/o Messrs Bell, Brothers & M'Lelland, 135 Buchanan street, Glasgow,		23 Nov., 1886
GILCHRIST, ARCHIBALD, 36 Finnieston street, Glasgow,		16 Dec., 1902
GILCHRIST, JAMES, 3 Kingsborough gardens, Kelvinside, Glasgow,	G. / M.	26 Dec., 1866 / 29 Oct., 1878
GILL, WILLIAM NELSON, 11 Kersland street, Hillhead, Glasgow,		23 Feb., 1904
GILLESPIE, ANDREW, 65 Bath street, Glasgow,		20 Nov., 1894
GILLESPIE, JAMES, 21 Minerva street, Glasgow,	G. / M.	24 Feb., 1874 / 24 Mar., 1891
GILLESPIE, JAMES, Jun., Margaretville, Orchard street, Motherwell,		18 Dec., 1900
GILLIES, JAMES, 14 Walmer terrace, Glasgow,		21 Mar., 1905
GILMOUR, JOHN H., River Bank, Irvine,		20 Feb., 1900
GLASGOW, JAMES, Fernlea, Paisley,		25 Jan., 1898
†GOODWIN, GILBERT S., Alexandra buildings, James street, Liverpool,		28 Mar., 1866
GORDON, A. G., c/o Messrs Shewan, Tomes, & Co., Hongkong, China,		23 April, 1901
GORDON, JOHN, 152 Craigpark street, Glasgow,		26 Mar., 1895
GORRIE, JAMES M., 1 Broomhill terrace, Partick, Glasgow,		22 Nov., 1898
GOUDIE, ROBERT, 37 West Campbell street, Glasgow,		27 Oct., 1903
GOUDIE, WILLIAM J., B.Sc., 6 Beaton road, Maxwell Park, Glasgow,	G. / M.	21 Dec., 1897 / 29 Oct., 1901
GOURLAY, R. CLELAND, Endyne, Oakshaw street, Paisley,	G. / M.	24 Dec., 1895 / 27 Oct., 1903
GOVAN, ALEXANDER, The Sheiling, Craigendoran,		24 Oct., 1899

GOW, GEORGE, Messrs Macfarlane & Co., Wallace building, Greenock,	20 Mar., 1900
GOWAN, A. B., Byram, Maxwell drive, Pollokshields, Glasgow,	G. 24 Jan., 1882 M. 22 Jan., 1895
GRACIE, ALEXANDER, Fairfield Shipbuilding and Engineering Company, Govan,	G. 26 Feb., 1884 M. 24 Nov., 1896
GRAHAM, JOHN, 25 Broomhill terrace, Partick,	23 Oct., 1900
GRAHAM, JOHN, 15 Armadale street, Dennistoun, Glasgow,	G. 19 Mar., 1901 M. 21 Apr., 1903
GRAHAM, WALTER, Kilblain Engine works, Nicholson street, Greenock,	G. 28 Jan., 1896 M. 15 June, 1898
GRANT, THOMAS M., 17 Clarence drive, Hyndland, Glasgow,	25 Jan., 1876
GRAY, DAVID, 77 West Nile street, Glasgow,	21 Nov., 1899
GRAY, WILLIAM, 6 Lloyd's avenue, London, E.C.,	26 Jan., 1904
GRETCHIN, G. L., Works Manager, Chantiers Navals Ateliers and Founderies de Nicolaieff, Nicolaieff, Russia,	25 Jan., 1898
GRIEVE, JOHN, Engineer, Motherwell,	25 Jan., 1898
GRIGG, JAMES, 135 Balshagray avenue, Partick,	20 Jan., 1903
GROUNDWATER, CHARLES LAMONT, c/o Messrs Mackay, Macarthur Ltd., Bankok, Siam,	21 Mar., 1905
GROVES, L. JOHN, Engineer, Crinan Canal house, Ardrishaig,	20 Dec., 1881
GUTHRIE, JOHN, The Crown Iron works, Glasgow,	27 Oct., 1896
HAIG, ROBERT, The Mechanical Retorts Co., Limited, Murray street, Paisley,	22 Jan., 1901
HAIGH, WILLIAM R., 6 Elmwood gardens, Jordanhill,	22 Dec., 1896
HALKET, JAMES P., Glengall Iron works, Millwall, London, E.,	26 Oct., 1897
HALL, WILLIAM, Shipbuilder, Aberdeen,	25 Jan., 1881
HAMILTON, ARCHIBALD, Clyde Navigation Chambers, Glasgow,	G. 24 Feb., 1874 M. 24 Nov., 1885
HAMILTON, CLAUD, 247 St. Vincent street, Glasgow,	15 June, 1898
HAMILTON, DAVID C., Clyde Shipping Company, 21 Carlton place, Glasgow,	G. 23 Dec., 1873 M. 22 Nov., 1881
HAMILTON, JAMES, Ardedynn, Kelvinside, Glasgow,	G. 26 Dec., 1863 M. 18 Mar., 1876
HAMILTON, JAMES, 6 Kyle park, Uddingston,	20 Nov., 1900
*†HAMILTON, JOHN, 22 Athole gardens, Glasgow,	
HAMILTON, JOHN K., 230 Berkeley street, Glasgow,	15 May, 1900
HAMILTON, ROBERT SMITH, Flemington, Maxwell Park gardens, Pollokshields, Glasgow,	22 Mar., 1904

HARMAN, BRUCE, 35 Connaught road, Harlenden, London, N.W.,	G. 2 Nov., 1880 M. 22 Jan., 1884
HARRIS, WILLIAM, 73 Robertson street, Glasgow,	22 Nov., 1904
HARRISON, J. E., 160 Hope street, Glasgow,	G. 26 Feb., 1889 M. 22 Feb., 1898
HART, P. CAMPBELL, 134 St., Vincent street, Glasgow,	24 Nov., 1896
HARVEY, JAMES, 224 West street, Glasgow,	24 Jan., 1899
HARVEY, JOHN H., Messrs Wm. Hamilton & Co., Port-Glasgow,	22 Feb., 1887
HARVEY, THOMAS, Grangemouth Dockyard Co., Grangemouth,	19 Dec., 1899
HAY, JOHN, Wansfell, The Grove, Finchley, London, N.,	26 Nov., 1901
HAY, RANKIN, 44 Windsor terrace, St. George's road, Glasgow,	18 Dec., 1900
HAYWARD, THOMAS ANDREW, 18 Carrington street, Glasgow,	22 Mar., 1898
†HENDERSON, A. P., 30 Lancefield quay, Glasgow,	25 Nov., 1879
HENDERSON, CHARLES A., The Basin House, Exeter,	G. 24 Jan., 1899 M. 27 Oct., 1903
HENDERSON, FREDERICK N., Meadowside, Partick, Glasgow,	26 Mar., 1895
HENDERSON, H. E., 32 Curzon road, Waterloo, near Liverpool,	G. 22 Nov., 1898 M. 3 May, 1904
HENDERSON, J. BAILIE, Government Hydraulic Engineer, Brisbane, Queensland,	18 Dec., 1888
HENDERSON, JAMES BLACKLOCK, D.Sc., 146 Cambridge drive, Glasgow,	20 Nov., 1900
HENDERSON, JOHN FRANCIS, B.Sc., Albion Motor Car Co., Ltd., South street, Scotstoun, Glasgow,	16 Dec., 1902
†HENDERSON, JOHN L.,	25 Nov., 1879
HENDERSON, ROBERT, 777 London road, Glasgow,	19 Mar., 1901
HENDERSON, WILLIAM STEWART, Belwood, Coatbridge,	24 Nov., 1896
HENDIN, ALEXANDER JAMES, 14 Hamilton terrace, W., Partick, Glasgow,	22 Dec., 1903
HENDRY, JAMES C., Rosebank, Gartsherrie road, Coatbridge,	18 Dec., 1900
HENRY, ERENTZ, 13 Ann street, Hillhead, Glasgow,	20 Feb., 1900
HERRIOT, W. SCOTT, Ravenswood, Partick, W.,	28 Oct., 1890
HETHERINGTON, EDWARD P., Messrs John Hetherington & Co, Ltd., Pollard street, Manchester,	22 Nov., 1892
HIDE, WILLIAM SEYMOUR, Messrs Amos & Smith, Albert Dock works, Hull,	18 Dec., 1888
HILLHOUSE, PERCY ARCHIBALD, B.Sc., Whitworth, Busby,	3 May, 1904
HISLOP, GEORGE ROBERTSON, Jun., 13 St. James' place, Paisley,	18 Apr., 1905
HOGARTH, W. A., 293 Onslow drive, Glasgow,	20 Nov., 1900

HOGG, CHARLES P., 53 Bothwell street, Glasgow, 2 Nov., 1880

HOGG, JOHN, Victoria Engine works, Airdrie, 20 Mar., 1883

HÖK, W., 10 Karlaplan, Stockholm, Sweden, 29 Oct., 1901

HOLLIS, H. E., 40 Union street, Glasgow, { A. 20 Nov., 1897 / M. 24 Oct., 1899

HOLMES, F. G., Town Hall, Govan, 23 Mar., 1880

HOMAN, WILLIAM M'L., P.O. Box 24, Bethlehem, Orange River Colony, { G. 26 Jan., 1892 / M. 26 Oct., 1897

HORNE, GEORGE S., Corozal, Iverton road, Johnstone, 21 Feb., 1899

HORNE, JOHN, Dysart House, St. Aiban's road, Carlisle, 23 Nov., 1897

†HOUSTON, COLIN, Harbour Engine works, 60 Portman street, Glasgow, 25 Mar., 1890

HOUSTON, JAMES, Junr., Brisbane house, Bellahouston, 25 Jan., 1898

HOUSTON, PERCIVAL T., Coronation house, 4 Lloyd's avenue, London, E.C., { G. 22 Nov., 1898 / M. 2 May 1905

HOUSTON, WILLIAM CAMPBELL, B.Sc., Herriot Watt College, Edinburgh, { G. 26 Oct., 1897 / M. 3 Mar., 1903

HOWARD, JOHN ROWLAND, 56 Osborne road, Levenshulme, Manchester, 18 Dec., 1900

HOWAT, WILLIAM, 58 Wilton street, Glasgow, 22 Feb., 1898

†HOWDEN, JAMES, 195 Scotland street, Glasgow, Original

HUBBARD, ROBERT SOWTER, Townsend Downey Shipbuilding Co., Shooter Island, Richmond, New York, 19 Dec., 1899

HUME, JAMES HOWDEN, 195 Scotland street, Glasgow, 22 Dec., 1891

HUNT, WILFRED, 121 West George street, Glasgow, 24 Jan., 1905

HUNTER, GILBERT M., Newyards, Maybole, { G. 19 Oct., 1886 / M. 26 Nov., 1889

HUNTER, JAMES, Aberdeen Iron works, Aberdeen, 25 Jan., 1881

HUNTER, JAMES, 20 Feb., 1900

HUNTER, JOHN, Bracklinn, Bearsden, { A. 22 Jan., 1895 / M. 21 Mar., 1899

HUNTER, JOSEPH GILBERT, P.O. Box 671, Newport News, Va., U.S.A., 24 Feb., 1891

HUNTER, MATTHEW, Burnbank, Whiteinch, 19 Mar., 1901

†HUTCHEON, JAMES, Craigholme, South Brae drive, Scotstounhill, 19 Mar., 1901

HUTCHESON, ARCHIBALD, 37 Mair street, Plantation, Glasgow, 22 Dec., 1896

HUTCHESON, JOHN, 37 Mair street, Plantation, Glasgow, 22 Mar., 1898

HUTCHISON, JAMES H., Shipbuilder, Port-Glasgow, 26 Mar., 1895

HUTCHISON, JOHN S., 107 Douglas street, Glasgow, 24 Apr., 1900

HUTCHISON, M., 50 Gibson street, Hillhead, Glasgow, 29 Oct., 1901

HUTSON, ALEXANDER, 17 James street, Liverpool, 19 Dec., 1899

HUTSON, GUYBON, Culdees, Minard road, Partickhill, Glasgow, 21 Mar., 1893

HUTSON, JAMES, 117 Balshagray avenue, Partick, 19 Dec., 1899

HYND, ALEXANDER, Federal Supply and Cold Storage Co., of South Africa, Ltd., Durban, South Africa, 27 Oct., 1903

†INGLIS, JOHN, LL.D., Point House shipyard, Glasgow, 1 May, 1861

INGLIS, JOHN FRANCIS, 46 Princes terrace, Dowanhill, Glasgow, { G. 26 Oct., 1897 / M. 20 Jan., 1903 }

INNES, W., Metropolitan Electrical Station, Poplar, London, { G. 22 Feb., 1898 / M. 27 Oct., 1903 }

IRELAND, WILLIAM, 7 Ardgowan terrace, Glasgow, 25 Feb., 1890

JACK, ALEXANDER, 164 Windmillhill, Motherwell, 21 Nov., 1893

JACK, JAMES R., Mavisbank. Dumbarton, 27 Apr., 1897

JACKSON, DANIEL, Thornbank, Dumbarton, 24 Oct., 1899

JACKSON, HAROLD D., Westdel, Dowanhill, Glasgow, { G. 24 Mar., 1891 / M. 20 Dec., 1898 }

JACKSON, WILLIAM, Govan Engine works, Govan, 21 Dec., 1875

JACKSON, WILLIAM STENHOUSE, 109 Hope street, Glasgow, { G. 29 Oct., 1901 / M. 23 Feb., 1904 }

JAMIESON, Professor ANDREW, F.R.S.E., 16 Rosslyn terrace, Kelvinside, Glasgow, 26 Mar., 1889

JEFF, WILLIAM, Northfleet Engineering works, Northfleet, Kent, 18 Dec., 1900

JEFFERY, ARTHUR W., 71 Dixon avenue, Glasgow, 23 April, 1901

JOHNSTON, DAVID, 9 Osborne terrace, Copland road, Glasgow, 25 Feb., 1879

JOHNSTON, ROBERT, Kirklee, Wallace street, Kilmarnock, 22 Mar., 1898

JOHNSTONE, GEORGE, F.R.S.E., Marine Superintendent, British India Steam Navigation Co., Ltd., 16 Strand road, Calcutta, India, 21 Mar., 1899

JONES, ARTHUR J. E., 118 Napiershall street, Glasgow, 29 Oct., 1901

JONES, ARTHUR LLEWELLYN, Lloyd's Register, 342 Argyle street, Glasgow, 25 Oct., 1904

JONES, LLEWELLYN, The Stirling Boiler Co., Ltd., 25 Victoria street, Westminster, London, 25 Oct., 1892

KAY, ALEXANDER J., 21 Endsleigh gardens, Partickhill, Glasgow, { G. 24 Oct., 1893 / M. 28 Apr., 1903 }

KEEGAN, THOMAS J. M., 18 Smal street, Johannesburg, South Africa, 22 Jan., 1901

KEELING, THOMAS, 42 Prospecthill road, Langside, Glasgow,	19 Feb., 1901
KELLY, ALEXANDER, 100 Hyde Park street, Glasgow,	23 Feb., 1897
KELSO, MATTHEW GLEN, 47 Oxford street, Glasgow,	27 Oct., 1903
KEMP, DANIEL, 62 Abbey drive, Jordanhill,	G. 23 Nov., 1886 M. 20 Dec., 1898
KEMP, EBENEZER, D., Messrs Cammell, Laird & Co., Ltd., Birkenhead,	G. 20 Feb., 1883 M. 25 Oct., 1892
KEMP, ROBERT G., 60 Abbey drive, Jordanhill, Glasgow,	G. 28 Oct., 1890 M. 2 May, 1905
KEMPT, IRVINE, Jun., 37 Falkland mansions, Hyndland, Glasgow,	G. 26 Feb., 1895 M. 27 Apr., 1897
KENNEDY, ALEXANDER M'A., "Glenholm," Greenock,	30 Apr., 1895
KENNEDY, JOHN, Messrs R. M'Andrew & Co., Suffolk House, Laurence Pountney Hill, London, E.C.,	23 Jan., 1877
KENNEDY, RANKIN, Bute villa, Springboig, Shettleston,	3 May, 1904
KENNEDY, ROBERT, B.Sc., Messrs Glenfield & Kennedy, Kilmarnock,	23 Mar., 1897
KENNEDY, THOMAS, Messrs Glenfield & Kennedy, Kilmarnock,	22 Feb., 1876
KENNEDY, WILLIAM, 13 Victoria crescent, Dowanhill, Glasgow,	24 Apr., 1894
KER, WILLIAM ARTHUR, Manager, Patella Works, Paisley,	16 Dec., 1902
KERR, JAMES, Lloyd's Register of Shipping, Hull,	22 Feb., 1898
KERR, JOHN, 31 Churchill street, Princes Park, Liverpool	22 Mar., 1904
KINCAID, JOHN G., 30 Forsyth street, Greenock,	22 Feb., 1898
KING, J. FOSTER, The British Corporation, 121 St. Vincent street, Glasgow,	26 Mar., 1895
KINGHORN, A. J., 59 Robertson street, Glasgow,	24 Oct., 1899
KINGHORN, JOHN G., Tower Buildings, Water street, Liverpool,	23 Dec., 1879
KINLOCH, JAMES, 398 Dumbarton road, Glasgow,	25 Oct., 1904
KINMONT, DAVID W., Contractor's Office, Larkhall,	G. 20 Feb., 1894 M. 19 Mar., 1901
†KIRBY, FRANK E., Detroit, U.S.A.,	24 Nov., 1885
KLINKENBERG, JOHN, 4 Derby street, Glasgow,	16 Dec., 1902
KNIGHT, CHARLES A., c/o Messrs Babcock & Wilcox, Ltd., Oriel House, Farringdon st., London, E.C.,	27 Jan., 1885
KNOX, ROBERT, 10 Clayton terrace, Dennistoun, Glasgow,	24 Nov., 1896
LACKIE, WILLIAM W., 75 Waterloo street, Glasgow,	22 Nov., 1898
†LAGE, RENAUD, Ilha do Vianna, Rio de Janeiro, P.O. Box 1082,	18 Apr., 1905

LAIDLAW, D., 147 East Milton street, Glasgow,	18 Mar., 1902
LAIDLAW, JOHN, 98 Dundas street, s.s., Glasgow,	25 Mar., 1884
LAIDLAW, ROBERT, 147 East Milton street, Glasgow,	26 Nov., 1862
LAIDLAW, T. K., 147 East Milton street, Glasgow,	18 Mar., 1902
LAIDLAW, THOMAS, 52 Norse road, Scotstoun, Glasgow,	26 Nov., 1901
LAING, ANDREW, The Wallsend Slipway Company, Newcastle-on-Tyne,	20 Mar., 1880
LAIRD, ANDREW, 95 Bath street, Glasgow,	22 Nov., 1898
LAMBERT, JOHN, Corporation Electricity Works, Perth,	18 Dec., 1900
LAMBERTON, ANDREW, Sunnyside Engine works, Coatbridge,	27 Apr., 1897
LAMBIE, ALEXANDER, Ravenshall, Port-Glasgow,	19 Mar., 1901
LANG, C. R., Holm Foundry, Cathcart, Glasgow,	G. 20 Nov., 1888 M. 26 Nov., 1895
LANG, JAMES, Messrs George Smith & Sons, 75 Bothwell street, Glasgow,	24 Feb., 1880
LANG, JOHN, Jun., Lynnhurst, Johnstone,	26 Feb., 1884
LANG, ROBERT, Quarrypark, Johnstone,	25 Jan., 1898
LAUDER, THOMAS H., Kirkton, Gerard avenue, Parkhead, Glasgow,	G. 19 Dec., 1893 M. 27 Oct., 1903
LAURENCE, GEORGE B., Clutha Iron works, Paisley road, Glasgow,	21 Feb., 1888
LAW, DAVID, Ibrox Iron works, Ibrox, Glasgow,	20 Dec., 1904
†LEE, ROBERT, 105 Clarence drive, Partickhill, Glasgow,	G. 21 Dec., 1888 M. 22 Mar., 1896
LEITCH, ARCHIBALD, 40 St. Enoch square, Glasgow,	22 Dec., 1896
LEMKES, C. R. L., 5 Wellington street, Glasgow,	A. 26 Feb., 1888 M. 22 Mar., 1894
LENNOX, ALEXANDER, 34 Glasgow street, Hillhead, Glasgow,	G. 23 Jan., 1894 M. 19 Mar., 1901
LESLIE, JAMES T. G., 148 Randolph terrace, Hill street, Garnethill, Glasgow,	25 Apr., 1893
LESLIE, JOHN, Struan, Victoria drive, Scotstounhill, Glasgow,	G. 20 Dec., 1892 M. 27 Oct., 1903
LESLIE, WILLIAM, Viewmount, Emerald Hill terrace, Perth, West Australia,	24 Feb., 1891
LESTER, WILLIAM R., 11 West Regent street, Glasgow,	G. 21 Nov., 1883 M. 24 Jan., 1899
LEWIN, HARRY W., 154 West Regent street, Glasgow,	20 Dec., 1898
†LINDSAY, CHARLES C., 180 Hope street, Glasgow,	G. 23 Dec., 1873 M. 24 Oct., 1876
LINDSAY, W. F., 203 Nithsdale road, Pollokshields, Glasgow,	19 Mar., 1901
LITHGOW, WILLIAM T., Port-Glasgow,	21 Feb., 1893
LIVESEY, ROBERT M., c/o Messrs Topham Jones & Railton, H.M. Dockyard Extension, Gibraltar,	26 Jan., 1897

†LOBNITZ, FRED., Auchinbothie, Kilmalcolm,	G. 24 Mar., 1885 M. 20 Nov., 1896
LOCKIE, JOHN, Wh.Sc., 2 Custom House Chambers, Leith,	26 Jan., 1897
LONGBOTTOM, Professor JOHN GORDON, Technical College, George street, Glasgow,	22 Nov., 1898
LORIMER, ALEXANDER SMITH, Kirklinton, Langside, Glasgow,	G. 21 Nov., 1899 M. 27 Oct., 1903
LORIMER, HENRY DÜBS, Kirklinton, Langside, Glasgow,	G. 21 Nov., 1899 M. 3 May, 1904
†LORIMER, WILLIAM, Glasgow Locomotive works, Gushetfaulds, Glasgow,	27 Oct., 1896
†LOUDON, GEORGE FINDLAY, 10 Claremont Terrace, Glasgow,	25 Jan., 1896
LOWSON, JAMES, 10 West Campbell street, Glasgow,	27 Oct., 1903
LUKE, W. J., Messrs John Brown & Co., Ltd., Clydebank,	24 Jan., 1898
LUSK, HUGH D., c/o Mrs Nelson, Larch villa, Annan,	21 Feb., 1880
LYALL, JOHN, 33 Randolph gardens, Partick,	27 Oct., 1888

MACALPINE, JOHN H., 615 Walnut street, Philadelphia, U.S.A.,	20 Dec., 1898
M'ARTHUR, DUNCAN, 6 Bank stieet, Greenock,	20 Dec., 1904
M'ARTHUR, JAMES D., Oriental avenue, Bangkok, Siam,	26 Apr., 1898
MCAULAY, W.	22 Nov., 1898
MACCALLUM, P. F., 93 Hope street, Glasgow,	G. 22 Nov., 1880 M. 27 Oct., 1903
MCCALLUM, DAVID BROADFOOT, 174 Cathedral road, Cardiff,	23 Feb., 1904
†MACCOLL, HECTOR, Bloomfield, Belfast,	24 Mar,, 1874
†MACCOLL, HUGO, Wreath Quay Engineering works, Sunderland,	G. 20 Dec., 1881 M. 22 Oct., 1889
M'COLL, PETER, 197 Byars road, Partick,	G. 18 Dec., 1883 M. 24 Jan., 1899
M'CREATH, JAMES, 208 St. Vincent street, Glasgow,	23 Oct., 1883
M'DONALD, ALEX., 9 Sutherland street, Hillhead, Glasgow,	24 Jan., 1905
MACDONALD, D. H., Brandon works, Motherwell,	24 Mar., 1896
MACDONALD, JOHN, Bridge Turbine Works, Pollokshaws, Glasgow,	G. 18 Dec. 1883 M. 21 Mar., 1899
MACDONALD, JOHN DRON, 3 Rosemount terrace, Ibrox, Glasgow,	19 Mar., 1901
MACDONALD, ROBERT COWAN, Merrylee, Trefoil avenue, Shawlands, Glasgow,	G. 21 Nov., 1899 M. 28 Apr., 1903
MACDONALD, THOMAS, 9 York street, Glasgow,	25 Jan., 1898
MACDONALD, WILLIAM, 48 Dalhousie street, Glasgow,	22 Dec., 1903

MCDOUGALL, ROBERT MELVIN, 86 Dale street, Glasgow,		20 Nov., 1900
M'DOWALL, JOHN JAS., Vulcan Engine Works, Piraeus, Greece,		29 Oct., 1901
M'EWAN, JAMES, Cyclops Foundry Co., Whiteinch, Glasgow,		26 Feb., 1884
M'EWAN, JOSEPH, 35 Houldsworth street, Glasgow,		27 Jan., 1891
MACFARLANE, DUNCAN, Jun., 58 Hydepark street, Glasgow,	G. M.	26 Oct., 1897 27 Oct., 1903
MACFARLANE, JAMES W., Cartbank, Cathcart, Glasgow,		2 Nov., 1880
†MACFARLANE, WALTER, 23 Park Circus, Glasgow,		26 Oct., 1886
MCFARLANE, GEORGE, 34 West Georges treet, Glasgow,	G. M.	24 Feb., 1874 24 Nov., 1885
MACFEE, JOHN, Castle Chambers, Renfield street, Glasgow,		22 Jan., 1901
M'GEE, DAVID, c/o Messrs John Brown & Co., Clydebank,		22 Dec., 1896
†M'GEE, WALTER, Stoney brae, Paisley,		25 Jan., 1898
M'GIBBON, W. C., 2 Carlton Court, Bridge street, Glasgow,		18 Dec., 1900
MACGREGOR, J. GRANT, c/o L. & N. Railway Co., 10th Broadway, Louisville, Ky., U.S.A.,	G. M.	21 Dec., 1886 28 Apr., 1891
MCGREGOR, JOHN B., 6 Oxford terrace, Renfrew,	G M.	18 Dec., 1883 27 Apr., 1897
MCGREGOR, THOMAS, 10 Mosesfield terrace, Springburn, Glasgow,		26 Jan., 1886
M'HOUL, JOHN B., 2 Windsor terrace, Langside, Glasgow,	G M.	24 Jan., 1899 27 Oct., 1903
M'ILVENNA, JOHN, 13 Caird drive, Partickhill, Glasgow,		19 Mar., 1901
MACILWAINE, GEORGE W., 7 Havelock street, Dowanhill, Glasgow,		18 Mar., 1902
M'INDOE, JOHN B., 15 Surrey street, Coatbridge,		21 Mar., 1899
M'INTOSH, DONALD, Dunglass, Bowling,		20 Feb., 1894
M'INTOSH, JOHN, 5 Douglas terrace, Paisley,	G. M.	22 Jan., 1895 27 Oct., 1903
M'INTOSH, JOHN F., Caledonian Railway, St. Rollox, Glasgow,		28 Jan., 1896
MACKINTOSH, JOHN, 2 Buchanan terrace, Paisley,	G. M.	18 Dec., 1894 28 Apr., 1903
MCINTOSH, THOMAS WILLIAM, 58 Hydepark street, Glasgow		24 Nov., 1903
MACKAY, HENRY JAMES, 144 Buccleuch street, Garnethill, Glasgow,		18 Feb., 1902
MACKAY, LEWIS CHAMBERS, 20 Glasgow street, Hillhead, Glasgow,	G. M.	22 Dec., 1896 22 Nov., 1904
MACKAY, W. NORRIS, 77 St. George's Road, Glasgow,	S. M.	22 Jan., 1901 25 Oct., 1904
M'KEAND, ALLAN, 3 St. James street, Hillhead, Glasgow,	G. M.	19 Dec., 1884 20 Mar., 1892

MACKECHNIE, JOHN, 342 Argyle street, Glasgow,	20 Dec., 1898
MCKECHNIE, JAMES, Messrs Vickers, Sons, & Maxim, Barrow-in-Furness,	24 Apr., 1888
MACKENZIE, JAMES, 8 St. Alban's road, Bootle,	G. 25 Oct., 1881 M. 24 Jan., 1899
MACKENZIE, THOMAS B., Elenslee, Wilson street, Motherwell,	G. 23 Jan., 1885 M. 26 Nov., 1893
MCKENZIE, JOHN, Messrs J. Gardiner & Co., 24 St. Vincent place, Glasgow,	25 Apr., 1893
MCKENZIE, JOHN, Speedwell Engineering works, Coatbridge,	25 Jan., 1898
MACKIE, WILLIAM, 3 Park terrace, Govan,	G. 21 Dec., 1897 M. 24 Mar., 1903
MACKIE, WILLIAM A., Falkland bank, Partickhill, Glasgow,	22 Mar., 1881
MCKIE, J. A., Copland works, Govan.	25 Jan., 1898
†MACKINLAY, JAMES T. C., 110 Gt Wellington street, Kinning park, Glasgow,	27 Oct., 1896
M'KILLOP, PETER ALEXANDER, 45 Hope street, Glasgow,	21 Mar., 1905
M'KINNEL, WILLIAM, c/o Messrs S. Osborne & Co., Clyde Steel Works, Sheffield.	A. 21 Feb., 1893 M. 22 Feb., 1898
M'LACHLAN, EWEN, 168 Kenmure street, Pollokshields, Glasgow,	21 Feb., 1899
MCLACHLAN, JOHN, Saucel Bank House, Paisley,	26 Oct., 1897
MACLAREN, JOHN F., B.Sc., Eglinton foundry, Canal street, Glasgow,	23 Feb., 1892
MACLAREN, ROBERT, Eglinton foundry, Canal street, Glasgow,	G. 2 Nov., 1880 M. 22 Dec., 1885
MCLAREN, JOHN ALEXANDER,	22 Nov., 1898
MCLAREN, RICHARD ANDREW, South Gallowhill house, Paisley,	21 Apr., 1903
MCLAREN, WILLIAM, 9 Westbank quadrant, Hillhead, Glasgow,	26 Nov., 1901
MCLAURIN, DUNCAN, Cartside Mills, Milliken Park, Renfrewshire,	23 Oct., 1900
MACLAY, DAVID M., Dunourne, Douglas street, Motherwell,	18 Dec., 1900
†MACLEAN, ANDREW, Messrs Barclay, Curle & Co., Whiteinch,	3 May, 1904
MACLEAN, Prof. MAGNUS, M.A., D.Sc., 51 Kersland street, Hillhead, Glasgow,	21 Nov., 1899
MACLEAN, WILLIAM DICK, Nuevas Hilaturas del Ter, Torello, Cataluña Spain,	25 Jan., 1898
MCLEAN, JOHN, Messrs Weir & McLean, 45 Hope street, Glasgow,	16 Dec., 1902
MCLEAN, JOHN, Lower Barraca, Valetta, Malta,	G. 21 Nov., 1899 M. 22 Dec., 1903

†MACLELLAN, WILLIAM T., Clutha Iron works, Glasgow,	21 Dec., 1886
MCLELLAN, ALEX., Clyde Navigation Trust, 16 Robertson street, Glasgow,	G. 18 Dec., 1900 A.M. 18 Ap., 1903 M. 27 Oct., 1903
MCLELLAN, DUGALD, Caledonian Railway Co., Goods Yard, Buchanan street, Glasgow,	22 Jan., 1901
MACMILLAN, HUGH MILLAR, B.Sc., Messrs. Wigham, Richardson, & Co., Newcastle-on-Tyne,	18 Dec., 1900
*†MACMILLAN, WILLIAM, Holmwood, Whittingehame drive, Kelvinside, Glasgow,	Mar., 1865
MCMILLAN, JOHN, Resident Electrical Engineer's Office, Falkirk,	G. 27 Jan., 1885 M. 24 Jan., 1899
MCMILLAN, W. MACLEOD, Dockyard, Dumbarton,	22 Jan., 1901
MACMURRAY, WILLIAM, Taller Bisayas, Yloilo, Philippine Islands,	18 Mar., 1902
MCMURRAY, THOMAS H., 22 Cliftonville avenue, Belfast,	22 Jan., 1901
M'NAIR, JAMES, Norwood, Prestwick road, Ayr,	26 Nov., 1895
MACNAMARA, JOSEPH Wortley, near Sheffield,	20 Jan., 1903
M'NEIL, JOHN, Helen street, Govan,	23 Dec., 1884
MACNICOLL, NICOL, 6 Dixon street, Glasgow,	19 Mar., 1901
M'ONIE, PETER SMITH, 9 Grant street, Greenock,	20 Dec., 1904
MACOUAT, R. B., Victoria Bolt and Rivet works, Cranstonhill, Glasgow,	21 Mar., 1899
M'WHIRTER, WILLIAM, 214 Holm street, Glasgow,	24 Mar., 1891
MACK, JAMES, 22 Rutland street, Edinburgh,	G. 21 Dec., 1886 M. 20 Dec., 1898
MALCOLM, WILLIAM GEORGE, Boyack house, Pollokshields, Glasgow,	21 Feb., 1905
MANSON, JAMES, G. & S. W. Railway, Kilmarnock,	21 Feb., 1899
MARRIOTT, ALFRED, 44 Kelburne avenue, Dumbreck, Glasgow,	20 Dec., 1904
MARRIOTT, REUBEN, Plantation Boiler Works, Govan,	23 Feb., 1897
MARSHALL, ALEXANDER, Glenmavis, Melrose avenue, Rutherglen,	21 Mar., 1905
MARSHALL, DAVID, Glasgow Tube works, Glasgow,	22 Jan., 1895
MARSHALL, JOHN, Ashgrove, Kilwinning,	18 Dec., 1900
MARTIN, WILLIAM CRAMMOND, 10 West Campbell street, Glasgow,	27 Oct., 1903
MATHESON, DONALD A., Caledonian Railway Co., Buchanan street station, Glasgow,	26 Jan., 1897
MATHEWSON, GEORGE, Bothwell works, Dunfermline,	21 Dec., 1875
MATHIESON, JAMES H., Saracen Tool Works, Glasgow,	29 Oct., 1901
MATTHEY, C. A., c/o W. Hope Campbell, Esq., 42 Krestchatik, Kieff, S. Russia,	26 Oct., 1897
MAVOR, HENRY A., 47 King street, Bridgeton, Glasgow,	22 Apr., 1884
MAVOR, SAM, 37 Burnbank gardens, Glasgow,	20 Nov., 1894

MAXTON, JAMES, 4 Ulster street, Belfast,		22 Jan., 1901
MAY, WILLIAM W., Woodbourne, Minard avenue, Partickhill, Glasgow,		25 Jan., 1876
MAYER, WILLIAM, Morwell House, Dumbarton,		23 Feb., 1897
MECHAN, HENRY, Messrs Mechan & Sons, Scotstoun Iron works, Glasgow,		25 Jan., 1887
MECHAN, SAMUEL, 22 Kingsborough gardens, Kelvinside Glasgow,		27 Oct., 1891
MELVILLE, WILLIAM, Glasgow and South Western Railway, St. Enoch square, Glasgow,		23 Jan., 1883
MIDDLETON, R. A., 20 The Grove, Benton, near Newcastle-on-Tyne,	G. M.	24 Jan., 1882 28 Oct., 1890
MILLAR, SIDNEY, Harthill house, Cambuslang,	G. M.	26 Feb., 1889 21 Dec., 1897
MILLAR, THOMAS, Walker Shipyard, Newcastle-on-Tyne,	G. M.	25 Nov., 1884 27 Oct., 1903
MILLAR, WILLIAM, Towersland, Octavia terrace, Greenock,		19 Dec., 1899
MILLER, ARTHUR C., 12 Caird drive, Partickhill, Glasgow,		19 Mar., 1901
MILLER, GEORGE M'EWAN, 3 Clydeview, Partick,		25 Oct., 1904
MILLER, JAMES, 3 Roebuck terrace, Stenhousemuir, Larbert,	G. M.	22 Nov., 1898 2 May, 1905
MILLER, JOHN, Etruria villa, South Govan,	G. M.	23 Apr., 1889 2 May, 1905
MILLER, ROBERT F., Messrs Wardlaw & Miller, 109 Bath street, Glasgow,	G. M.	25 Feb., 1890 27 Oct., 1903
MILNE, CHARLES W., Fairmount, Scotstounhill, Glasgow,		26 Nov., 1901
MILNE, GEORGE, 10 Bothwell street, Glasgow,		22 Jan., 1901
MITCHELL, ALEXANDER, Hayfield house, Springburn, Glasgow,		26 Jan., 1886
MITCHELL, GEORGE A., F.R.S.E., 5 West Regent street, Glasgow,		25 Jan., 1898
MITCHELL, THOMAS, Gower street, Bellahouston, Glasgow,		20 Nov., 1888
MOIR, ERNEST W., c/o Messrs S. Pearson & Son, 10 Victoria street, Westminster, London,	G. M.	25 Jan., 1881 24 Jan., 1899
MOIR, JAMES, 70 Wellington street, Glasgow,		16 Dec., 1902
MOIR, JOHN, Clyde Shipbuilding and Engineering Company, Port-Glasgow,		23 Feb., 1897
MOIR, THOMAS, 10 Syriam terrace, Springburn, Glasgow,		23 Apr., 1901
MOLLISON, HECTOR A., B.Sc., 33 Fotheringay road, Maxwell Park, Glasgow,	G. M.	22 Nov., 1892 20 Nov., 1900
MOLLISON, JAMES, 30 Balshagray avenue, Partick,		21 Mar., 1876
MONROE, ROBERT, Eastbrook house, Dinas Powis, Glam.,		26 Jan., 1904
MOORE, RALPH D., B.Sc., Leabank, Bearsden,		27 Apr., 1897
MOORE, ROBERT H., Caledonian Steel Castings Co., Govan,		16 Dec., 1902

MOORE, ROBERT T., D.Sc., 13 Clairmont gardens, Glasgow,	27 Jan., 1891
MORGAN, ROBERT, Arnsbrae, Dumbreck, Glasgow,	24 Mar., 1903
MORISON, WILLIAM, 23 St. Andrew's drive, Pollokshields, Glasgow,	20 Mar., 1888
MORISON, WILLIAM B., 7 Rowallan gardens, Broomhill, Glasgow,	20 Nov., 1900
MORRICE, RICHARD WOOD, 24 Battlefield road, Langside, Glasgow,	23 Feb., 1897
MORRISON, ARTHUR MACKIE, Merchiston, Scotstounhill, Glasgow, W.,	G. 17 Dec., 1889 M. 8 Mar., 1903
MORRISON, WILLIAM, 2 Oxenfoord terrace, Girvan,	19 Feb., 1901
MORT, ARTHUR, Calder view, Motherwell,	G. 26 Jan., 1897 M. 19 Dec., 1899
MORTON, DAVID HOME, 130 Bath street, Glasgow,	20 Nov., 1900
MORTON, ROBERT, 8 Prince's square, Buchanan street, Glasgow,	G. 17 Dec., 1878 M. 23 Jan., 1883
MORTON, ROBERT C., 16 Vinicombe street, Hillhead, Glasgow,	26 Nov., 1901
MORTON, THOMAS, M. G., Errol works, Errol,	26 Jan., 1904
MOTION, ROBERT, Ancrum, Lenzie,	23 Feb., 1892
MOWAT, MAGNUS, Jun., Civil Engineer, Millwall Docks, London,	G. 26 Oct., 1897 M. 26 Nov., 1901
MOYES, JOHN YOUNG, 12 Ruthven street, Glasgow,	27 Oct., 1903
†MUIR, HUGH, 7 Kelvingrove terrace, Glasgow,	17 Feb., 1864
MUIR, JAMES, Messrs John King & Co., Ltd., Engineers, Calcutta,	21 Feb., 1905
MUIR, JAMES E., 105 West George street, Glasgow,	22 Dec., 1896
†MUIR, JOHN G.,	24 Jan., 1882
MUIR, PETER GILLESPIE, 24 Laburnum avenue, Wallsend-on-Tyne,	18 Mar., 1902
MUIR, ROBERT WHITE, 97 St. James road, Glasgow,	21 Dec., 1897
MUMME, CARL, 30 Newark street, Greenock,	22 Oct., 1895
MUMME, ERNEST CHARLES, Hajipur-Begam Sarai Railway Extension, Begam Sarai P.O., Tirhoot State Railway, India,	G. 22 Nov., 1892 M. 20 Feb., 1900
MUNN, ROBERT A., Twynham, 5 Winn road Southampton,	22 Dec., 1896
MUNRO, JAMES, Torquil, Carmyle avenue, Carmyle,	16 Dec., 1902
MUNRO, JOHN, 51 Polwarth gardens, Hyndland, Glasgow,	23 Apr., 1901
MUNRO, ROBERT D., Scottish Boiler Insurance Company, 111 Union street, Glasgow,	19 Dec., 1882

Murdoch, Frederick Teed, Nile House, Mansourah, Egypt,	25 Feb., 1896
Murdoch, J. A., 7 Park Circus place, Glasgow,	G. 25 Oct., 1892 M. 20 Nov., 1900
Murray, Angus, Strathroy, Dumbreck,	G. 14 May, 1878 M. 19 Nov., 1889
Murray, Henry, Shipbuilder, Port-Glasgow,	22 Dec., 1896
Murray, James, Rossbank, Port-Glasgow,	22 Dec., 1896
Murray, James, Messrs Murray MacVinnie & Co., Mavisbank quay, S.S., Glasgow,	26 Jan., 1886
Murray, Richard, 109 Hope street, Glasgow,	26 Oct., 1897
Murray, Thomas Blackwood, B.Sc., 92 Camperdown road, Scotstoun, Glasgow,	22 Dec., 1891
Murray, Thomas R., Keverstone, Cleveland walk, Bath,	25 Feb., 1896
Myles, David, Northumberland Engine works, Wallsend-on-Tyne,	G. 20 Dec., 1887 M. 19 Dec., 1899
Mylne, Alfred, 81 Hope street, Glasgow,	G. 26 Jan., 1897 M. 24 Mar., 1903
Nagao, Hanpei, c/o Taipeifu, Formosa, Japan,	24 Dec., 1901
Napier, Henry M., Shipbuilder, Yoker, near Glasgow,	25 Jan., 1881
†**Napier, Robert T.**, 75 Bothwell street, Glasgow,	20 Dec., 1881
Needham, James H., Rossbank, Port-Glasgow,	18 Mar., 1902
Neill, Hugh, Jun., 99 Clarence drive, Hyndland, Glasgow,	G. 21 Nov., 1899 M. 3 May, 1904
Neilson, James, Alma boiler works, Glasgow,	24 Mar., 1903
Nelson, Andrew S., Snowdon, Sherbrooke avenue, Pollokshields, Glasgow,	27 Oct., 1896
Nielson, John Frederick, Messrs John Brown & Co., Ltd., Clydebank,	24 Nov., 1903
Ness, George, 111 Union street, Glasgow,	23 Feb., 1897
Nicol, R. Gordon, 15 Regent Quay, Aberdeen,	20 Nov., 1900
†**Norman, John**, 65 West Regent street, Glasgow,	11 Dec., 1861
Norris, Charles G., 504 Stockport road, Manchester,	29 Oct., 1901
O'Neill, J. J., 19 Roxburgh street, Kelvinside, Glasgow,	24 Nov., 1896
Oliphant, William, 207 Bath street, Glasgow,	23 Feb., 1897
†**Ormiston, John W.**, 213 St. Vincent street, Glasgow,	28 Nov., 1860
Orr, Alexander T., Marine Department, London and North-Western Railway, Holyhead,	24 Mar., 1883
Orr, John R., Motherwell Bridge Co., Motherwell,	24 Jan., 1899
Osborne, Hugh, 31 Broomhill terrace, Partick,	G. 22 Dec., 1891 M. 27 Oct., 1903

PARKER, EDWARD HENRY, 11 Strathmore gardens, Hillhead, Glasgow,	16 Dec., 1902
PARSONS, The Hon. CHARLES ALGERNON, M.A., C.B., Holeyn Hall, Wylam-on-Tyne,	28 Apr., 1903
PATERSON, JAMES V., Red Star Line Pier 14, North River, New York,	G. 24 Jan., 1888 M. 27 Oct., 1903
PATERSON, JOHN, Edradour, Dalmuir,	22 Jan., 1901
PATERSON, W. L. C., 5 Elmwood terrace, Jordanhill, Glasgow,	21 Nov., 1883
PATON, Professor GEORGE, Royal Agricultural College, Cirencester,	22 Nov., 1887
PATRICK, ANDREW CRAWFORD, Johnstone,	25 Jan., 1898
PATTERSON, JAMES, Maryhill Iron works, Glasgow,	22 Nov., 1898
PATTERSON, JAMES, 130 Elliot street, Glasgow,	18 Dec., 1900
PATTIE, ALEXANDER W., Hong Kong & Whampoa Dock Co., Hong Kong,	22 Jan., 1895
PAUL, H. S., Levenford works, Dumbarton,	24 Jan., 1899
PAUL, JAMES, Kirkton, Dumbarton,	24 Mar., 1903
PAUL, MATTHEW, Levenford works, Dumbarton,	G. 26 Feb., 1884 M. 21 Dec., 1886
PEACOCK, JAMES, Oriental Steam Navigation Co., 13 Fenchurch avenue, London, E.C.	G. 22 Nov., 1881 M. 21 Feb., 1899
PEARSON, THOMAS, c/o Arnott, 342 Gairbraid street, Glasgow,	2 May 1905
PECK, EDWARD C., Messrs Yarrow & Company, Poplar, London,	G. 23 Dec., 1873 M. 23 Oct., 1888
PECK, JAMES J., 52 Randolph gardens, Broomhill, Glasgow,	22 Dec., 1896
PECK, NOEL E., 4 Ashgrove terrace, Partickhill road, Glasgow,	18 Dec., 1900
PENMAN, ROBERT REID, 36 Circus drive, Dennistoun, Glasgow,	25 Jan., 1898
PENMAN, WILLIAM, Springfield house, Dalmarnock, Glasgow,	25 Jan., 1898
PERITON, WILLIAM JOHN, 13[2] Drury buildings, 23 Water street, Liverpool,	25 Oct., 1904
PETROFF, ALEXANDER, 60 Thornton avenue, Streatham Hill, London, S.W.,	19 Mar., 1901
PHILIP, WILLIAM LITTLEJOHN, Sherbrooke, Box, Wilts,	24 Jan., 1899
PICKERING, JONATHAN, 50 Wellington street, Glasgow,	3 Mar., 1903
POCOCK, J. HERBERT, 39 Falkland mansions, Kelvinside, Glasgow,	29 Oct., 1901
POLLOCK, DAVID, 128 Hope street, Glasgow,	23 Feb., 1897
POLLOK, ROBERT, Messrs John Brown & Co., Clydebank,	22 Dec., 1896
POOLE, WILLIAM JOHN, 65 Renfield street, Glasgow,	20 Dec., 1898

POPE, ROBERT BAND, Leven Shipyard, Dumbarton, 25 Oct., 1887
PORTCH, ERNEST C., 37 Vicar's hill, Ladywell, London, S.E., { G. 26 Oct., 1897 / M. 25 Oct., 1904 }
PRATTEN, WILLIAM J., Mornington, Derryvolgie avenue, Belfast, 22 Dec., 1896
PRINGLE, WILLIAM S., 15 Elm place, Aberdeen, { G. 24 Oct., 1893 / M. 16 Dec., 1902 }
PURDON, ARCHIBALD, Craigie place, Port-Glasgow, 27 Apr., 1897
PURVES, J. A., D.Sc., F.R.S.E., 53 York place, Edinburgh, 25 Oct., 1898
PURVIS, Prof. F. P., College of Naval Architecture, Imperial University, Tokio, Japan, 20 Nov., 1877
PUTNAM, THOMAS, Darlington Forge Co., Darlington, 15 June, 1898
PYLE, JAMES H., 38 Elliot street, Glasgow, 23 Feb., 1897

RAEBURN, CHARLES E., 12 Vinicombe street, Hillhead, Glasgow, 24 Oct., 1899
RAINEY, FRANCIS E., c/o Mr F. Nell, 97 Queen Victoria street, London, S.E., 27 Apr., 1897
RAIT, HENRY M., 155 Fenchurch street, London, 23 Dec., 1868
RAMAGE, RICHARD, Shipbuilder, Leith, 22 Apr., 1873
RANKIN, JOHN F., Eagle foundry, Greenock, 23 Mar., 1886
RANKIN, MATTHEW, c/o Messrs Rankin & Demas, Engineers, Smyrna, { G. 2 Nov., 1880 / M. 20 Mar., 1894 }
RANKIN, ROBERT, Jun., 6 Brighton place, Govan, 22 Jan., 1901
RANKINE, DAVID, 238 West George street, Glasgow, 22 Oct., 1872
RAPHAEL, ROBERT A., 72 Minard road, Crossmyloof, Glasgow, { G. 24 Dec., 1895 / M. 27 Oct., 1903 }
REED-COOPER, T. L., 70 West Cumberland street, Glasgow, 22 Dec., 1896
REID, ANDREW T., Hydepark Locomotive works, Glasgow, { G. 21 Dec., 1886 / M. 18 Dec., 1894 }
REID, GEORGE W., Inchanga, Hillfoot, Bearsden, 21 Nov., 1883
REID, J. MILLER, 110 Lancefield street, Glasgow, 23 Mar., 1897
†REID, JAMES, Shipbuilder, Port-Glasgow, 17 Mar., 1869
REID, JAMES, 3 Cart street, Paisley, 25 Jan., 1898
†REID, JAMES B., Chapelhill, Paisley, 24 Nov., 1891
REID, JAMES G., { G. 23 Dec., 1894 / M. 21 Feb., 1899 }
†REID, JOHN, 7 Park terrace, Kelvinside, Glasgow, { G. 21 Dec., 1886 / M. 18 Dec., 1894 }
REID, JOHN, Baltic Chambers, 50 Wellington street, Glasgow, 18 Dec., 1900

Reid, John Wilson, c/o Messrs Aspinwall & Co., Cochin, Malabar Coast,	21 Jan., 1902
Reid, Robert, British India Steam Navigation Co., Ltd., Columbo, Ceylon,	2 May 1905
Reid, Robert Shaw, 79 West Regent street, Glasgow,	21 Mar., 1899
Reid, Thomas, Jun., 6 Bridge street, Abbey, Paisley,	18 Dec., 1900
Reid, W. J. H., Redlea, Linwood, Nr. Paisley,	16 Dec., 1902
Reid, William Paton, 35 Dunearn street, Glasgow, W.,	23 Feb., 1904
Rennie, Archibald, 3 Bawhirley road, Greenock,	S. 31 Oct., 1902 M. 28 Apr., 1903
Rew, James H., Ardfern, Victoria place, Airdrie,	27 Oct., 1896
Reynolds, Charles H.,	G. 23 Dec., 1873 M. 22 Nov., 1881
Richardson, Andrew, Soho Engine works, Paisley,	26 Jan., 1904
Richmond, Sir David, North British Tube works, Govan,	21 Dec., 1897
Richmond, James, Roselyn, 95 Maxwell drive, Pollokshields, Glasgow,	G. 23 Jan., 1894 M. 23 Oct., 1900
Richmond, John R., Holm foundry, Cathcart, Glasgow,	28 Jan., 1896
Riddell, W. G., c/o Messrs John Hastie & Co., Kilblain Engine Works, Greenock,	21 Feb., 1899
Riekie, John, Argaith, Dumbreck, Glasgow,	29 Oct., 1901
Risk, Robert, Halidon Villa, Cambuslang,	23 Mar., 1897
Ritchie, Duncan, 293 Onslow drive, Dennistoun, Glasgow,	16 Dec., 1902
Ritchie, George, Parkhead Forge, Glasgow,	15 June, 1898
Roberts, W. G.	29 Oct., 1901
Robertson, Alexander, Jun., c/o Messrs Matthew Reid & Co., Kilmarnock,	22 Dec., 1896
Robertson, Alexander, 8 Darnley road, Pollokshields, Glasgow,	G. 26 Oct., 1886 M. 23 Feb., 1904
Robertson, Andrew R., 8 Park Circus place, Glasgow,	G. 12 Nov., 1892 M. 23 Feb., 1897
Robertson, Prof. David, B.Sc., 16 Rokeby avenue, Redland, Bristol,	G. 19 Dec., 1899 M. 28 Apr., 1903
Robertson, David W., Dalziel Bridge works, Motherwell,	26 Nov., 1901
Robertson, Duncan, Baldroma, Ibrox, Glasgow,	24 Oct., 1876
Robertson, Robert, B.Sc., 154 West George street, Glasgow,	20 Nov., 1900
Robertson, Robert, Messrs Watson, Gow & Co., Ltd., Etna Foundry, Lilybank road, Glasgow,	18 Apr., 1905
Robin, Matthew, 58 Dumbreck road, Dumbreck, Glasgow,	G. 20 Dec., 1887 M. 25 Jan., 1898
Robinson, J. F., 17 Victoria street, Westminster, London,	24 Apr., 1888
Robinson, Robert, 54 Balshagray avenue, Partick,	3 Mar., 1903
*†Robson, Hazelton R., 14 Royal crescent, Glasgow,	Original

RODGER, ANDERSON, Glenpark, Port-Glasgow, 21 Mar., 1893

RODGER, ANDERSON, Jun., Glenpark, Port-Glasgow, G. 15 June, 1898; M. 3 May, 1904

ROGER, GEORGE WILLIAM, 4 Lloyd's avenue, Fenchurch street, London, E.C., G. 24 Nov., 1896; M. 18 Dec., 1900

ROSE, JOSEPH, "Westoe," Scotstounhill, Glasgow, 3 May, 1904

ROSENTHAL, JAMES H., Oriel House, 30 Farringdon street, London, 24 Nov., 1896

ROSS, J. MACEWAN, St. Helens, Troon, G. 28 Nov., 1882; M. 27 Oct., 1891

ROSS, JAMES R., 7 Ashfield gardens, Jordanhill, Glasgow, 24 Nov., 1896

ROSS, RICHARD G., 21 Greenhead street, Glasgow, 11 Dec., 1861

ROSS, WILLIAM, Messrs Malone, Alliott & Co., Ltd., 101 St. Vincent street, Glasgow, 18 Dec., 1900

ROWAN, FREDERICK JOHN, 5 West Regent street, Glasgow, 26 Jan., 1892

ROWAN, JAMES, 231 Elliot street, Glasgow, G. 21 Dec., 1875; M. 27 Jan., 1885

ROWLEY, THOMAS, Board of Trade Offices, Virginia street, Greenock, 18 Dec., 1888

ROY, WILLIAM, Bowden view, Melksham, Wilts, G. 25 Jan., 1898; M. 21 Apr., 1903

ROYDS, ROBERT, B.Sc., c/o Mrs Dunbar, 12 Barrington drive, Glasgow, 20 Dec., 1904

RUDD, JOHN A., 177 West George street, Glasgow, G. 24 Jan., 1888; M. 15 June, 1898

RUSSELL, ALEXANDER C., 655 Hawthorn street, Springburn, Glasgow, G. 15 Apr., 1902; M. 22 Dec., 1903

RUSSELL, FREDERICK ALEXANDER, 20 Skirving street, Shawlands, Glasgow, 25 Jan., 1888

†RUSSELL, GEORGE, Belmont, Uddingston, G. 22 Dec., 1858; M. 4 Mar., 1863

†RUSSELL, JAMES, Waverley, Uddingston, G. 24 Nov., 1891; M. 25 Jan., 1898

RUSSELL, JAMES E., c/o Cluness, 25 Woodside quadrant, W., Glasgow, G. 22 Dec., 1891; M. 27 Oct., 1903

RUSSELL, JOSEPH, Shipbuilder, Port-Glasgow, 22 Feb., 1881

RUSSELL, JOSEPH WILLIAM, 50 Charles street, St. Rollox, Glasgow, G. 6 Apr., 1887; M. 25 Jan., 1898

RUSSELL, THOMAS W., Admiralty, 21 Northumberland avenue, London, W.C., 27 Apr., 1897

SADLER, Prof. HERBERT C., D.Sc., University of Michigan, Ann Arbor, Michigan, U.S.A., G. 19 Dec., 1893; M. 23 Oct., 1900

SALMOND, HENRY, 93 Hope street, Glasgow, 18 Dec., 1900

SAMPSON, ALEXANDER W., Bonnington, 9 Beech avenue, Bellahouston, Glasgow,	22 Dec., 1896
SAMSON, PETER, Board of Trade Offices, 54 Victoria street, Westminster, London, S.W.,	24 Oct., 1876
SAMUEL, JAMES, Jun., 185 Kent road, Glasgow,	24 Feb., 1885
SANDERSON, JOHN, Lloyd's Register, Royal Exchange, Middlesbro'-on-Tees,	20 Feb., 1883
SAYERS, JAMES EDMUND, 189 St. Vincent street, Glasgow,	24 Dec., 1901
SAYERS, WILLIAM BROOKS, 189 St. Vincent street, Glasgow,	25 Oct., 1892
SCOBIE, ALEXANDER, 58 West Regent street, Glasgow,	G. 27 Oct., 1885 M. 23 Feb., 1904
†SCOBIE, JOHN, c/o Alfred Scobie, Esq., 58 West Regent street, Glasgow,	G. 25 Mar., 1878 M. 23 Oct., 1889
SCOTT, CHARLES CUNNINGHAM, Greenock Foundry, Greenock,	27 Oct., 1896
SCOTT, CHARLES WOOD, Dunarbuck, Bowling,	15 June, 1898
SCOTT, JAMES, Rock Knowe, Tayport, N.B.,	22 Dec., 1896
SCOTT, JAMES, Jun., Strathclyde, Bowling,	15 June, 1898
SCOTT, JAMES G.,	19 Mar., 1901
SCOTT, JOHN, 11 Grosvenor street, Edinburgh,	25 Jan., 1881
SEATH, WILLIAM Y., 121 St. Vincent street, Glasgow,	G. 23 Mar., 1886 M. 27 Oct., 1903
SELBY-BIGGE, D., 27 Mosley street, Newcastle-on-Tyne,	21 Feb., 1899
SHANKS, JAMES KIRKWOOD, Engineer, Beechfield, Denny,	23 Apr., 1901
SHANKS, WILLIAM, Tubal works, Barrhead,	15 June, 1898
SHARER, EDMUND, Scotstoun house, Scotstoun, Glasgow,	30 Apr., 1895
SHARP, JOHN, 28 Burnbank gardens, Glasgow,	G. 24 Oct., 1882 M. 22 Nov., 1898
SHARPE, ROBERT, Corporation Gas Works, Belfast,	22 Jan., 1901
SHEARER, Sir JOHN, 13 Crown terrace, Dowanhill, Glasgow,	23 Oct., 1900
SHEDDEN, WILLIAM, 3 Andrew's street, Paisley,	24 Oct., 1899
SHEPHERD, JOHN W., Carrickarden, Bearsden,	26 Mar., 1889
SHUTE, ARTHUR E., 12 Clydeview, Partick, Glasgow,	27 Oct., 1896
SHUTE, CHARLES W., 38 Rowallan gardens, Partick, Glasgow,	27 Oct., 1896
SHUTE, T. S., 8 Belvidere road, Sunderland,	G. 19 Dec., 1893 M. 22 Feb., 1898
SIME, JOHN, 96 Buchanan street, Glasgow,	26 Jan., 1897
†SIMPSON, ALEXANDER, 175 Hope street, Glasgow,	22 Jan., 1862
SIMPSON, ROBERT, B.Sc., 175 Hope street, Glasgow,	25 Jan., 1887
SIMPSON, WILLIAM, 15 Regent Quay, Aberdeen,	20 Nov., 1900
SINCLAIR, D. S., London road Iron works, Glasgow,	24 Dec., 1901

SINCLAIR, NISBET, 2 Gardenside avenue, Carmyle,	G. 20 Mar., 1877 M. 20 Dec., 1887
SLIGHT, GEORGE H., Jun., c/o James Slight, Esq., 131 West Regent street, Glasgow,	G. 28 Nov., 1882 M. 22 Oct., 1889
SMAIL, DAVID, c/o Messrs George Webster & Son, 19 Waterloo street, Glasgow,	22 Jan., 1901
SMALL, WILLIAM O., Douglas avenue, Carmyle,	23 Feb., 1897
SMART, LEWIS A., Birkbeck Bank Chambers, Holborn, London,	22 Mar., 1898
SMILLIE, SAMUEL, 71 Lancefield street, Glasgow,	A. 24 Jan., 1888 M. 22 Feb., 1898
SMITH, ALEXANDER, 658 Shields road, Glasgow,	G. 24 Nov., 1891 M. 29 Oct., 1901
SMITH, HERBERT GARDNER, Leewood, Helensburgh,	26 Nov., 1901
SMITH, HUGH WILSON, Netherby, N. Albert road, Pollokshields, Glasgow,	25 Jan., 1898
SMITH, JAMES, Tinley Manor, Chakas Kraal, Durban, South Africa,	23 Oct., 1888
SMITH, JAMES A., Union Bank house, Virginia place, Glasgow,	G. 18 Dec., 1894 A.M. 28 Apr, 1903 M. 27 Oct., 1903
SMITH, OSBOURNE, Possil Engine works, Glasgow,	24 Dec., 1895
SMITH, ROBERT, c/o Mrs Chisholm, 229 North street, Glasgow,	20 Mar., 1900
SMITH, ROBERT, Burnlea place, Milton of Campsie,	21 Feb., 1905
SMITH, ROBERT BRUCE,	20 Jan., 1903
SMITH, WILLIAM J., 7 Newark drive, Pollokshields, Glasgow,	24 Jan., 1899
SNEDDON, RICHARD M., 45c Whifflet street, Coatbridge,	G. 21 Nov., 1899 M. 18 Mar., 1902
SNEDDON, W. R., Shipyard, Irvine,	22 Jan., 1901
SNOWBALL, EDWARD, 10 Broomfield terrace, Springburn, Glasgow,	22 Feb., 1870
SOMERVAIL, PETER A., Dalmuir Ironworks, Dalmuir,	25 Jan., 1887
SOMERVILLE, THOMAS A., 267 University street, Montreal, Canada,	22 Feb., 1898
SOTHERN, JOHN W., 59 Bridge street, Glasgow,	29 Oct., 1901
SPALDING, WILLIAM, 9 Crown Circus road, W., Glasgow,	G. 25 Oct., 1892 M. 16 Dec., 1902
SPENCE, WILFRID L., Oakleigh, Alloa,	28 Apr., 1903
SPROUL, A., 13 Greenlaw avenue, Paisley,	19 Mar., 1901
STARK, JAMES, 13 Princes gardens, Dowanhill, Glasgow,	27 Oct., 1896
STARK, JAMES, Penang, Straits Settlement,	G. 22 Dec., 1891 M. 26 Jan., 1904
†STEPHEN, ALEXANDER E., 8 Princes terrace, Dowanhill, Glasgow,	18 Dec., 1883

†STEPHEN, FREDERICK J., Linthouse, Govan,	30 Apr., 1895
STEPHEN, J. M., 12 Campania place, Govan,	19 Mar., 1901
*†STEPHEN, JOHN, Linthouse, Govan,	
STEVEN, JAMES, Eastvale place, Kelvinhaugh, Glasgow,	23 Oct., 1900
STEVEN, JOHN, Eastvale place, Kelvinhaugh, Glasgow,	26 Oct., 1897
STEVEN, JOHN A., 12 Royal crescent, Glasgow,	G. 22 Nov., 1881 M. 3 May, 1904
STEVEN, JOHN WILSON, 8 Clarence Drive, Hyndland, Glasgow,	20 Dec., 1898
STEVEN, WILLIAM, 37 Cranworth street, Hillhead, Glasgow,	23 Jan., 1894
STEVENS, JOHN, Marsden, Renfrew,	23 Mar., 1897
STEVENSON, WILLIAM F., 49 Park drive, South, Whiteinch, Glasgow,	18 Dec., 1900
STEWART, ALEXANDER W., 55 West Regent street, Glasgow,	23 Jan., 1894
†STEWART, JAMES, Harbour Engine works, 60 Portman street, Glasgow,	25 Mar., 1890
STEWART, JAMES, Messrs L. Sterne & Co., 155 North Woodside road, Glasgow,	25 Oct., 1898
STEWART, JAMES, Dunolly, Holmfauldhead drive, South Govan,	23 Feb., 1904
STEWART, JAMES C., 54 George square, Glasgow,	24 Dec., 1901
STEWART, JOHN GRAHAM, B.Sc., Ault Wharrie, Dunblane,	22 Mar., 1892
STEWART, W. MAXWELL, 55 W. Regent street, Glasgow,	21 Nov., 1899
STRACHAN, ROBERT, 55 Clifford street, Ibrox, Govan,	22 Nov., 1898
STRATHERN, ALEXANDER G., Hillside, Stepps, N.B.,	25 Apr., 1899
STUART, JAMES, 94 Hope street, Glasgow,	22 Oct., 1889
STUART, JAMES TAIT, 2 Bowmont terrace, Kelvinside, Glasgow,	18 Dec., 1900
SURTEES, FRANCIS VERE, Messrs Lobnitz & Co., Ltd., Renfrew,	19 Feb., 1901
SUTHERLAND, SINCLAIR, North British Tube works, Govan,	21 Dec., 1897
SYME, JAMES, 8 Glenavon terrace, Partick,	23 Jan., 1877

TANNETT, JOHN CROYSDALE, Vulcan works, Paisley,	25 Jan., 1898
TATHAM, STANLEY, Montana, Burton road, Branksome park, Bournemouth, W.,	G. 21 Dec., 1880 M. 15 June, 1898
TAVERNER, H. LACY, 12 Mosley street, Newcastle-on-Tyne,	22 Dec., 1896
TAYLOR, BENSON, 21 Thornwood avenue, Partick,	20 Nov., 1900
TAYLOR, JAMES, 3 Westminster terrace, Ibrox, Glasgow,	16 Dec., 1902

TAYLOR, PETER, Selby Shipbuilding and Engineering Co., Ltd., Ousegate, Selby,	28 Apr., 1885
TAYLOR, ROBERT, 28 Ardgowan street, Greenock,	27 Oct., 1896
TAYLOR, STAVELEY, Messrs Russell & Company, Port-Glasgow,	25 Mar., 1879
TAYLOR, THOMAS, c/o Messrs Smith, Bell & Co., Manila, Phillipine Islands,	29 Oct., 1901
TERANO, Prof. SEIICHI, College of Engineering, Imperial University, Tōkyō, Japan,	21 Feb., 1899
THISTLETHWAITE, JOHN DICKINSON, Mechanical Engineer, Harbours and Rivers Department, Brisbane, Queensland,	28 Apr., 1903
THODE, GEORGE W., Brandes Strasse, 9, Rostock, I.M., Germany,	27 Jan., 1885
THOM, JOHN, 8 Park Avenue, Glasgow,	26 Feb., 1889
THOMPSON, W. B., Ellengowan, Dundee,	14 May, 1878
THOMSON, Prof. ARTHUR W., D.Sc., College of Science, Poona, India,	26 Apr., 1887
THOMSON, G. CALDWELL, c/o Messrs Thomas Firth & Sons, Lalamander Steel Works, Riga, Russia,	24 Oct., 1893
THOMSON, GEORGE, 14 Caird drive, Partickhill, Glasgow,	18 Dec., 1883
THOMSON, GEORGE 11 Randolph place, Edinburgh,	G. 23 Nov., 1880 M. 20 Nov., 1894
THOMSON, GEORGE, C., 53 Bedford road, Rockferry, nr. Birkenhead,	G. 24 Feb., 1874 M. 22 Oct., 1889
THOMSON, JAMES, Hayfield, Motherwell,	G. 20 Nov., 1894 M. 20 Nov., 1900
THOMSON, JOHN, 3 Crown terrace, Dowanhill, Glasgow,	20 May, 1868
THOMSON, JOHN, 15 Broomhill terrace, Partick, W.	26 Nov., 1901
THOMSON, R. H. B., Govan Shipbuilding yard, Govan,	26 Feb., 1895
THOMSON, ROBERT, Messrs Barr, Thomson & Co., Ltd., Kilmarnock,	25 Jan., 1898
THOMSON, WILLIAM, 20 Huntly gardens, Kelvinside, Glasgow,	G. 23 Dec., 1884 M. 27 Oct., 1896
THOMSON, WILLIAM, Royal Institution Laboratory, Manchester,	17 Feb., 1908
TIDD, E. GEORGE, 68 Gordon street, Glasgow,	22 Oct., 1895
TOD, PETER, c/o Messrs E. H. Williamson & Co., Engineers, Lightbody street, Liverpool,	G. 27 Oct., 1885 M. 27 Oct., 1903
TODD, DAVID R., 39-40 Arcade Chambers, St. Mary's Gate and Dean's Gate, Manchester,	G. 25 Jan., 1887 M. 25 Oct., 1892
TORRIE, JAMES, Stewarton,	18 Mar., 1902
TULLIS, DAVID K., Kilbowie Iron works, Kilbowie,	23 Nov., 1897
TULLIS, JAMES, Kilbowie Iron works, Kilbowie,	23 Nov., 1897
TURNBULL, ALEXANDER, St. Mungo's works, Bishopbriggs, Glasgow,	21 Nov., 1876

TURNBULL, ALEXANDER POTT, 65 West Regent street, Glasgow,	25 Jan., 1898
TURNBULL, CAMPBELL, 190 West George street, Glasgow,	G. 27 Oct., 1891 M. 27 Oct., 1903
TURNBULL, JAMES, Basford house, Seymour grove, Manchester,	G. 22 Mar., 1892 M. 27 Oct., 1903
TURNBULL, W. L., 190 West George street, Glasgow,	G. 27 Oct., 1891 M. 27 Oct., 1903
TURNER, THOMAS, Caledonia works, Kilmarnock,	22 Jan., 1901
WADDELL, JAMES, 15 Moray place, Glasgow,	23 Mar., 1897
WALKER, ARCHIBALD, Netherby, Walm Lane, Cricklewood, London, N.W.,	26 Nov., 1901
WALKER, JOHN, Hillside, Newlands road, Newlands,	G. 20 Nov., 1894 M. 19 Dec., 1899
WALLACE, DUNCAN M., 65 Union street, Greenock,	27 Oct., 1896
WALLACE, JAMES LOCH, 15 Clifford street, Glasgow, S.S.,	18 Feb., 1902
WALLACE, JOHN, Jun., Kidbrooke, Hanover street, Helensburgh,	G. 26 Jan., 1892 M. 22 Jan., 1901
WALLACE, PETER, Ailsa Shipbuilding Co., Troon,	23 Jan., 1883
WALLACE, W. CARLILE, Messrs John Brown & Co., Ltd., 22 Thames street, New York, U.S.A.,	24 Mar., 1885
WANNOP, CHARLES H., Messrs A. Stephen & Son, Linthouse, Glasgow,	G. 24 Feb., 1885 M. 22 Mar., 1904
WARD, J. C. A., 121 North Side, Clapham Common, London, S.W.,	22 Nov., 1898
WARD, JOHN, Leven Shipyard, Dumbarton,	26 Jan., 1886
WARDE, HENRY W., 69a Waterloo street, Glasgow,	15 June, 1898
WARDEN, WILLOUGHBY C., 68 Gordon street, Glasgow,	24 Mar., 1896
WARNOCK, WILLIAM FINDLAY, 274 Bath street, Glasgow,	21 Jan., 1902
WATKINSON, Prof. W. H., 15 Croxteth road, Liverpool,	19 Dec., 1893
WATSON, JAMES W., 6 Kirklee road, Kelvinside, Glasgow,	17 Feb., 1903
WATSON, JOHN, 9 Woodside crescent, Glasgow, W.,	G. 22 Nov., 1898 M. 25 Oct., 1904
WATSON, ROBERT, 10 East Nelson street, Glasgow,	G. 22 Mar., 1881 M. 29 Oct., 1901
WATSON, WILLIAM, Clyde Shipping Company, Greenock,	24 Nov., 1896
WATT, ALEXANDER, Inchcape, Paisley,	25 Jan., 1898
WATT, ROBERT D., Messrs Scott's Shipbuilding and Engineering Co., Greenock,	G. 27 Apr., 1880 M. 27 Oct., 1903
WEBB, R. G., Messrs Richardson & Cruddas, Byculla, Bombay,	G. 21 Dec., 1875 M. 26 Oct., 1886

WEBSTER, JAMES, North British Locomotive Co., Ltd., Atlas works, Springburn, Glasgow,	21 Mar., 1899
WEDDELL, ALEXANDER H., B.Sc., Park villa, Uddingston,	G. 22 Dec., 1896 M. 16 Dec., 1902
WEDDELL, JAMES, Park villa, Uddingston,	22 Dec., 1896
WEDGWOOD, A., Dennystown Forge, Dumbarton,	18 Dec., 1900
WEDGWOOD, ARTHUR D., Forgemaster, Dumbarton,	26 Jan., 1897
WEIGHTON, Prof. R. L., M.A., 2 Park villas, Gosforth, Newcastle-on-Tyne,	G. 17 Dec., 1878 M. 22 Nov., 1887
†WEIR, GEORGE, Yass, near Sydney, New South Wales,	22 Dec., 1874
†WEIR, JAMES, Holmwood, 72 St. Andrew's drive, Pollokshields, Glasgow,	22 Dec., 1874
WEIR, JOHN, 46 Lawrence street, Partick,	G. 22 Apr., 1884 M. 26 Nov., 1895
†WEIR, THOMAS, China Merchants' Steam Navigation Co., Marine Superintendent's Office, Shanghai, China,	23 Apr., 1889
WEIR, THOMAS D., Messrs Brown, Mair, Gemmill & Hyslop, 162 St. Vincent street, Glasgow,	G. 19 Dec., 1876 M. 26 Feb., 1884
WEIR, WILLIAM, Holm foundry, Cathcart, Glasgow,	G. 28 Jan., 1896 M. 22 Nov., 1898
WEIR, WILLIAM, 231 Elliot street, Glasgow,	22 Jan., 1901
WELCH, ARCHIBALD, Clune bank, Port-Glasgow,	21 Feb., 1905
WELSH, JAMES, 3 Princes gardens, Dowanhill, Glasgow,	G. 24 Nov., 1885 M. 26 Oct., 1897
WELSH, THOMAS M., 3 Princes gardens, Dowanhill, Glasgow,	17 Feb., 1869
WEMYSS, GEORGE B., 57 Elliot street, Hillhead, Glasgow,	G. 28 Nov., 1882 M. 22 Jan., 1901
WEST, HENRY H., 5 Castle street, Liverpool,	23 Dec., 1886
WHITE, RICHARD S., Shirley, Jesmond, Newcastle-on-Tyne,	20 Feb., 1883
WHITEHEAD, ALEXANDER CULLEN, c/o Messrs Whitehead Bros., Engineers, P.O., Box 2786, Johannesburg, S.A.,	27 Oct., 1903
WHITEHEAD, JAMES, Howford, Mansewood, Pollokshaws, Glasgow,	6 Apr., 1887
WILKINS, WILLIAM OWEN, 175 West George street, Glasgow,	2 May 1905
WILLCOX, REGINALD, J. N., Messrs Fleming & Ferguson, Ltd., Paisley,	28 Apr., 1903
WILLIAMS, LLEWELLYN WYNN, B.Sc., Cathcart, Glasgow,	22 Feb., 1898
WILLIAMS, OWEN R., B.Sc., Railway Appliance works, Cathcart, Glasgow,	20 Nov., 1900
WILLIAMS, WILLIAM,	23 Jan., 1900
WILLIAMSON, ALEXANDER, 67 Esplanade, Greenock,	21 Mar., 1899
WILLIAMSON, Sir JAMES, C.B., Admiralty, Whitehall, London, S.W.,	23 Dec., 1884

WILLIAMSON, JAMES, Marine Superintendent, Gourock,	24 Mar., 1896
WILLIAMSON, ROBERT, Ormidale, Malpas, near Newport, Mon.,	20 Feb., 1883
WILSON, ALEXANDER, City Chambers, Glasgow,	28 Jan., 1896
WILSON, ALEXANDER, Hyde Park Foundry, Finnieston street, Glasgow,	23 Feb., 1897
WILSON, ALEXANDER HALL, B.Sc., Messrs Hall, Russell, & Co., Aberdeen,	23 Oct., 1900
WILSON, DAVID, Arecibo, Porto Rico, West Indies,	25 Oct., 1887
WILSON, GAVIN, Clyde Navigation Chambers, 16 Robertson street, Glasgow,	22 Oct., 1889
WILSON, JOHN, 101 Leadenhall street, London, E.C.,	24 Dec., 1895
WILSON, JOHN, 256 Scotland street, Glasgow,	22 Dec., 1903
WILSON, SAMUEL, 2 Whitehill gardens, Dennistoun, Glasgow,	3 Mar., 1903
WILSON, W. H., 261 Albert road, Pollokshields, Glasgow,	22 Feb., 1898
WILSON, WILLIAM CHEETHAM, 122 Balgray hill, Springbuin, Glasgow,	24 Nov., 1903
WILSON, WILLIAM J., Lilybank Boiler works, Glasgow,	30 Apr., 1895
WOOD, ROBERT C., c/o Messrs A. Rodger & Co., Shipbuilders, Port Glasgow,	23 Mar., 1897
WRENCH, WILLIAM G., 27 Oswald street, Glasgow,	25 Mar., 1890
WRIGHT, ROBERT, 1 Carment drive, Shawlands, Glasgow,	22 Dec., 1896
WYLIE, ALEXANDER, Kirkfield, Johnstone,	26 Oct., 1897
WYLLIE, JAMES BROWN, Messrs Wyllie & Blake, 219 St. Vincent street, Glasgow,	G. 25 Oct., 1887 M. 26 Jan., 1897

YARDLEY, ROBERT WILLIAM, Heysham Tower, Heysham, near Morecombe,	22 Mar., 1904
YOUNG, DAVID HILL, 30 Melville street, Pollokshields, Glasgow,	G. 20 Nov., 1900 M. 15 Apr., 1902
YOUNG, THOMAS, Rowington, Whittingehame drive, Kelvinside, Glasgow,	20 Mar., 1894
YOUNG, WILLIAM ANDREW, Millburn House, Renfrew,	26 Mar., 1895
YOUNGER, A. SCOTT, B.Sc, 141 Fenchurch street, London, E.C.	24 Nov., 1896

ASSOCIATE MEMBERS.

Name and address	Grade	Date
Adam, John William, Ferguslie villa, Paisley,		28 Apr., 1903
Agnew, William H., Messrs Cammell, Laird & Co., Birkenhead,	G. A.M.	28 Nov., 1882 27 Oct., 1903
Ainslie, James William, 377 Bath street, Glasgow,	G. A.M.	26 Nov., 1901 28 Apr., 1903
Allan, James, 326 West Princes street, Glasgow,	G. A.M.	24 Jan., 1888 2 May, 1905
Anderson, David, B.Sc., c/o Mrs Scotland, 9 Sutherland street, Hillhead, Glasgow,		20 Dec., 1904
Anderson, James, c/o Masson, 26 Merryland street, Govan,	A. A.M.	24 Apr., 1900 17 Feb., 1903
Anderson, Thomas, c/o M'Queen, 7 Grantly street, Shawlands, Glasgow,	G. A.M.	29 Oct., 1901 28 Apr., 1903
Arbuthnott, Donald S., c/o Messrs Charles Brand & Son, 65 Renfield street, Glasgow,	G. A.M.	23 Oct., 1888 27 Oct., 1903
Ardill, William, 17 Chatham grove, Withington, Manchester,		17 Feb., 1903
Arundel, Arthur S. D., Penn street works, Hoxton, London, N.,	G. A.M.	23 Dec., 1890 27 Oct., 1903
Atchley, Charles Atherton, 50 Wellington street, Glasgow,		24 Jan., 1905
Barbour, James Clinkskill, 14 Holyrood crescent, Glasgow,		24 Jan., 1905
Bennett, Duncan, 9 Leslie street, Pollokshields, Glasgow,	G. A.M.	26 Oct., 1897 27 Oct., 1903
Berry, Davidson, 21 Grange terrace, Langside, Glasgow,	G. A.M.	19 Mar., 1901 27 Oct., 1903
Blair, Archibald, 25 Peel street, Partick,	G. A.M.	27 Oct., 1891 3 May, 1904
Boyd, James, 20 Albert drive, Crosshill, Glasgow,		22 Mar., 1904
Brown, William, 22 Leven street, Pollokshields, Glasgow,	G. A.M.	26 Nov., 1901 21 Apr., 1903
Buchanan, Walter G., 17 Sandyford place, Glasgow,	G. A.M.	27 Jan., 1891 28 Apr., 1900
Buckle, Joseph, 31 Ferry road, Renfrew,	S. A.M.	31 Oct., 1902 28 Ap., 1903
Butler, James S., 21 Hamilton terrace, W., Partick,	G. A.M.	22 June, 1901 3 May, 1904

CAMERON, ANGUS J., c/o Granger, 5 Osborne place, Copland road, Govan,	G. 20 Nov., 1900 A.M. 2 May, 1905
CLEGHORN, GEORGE, 2 Clelland place, Ibrox, Govan,	27 Oct., 1903
COCHRAN, ALEXANDER, Messrs Burns & Co., Ltd., Howrah, Calcutta,	3 Mar., 1903
COLEMAN, HENRY CHARLES, Isaac Peral 25, Cadiz, Spain,	3 May, 1904
COOK, ROBERT TEMPLETON, 2 Wyndham park, Ardbeg, Rothesay, N.B.,	25 Oct., 1904
CRAIG, JAMES, B.Sc., Netherlea, Partick,	G. 22 Feb., 1889 A.M. 28 Apr., 1903
DEKKE, K. S., Bergen, Norway,	G. 22 Dec., 1891 A.M. 27 Oct., 1903
DIACK, JAMES A., 4 Rosemount terrace, Ibrox, Glasgow,	G. 22 Jan., 1895 A.M. 27 Oct., 1903
DICKIE, JAMES BLACK, B.Sc., Sorrento, Terregles avenue, Pollokshields,	20 Dec., 1904
DRYSDALE, HUGH R. S., 24 Kilmailing terrace, Cathcart, Glasgow,	17 Feb., 1903
DUNLOP, ALEXANDER, 14 Derby terrace, Sandyford, Glasgow,	G. 21 Dec., 1897 A.M. 28 Apr., 1903
EDMISTON, ALEXANDER A., Ibrox house, Govan,	G. 22 Feb., 1898 A.M. 27 Oct., 1903
FALLON, ALFRED H., Bellview, off Craigton road, Govan,	17 Feb., 1903
FAUT, ALEXANDER, 3 Holland place, Glasgow,	G. 19 Dec., 1899 A.M. 21 Apr., 1903
FERGUS, ALEXANDER, 7 Ibrox place, Ibrox, Glasgow,	G. 22 Dec., 1891 A.M. 3 May, 1904
FERGUSON, DANIEL, 27 Oswald street, Glasgow,	27 Oct., 1903
FERNIE, JOHN, 6 Edelweiss terrace, Partickhill, Glasgow,	S. 31 Oct., 1902 A.M. 28 Apr., 1903
FINDLATER, JAMES, 124 Pollok street, Glasgow, S.S.,	G. 19 Dec., 1899 A.M. 23 Feb., 1904
FINDLAY, EDWYN ALFRED, 5 Cranworth street, Hillhead, Glasgow,	25 Oct., 1904
FLETCHER, WILLIAM DAWSON, 11-15 East Vermont street, Kinning Park, Glasgow,	23 May, 1905
FRANCE, JAMES, 8 Hanover terrace, Kelvinside, Glasgow,	G. 26 Oct., 1897 A.M. 27 Oct., 1903
FROST, EVELYN F. M., 76 Hill street, Garnethill, Glasgow,	S. 31 Oct., 1902 A.M. 28 Apr., 1903

GALLACHER, PATRICK, 72 Fulbar street, Renfrew, 21 Apr., 1903

GILCHRIST, JAMES, B.Sc., Caledonian Railway Company, Buchanan street, Glasgow, 26 Apr., 1904

GILMOUR, ANDREW, 3 Allanshaw street, Hamilton, West, {G. 20 Dec., 1898 / A.M. 2 May, 1905}

HAY, JAMES, Devon bank, High Crosshill, Rutherglen, 20 Dec., 1604

HORN, PETER ALLAN, 29 Regent Moray street, Glasgow, {G. 26 Oct., 1897 / A.M. 27 Oct., 1903}

HOWIE, WILLIAM, 10 Camperdown road, Scotstoun, Glasgow, {G. 23 Apr., 1901 / A.M. 28 Apr., 1903}

HUTCHEON, ALEXANDER, 5 Belmont street, Hillhead, Glasgow, 20 Dec,, 1904

HUTCHISON, ROBERT, c/o Messrs Burns & Co., Engineers, Howrah, Calcutta, {G. 24 Oct., 1899 / A.M. 27 Oct., 1903}

IRVINE, ARCHIBALD B. 8 Newton terrace, Glasgow, {G. 20 Nov., 1894 / A.M. 27 Oct., 1903}

JOHNSON, HERBERT AUGUST, 41 James street, Holderness road, Hull, 22 Mar., 1904

JOHNSTONE, ALEXANDER C., 307 Ruchill street, Ruchill, Glasgow, {G. 25 Jan., 1898 / A.M. 27 Oct., 1903}

JOHNSTONE, JOHN GAVIN, B.Sc., 11 Maxwell terrace, Pollokshields, Glasgow, 22 Dec., 1903

JOHNSTONE, ROBERT, c/o Mrs M'Vicar, 28 Wood street, Partick, {G. 26 Apr., 1898 / A.M. 27 Oct., 1903}

JONES, T. C., 17 Kent Avenue, Jordanhill, Glasgow, {G. 23 Nov., 1897 / A.M. 27 Oct., 1903}

KIRK, JOHN, Killearn Lodge, Helensburgh, {G. 20 Nov., 1894 / A.M. 28 Apr., 1903}

KNOX, ALEXANDER, 10 Westbank terrace, Hillhead, Glasgow, {G. 23 Nov., 1897 / A.M. 22 Dec., 1903}

LAMB, STUART D. R., Contractor's Office, Camden house, Southwick, Sunderland, {G. 23 Jan., 1900 / A.M. 23 Feb., 1904}

LEARMONTH, ROBERT, c/o H. Drysdale, 590 Dalmarnock road, Glasgow, {G. 26 Nov., 1901 / A.M. 21 Apr., 1903}

LE CLAIR, LOUIS J., 115 Donore terrace, South Circular road, Dublin, {G. 24 Nov., 1896 / A.M. 21 Apr., 1903}

LEE, JOHN, 10 Bisham gardens, Highgate, London, N.,	G. A.M.	26 Jan., 1886 21 Apr., 1903
LEWIS, THOMAS, 37 Crow road, Partick,		2 May, 1905
LITTLE, SIMON MURE, 32 Sutherland ter., Glasgow, W.,		24 Jan., 1905
LOUDON, JAMES MAY, 22 Clarendon street, Glasgow,	A. A.M.	21 Jan., 1902 2 May 1905
LOWE, JAMES, c/o Manson, 10 Corunna street, Glasgow,	G. A.M.	24 Oct., 1899 23 Feb., 1904
LYNN, ROBERT R., 7 Highburgh terrace, Dowanhill, Glasgow,		20 Jan., 1903
LYONS, LEWIS JAMES, 119, 33rd street, Newport-News, Virginia, U.S.A.		23 Feb., 1904
MCCULLOCH, JOHN, 49 Arlington street, Glasgow,	G. A.M.	23 Oct., 1900 3 May, 1904
MCEWAN, JOHN, 3 Norse road, Scotstoun, Glasgow,	G. A.M.	26 Oct., 1887 28 Apr., 1903
MCGILVRAY, JOHN A., 555 Govan road, Govan,	G. A.M.	26 Oct., 1897 27 Oct., 1903
MCINTYRE, JAMES N., 33 Hayburn crescent, Partick,	G. A.M.	20 Nov., 1900 27 Oct., 1903
MCIVOR, JOHN, Moss cottage, Nitshill, Glasgow,		3 Mar., 1903
M'KENZIE, WILLIAM JOHN, 5 Westbourne drive, Ibrox, Glasgow,		21 Feb., 1905
MACKIE, JAMES, 344 St. Vincent street, Glasgow,	G. A.M.	23 Mar., 1897 28 Apr., 1903
MACKINTOSH, R. D., P.O. Box 6075, Johannesburg, South Africa,	G. A.M.	20 Nov., 1898 27 Oct., 1904
MANNERS, EDWIN, 50 McCulloch street, Pollokshields, Glasgow,		17 Feb., 1903
MARTIN, JAMES, 7 Woodend drive, Jordanhill, Glasgow,		20 Dec., 1905
MEEK, WILLIAM M'CARTER, 21 Thornwood avenue, Partick,		25 Oct., 1904
MELENCOVICH, ALEXANDRE, 21 Peel street, Partick,	S. A.M.	31 Oct., 1902 22 Nov., 1904
MENZIES, GEORGE, 20 St. Vincent crescent, Glasgow,	G. A.M.	22 Jan., 1889 24 Nov., 1903
MILLAR, JOHN SIMPSON, 22 Rothesay gardens, Partick	G. A.M.	20 Nov., 1894 22 Dec., 1903
MILLAR, WILLIAM PETTIGREW, 4 Parkview gardens, Tollcross, Glasgow,	G. A.M.	18 Dec., 1900 17 Feb. 1903
MILLER, JAMES W., 84 Portland place, London, W.,	G. A.M.	20 Dec., 1898 2 May, 1905
MITCHELL, ALEXANDER ROBERTSON, Kilbowie cottages, Kilbowie hill, Clydebank,		24 Nov., 1903
MITCHELL, R. M., 24 Howard street, Bridgeton, Glasgow,	G. A.M.	23 Nov., 1897 22 Dec., 1903

MORGAN, ANDREW, 69 Devonshire street, Higher Broughton, Manchester,	G. / A.M.	18 Dec., 1900 / 22 Dec., 1903
MORRISON, A., Alt-na-craig, Greenock,	G. / A.M.	23 Nov., 1897 / 3 May, 1904
MUIR, ANDREW A., 189 Renfrew street, Glasgow,	G. / A.M.	22 Nov., 1898 / 23 Feb., 1904
NORMAN, MYLES GARNET, Karonga, Bracken Brae road, Bishopriggs,		18 Apr., 1905
NOWERY, W. F., c/o Jack, 71 Grant street, Glasgow,	G. / A.M.	21 Dec., 1897 / 28 Apr., 1903
POLLOCK, GILBERT F., 10 Beechwood drive, Tollcross, Glasgow,	G. / A.M.	27 Jan., 1891 / 2 May, 1905
RALSTON, SHIRLEY BROOKS, 34 Gray street, Glasgow,	G. / A.M.	23 Feb., 1897 / 23 Feb., 1904
RIDDLESWORTH, W. HENRY, M.Sc., 63 Polworth gardens, Partickhill, Glasgow,	G. / A.M.	24 Oct., 1899 / 28 Apr., 1903
ROBERTSON, ALFRED, J. C., c/o A. W. Robinson, 14 Phillips square, Montreal, Canada,		16 Dec., 1902
ROBERTSON, JOHN, Jun., 7 Maxwell terrace, Shields road, Pollokshields, Glasgow,		20 Jan., 1903
ROSS, JOHN RICHMOND, Messrs Balfour, Lyon & Co., Valparaiso,	G. / A.M.	25 Oct., 1898 / 26 Jan., 1904
ROSS, THOMAS C., 13 Hampden terrace, Mount Florida, Glasgow,	S. / A.M.	21 Apr., 1903 / 2 May, 1905
RUSSELL, JOHN, Orchard street, Motherwell,		21 Feb., 1905
SANGUINETTI, W. ROGER, Public Works Department, Selangor, Malay States,	G. / A.M.	20 Feb., 1900 / 2 May, 1905
SAUL, GEORGE, Yloilo Engineering works, Yloilo, Phillipine Islands,		21 Apr., 1903
SHEARER, JAMES, 30 McCulloch street, Pollokshields, Glasgow,		3 Mar., 1903
SLOAN, JOHN ALEXANDER, 37 Annette street, Crosshill, Glasgow,	G. / A.M.	25 Jan., 1898 / 25 Oct., 1904
SMITH, JAMES, 4 Clydeview, Partick, Glasgow,	G. / A.M.	18 Dec., 1900 / 28 Apr., 1903
SMITH, JAMES, 23 Barrington drive, Glasgow,	G. / A.M.	20 Dec., 1892 / 27 Oct., 1903
SPEAKMAN, EDWARD M., Obelisk cottage, Knutsford,		16 Dec., 1902

SPERRY, AUSTIN, 2353 Larkin street, San Francisco, Cal., U.S.A.,	G. A.M.	23 Mar., 1897 22 Mar., 1904
STEELE, DAVID J., Davaar, 41 Albert drive, Pollokshields, Glasgow,	G. A.M.	20 Dec., 1898 27 Oct., 1903
STEPHEN, DAVID BELFORD, 19 Aitken street, Alexandra Park, Glasgow,		24 Nov., 1903
STEVENS, THOMAS, 55 Ferry road, Renfrew,		21 Apr., 1903
STEVENSON, GEORGE, Hawkhead, Paisley,	G. A.M.	22 Nov., 1898 24 Mar., 1903
STEVENSON, GEORGE, Wellpark, Larbert,	G. A.M.	24 Apr., 1900 25 Oct., 1904
STIRLING, ANDREW, 3 Greenvale terrace, Dumbarton,	G. A.M.	21 Dec., 1875 22 Dec., 1903
STIRLING, WILLIAM, 236 Dumbarton road, Glasgow,		25 Oct., 1904
STOBIE, PETER, 33 Kelvinhaugh street, Glasgow,	S. A.M.	31 Oct., 1902 28 Apr., 1903
SYMINGTON, JAMES R., Messrs Butterfield & Swire, Hong Kong, China,	G. A.M.	21 Dec., 1886 26 Jan., 1904
TAYLOR,' J. F., 23 Roslea drive, Dennistoun, Glasgow,	G. A.M.	23 Nov., 1897 27 Oct., 1903
TOSTEE, EVENOR, (Fils) Forges et Fonderie de Providence, Flacq, Mauritius,		26 Jan., 1904
URE, SEBASTIAN, G. M., 514 St. Vincent street, Glasgow,		22 Dec., 1903
UTTING, SAMUEL, 65 Warwick road, London, S.W.		22 Dec., 1903
WELSH, GEORGE MUIR, 3 Princes gardens, Dowanhill, Glasgow,	G. A.M.	21 Dec., 1897 28 Apr., 1903
WHITELAW, ANDREW H., B.Sc., 74 Dundonald road, Kilmarnock,	G. A.M.	20 Nov., 1900 27 Oct., 1903
WILLIAMSON, ALEX., B.Sc., Craigbarnet, Greenock,	G. A.M.	20 Nov., 1900 20 Dec., 1904
WILSON, CHARLES A., 36 Bank street, Hillhead, Glasgow,		22 Mar., 1904
WOODS, JOSEPH, 87 Grosvenor Road, Ilford, Essex,	G. A.M.	25 Feb., 1896 27 Oct., 1903
WOODSIDE, HUGH R., Artnox, Dalry, Ayrshire,		16 Dec., 1902
YOUNG, JOHN, Jun., c/o Messrs Wallsend Slipway and Engineering Co., Ltd., Wallsend-on-Tyne,	G. A.M.	23 Nov., 1897 2 May, 1905

ASSOCIATES.

ADDIE, FRANK R., 8 Westbourne gardens, Kelvinside, Glasgow,	18 Dec., 1900
*AITKEN, THOMAS, 8 Commercial street, Leith,	
ALLAN, HENRY, 25 Bothwell street, Glasgow,	23 Jan., 1900
†ALLAN, JAMES A., 25 Bothwell street, Glasgow,	29 Oct., 1901
ARMOUR, WILLIAM NICOL, 40 West Nile street, Glasgow,	24 Nov., 1896
BAIN, W. B., 65 Waterloo street, Glasgow,	22 Jan., 1901
BARCLAY, THOMAS KINLOCH, 55 Lochleven road, Langside, Glasgow,	20 Mar., 1900
BEGG, WILLIAM, 34 Belmont gardens, Glasgow,	19 Dec., 1886
BLAIR, HERBERT J., 80 Gordon street, Glasgow,	23 Feb., 1897
BOWLES, GEOFFREY TATTON, Lieutenant, R.N., 25 Lowndes square, London, S.W.,	25 Oct., 1904
BOWMAN, FREDERICK GEORGE, 21 Kersland terrace, Hillhead, Glasgow,	22 Mar., 1904
BRECKNELL, GEORGE W., 79 West Regent street, Glasgow,	21 Feb., 1905
BROWN, Capt. A. R., 34 West George street, Glasgow,	21 Dec., 1897
BROWN, THOMAS J., 233 St. Vincent street, Glasgow,	29 Oct., 1901
BUCHANAN, JAMES, Dalziel Bridge works, Motherwell,	26 Nov., 1901
BURNS, Hon. JAMES C., 30 Jamaica street, Glasgow,	23 Oct., 1900
CAYZER, Sir CHARLES W., Bart., M.P., Gartmore, Perthshire,	27 Oct., 1903
CHRISTIE, WILLIAM, 4 Westminster gardens, Hillhead, Glasgow,	18 Apr., 1905
CLARK, ROBERT, 21 Bothwell street, Glasgow,	23 Feb., 1904
CLAUSSEN, A. L., 118 Broomielaw, Glasgow,	22 Jan., 1892
CLYDE, WALTER P., c/o Messrs Dobbie, M'Innes, Ltd., 45 Bothwell street, Glasgow,	24 Oct., 1899
CRAIGIE, JOHN, 113 South Cromwell road, Queen's park, Glasgow,	25 Oct., 1904

Names marked thus * were Associates of Scottish Shipbuilders' Association at incorporation with Institution, 1865.

Names marked thus † are Life Associates.

DAWSON, DAVID C., 12 York street, Glasgow,	27 Oct., 1903
DEWAR, JAMES, 11 Regent Moray street, Glasgow,	22 Dec., 1897
DODDRELL, EDWARD E., 11 Bothwell street, Glasgow,	26 Oct., 1897
DONALD, JAMES, 123 Hope street, Glasgow,	19 Dec., 1899
FARNELL, JOHN A., 11 Charing Cross mansions, Glasgow,	21 Feb., 1905
FERGUSON, PETER, 19 Exchange square, Glasgow,	27 Apr., 1897
FORREST, WILLIAM, 114 Dixon avenue, Glasgow,	19 Feb., 1901
GALLOWAY, JAMES, Jun., Whitefield works, Govan,	27 Oct., 1891
GARDINER, FREDERICK CROMBIE, 24 St. Vincent place, Glasgow,	20 Feb., 1900
GARDINER, WILLIAM GUTHRIE, 24 St. Vincent place, Glasgow,	20 Feb., 1900
GOVAN, WILLIAM, Belhaven, Milngavie,	21 Feb., 1905
GRAHAM, The Most Honourable The Marquis of, Buchanan Castle, Glasgow,	22 Mar., 1904
HAMILTON, DAVID JOHN, 9 Princes gardens, Glasgow, W.,	2 May, 1905
HENDERSON, JOHN B., Messrs John Brown & Co., Ltd., Clydebank,	22 Mar., 1904
HOLLIS, JOHN, c/o Messrs John Brown & Co., Ltd., 144 St. Vincent street, Glasgow,	23 Nov., 1897
HOPE, ANDREW, 50 Wellington street, Glasgow,	27 Oct., 1903
INVERCLYDE, The Right Honourable Lord, Castle Wemyss, Wemyss Bay,	22 Mar., 1904
KINGHORN, WILLIAM A., 81 St. Vincent street, Glasgow,	24 Oct., 1882
KIRSOP, JAMES NIXON, 79 St. George's place, Glasgow,	29 Oct., 1901
KYLE, JOHN, Cathay, Forres, N.B.,	23 Feb., 1897
M'ARA, ALEXANDER, 65 Morrison street, Glasgow,	22 Nov., 1892
MACBETH, GEORGE ALEXANDER, 65 Great Clyde street, Glasgow,	24 Jan., 1899
MACBRAYNE, DAVID HOPE, 119 Hope street, Glasgow,	22 Mar., 1904
MACBRAYNE, LAURENCE, 11 Park Circus place, Glasgow,	26 Mar., 1895
MACDOUGALL, DUGALD, 1 Cross-shore street, Greenock,	26 Jan., 1897

M'INTYRE, JOHN, 33 Oswald street, Glasgow,	23 Feb., 1897
M'INTYRE, T. W., 21 Bothwell street, Glasgow,	24 Jan., 1893
MACLAY, JOSEPH P., 21 Bothwell street, Glasgow,	18 Dec., 1900
M'PHERSON, Captain DUNCAN, Mavisbank, Gourock,	26 Jan., 1886
MERCER, JAMES B., Broughton Copper works, Manchester,	24 Mar., 1874
MILLAR, THOMAS, Hazelwood, Langside, Glasgow,	22 Mar., 1898
MOWBRAY, ARCHIBALD H., c/o Messrs Smith & M'Lean, Mavisbank, Glasgow,	22 Feb., 1898
MURRAY, JOHN BRUCE, 24 George square, Glasgow,	18 Mar., 1902
*NAPIER, JAMES S., 33 Oswald street, Glasgow,	
OVERTOUN, The Right Hon. Lord, Overtoun, Dumbartonshire,	27 Oct., 1903
PAUL, ROBERT, 82 Gordon street, Glasgow,	18 Apr., 1905
PAIRMAN, THOMAS, 54 Gordon street, Glasgow,	23 Jan., 1900
PRENTICE, THOMAS, 175 West George street, Glasgow,	24 Nov., 1896
RAEBURN, WILLIAM HANNAY, 81 St. Vincent street, Glasgow,	20 Feb., 1900
REID, JOHN, 30 Gordon street, Glasgow,	22 Dec., 1896
RIDDLE, JOHN C., c/o Messrs Walker & Hall, 8 Gordon street, Glasgow,	15 June, 1898
ROBERTSON, WILLIAM,	27 Apr., 1897
ROBINSON, DAVID, Hilbre, Balshagray avenue, Partick,	16 Dec., 1902
ROSS, THOMAS A., Glenwood, Bridge-of-Weir,	20 Mar., 1894
ROXBURGH, JOHN ARCHIBALD, 3 Royal Exchange square, Glasgow,	20 Feb., 1900
SERVICE, GEORGE WILLIAM, 175 West George street, Glasgow,	24 Nov., 1896
SERVICE, WILLIAM, 54 Gordon street, Glasgow,	23 Jan., 1900
SLOAN, WILLIAM, 53 Bothwell street, Glasgow,	20 Feb., 1900
†SMITH, GEORGE, c/o Messrs George Smith & Sons, 75 Bothwell street, Glasgow,	22 Jan., 1901
SMITH, JOHN, 41 Kelvinside gardens, Kelvinside, N., Glasgow,	22 Feb., 1898

SOTHERN, ROBERT M., 59 Bridge street, Glasgow,	18 Feb., 1902
STEWART, CHARLES R., Messrs J. Stone & Co., 46 Gordon street, Glasgow,	29 Oct., 1901
STEWART JOHN G., 65 Great Clyde street, Glasgow,	18 Dec., 1890
STRACHAN, G., Fairfield works, Govan,	26 Oct., 1891
TAYLOR, FRANK, 70 Hatfield road, Bedford Park, London, W.,	24 Dec., 1901
TAYLOR, WILLIAM GILCHRIST, 123 Hope street, Glasgow,	23 Jan., 1900
THOMSON, WILLIAM H., 32 Albert Road East, Crosshill, Glasgow,	19 Feb., 1901
WARREN, ROBERT G., 116 Hope street, Glasgow,	28 Jan., 1896
*WATSON, H. J., c/o Messrs Watson Brothers, 142 St. Vincent street, Glasgow,	
WEIR, ANDREW, 102 Hope street, Glasgow,	25 Jan., 1898
WHIMSTER, THOMAS, 67 West Nile street, Glasgow,	24 Oct., 1899
WILD, CHARLES WILLIAM, Broughton Copper Company, Limited, 49-51 Oswald street, Glasgow,	24 Mar., 1896
WILLIAMSON, JOHN, 99 Great Clyde street, Glasgow,	28 Apr., 1903
WILLOCK, FREDERICK GEORGE, 109 Hope street, Glasgow,	21 Mar., 1905
WREDE, FREDERICK LEAR, 25 Bentinck street, Greenock,	25 Jan., 1898
YOUNG, JOHN D., Scottish Boiler Insurance Company, 111 Union street, Glasgow,	19 Dec., 1882
YOUNG, ROBERT, Baltic Chambers, 50 Wellington street, Glasgow,	16 Dec., 1902

STUDENTS.

AITCHISON, JOHN WILSON,	20 Nov., 1900
AITKEN, JOHN, c/o Paterson, 37 Beech street, Preston,	28 Apr., 1903
ALEXANDER, ROBERT, 33 Melville street, Portobello,	23 Oct., 1900
ALEXANDER, WILLIAM, 31 Kelvingrove street, Glasgow,	19 Mar., 1901
ALEXANDER, WILLIAM, 13 Lawrence street, Partick,	25 Oct., 1904
ALISON, ALEXANDER E., Devonport, Auckland, New Zealand,	22 Nov., 1898
ALLAN, FREDERICK WM., 8 Gillsland road, Edinburgh,	21 Nov., 1899
ANDERSON, ADAM R.,	23 Mar., 1897
ANDREW, ARCHIBALD, 4 Thornwood terrace, Partick,	23 May, 1905
ANDERSON, JOHN, Jun., 3 Crow road, Partick,	2 May, 1905
AP.-GRIFFITH, YWAIN GORONWY, 39 White street, Partick,	3 Mar., 1903
APPLEBY, JOHN HERBERT, 133 Balshagray avenue, Partick,	27 Oct., 1903
APPLETON, EVELYN, Rosevale, Windsor road, Renfrew,	20 Dec., 1904
BAIRD, JAMES, Romiley, Erskine avenue, Dumbreck,	26 Jan., 1904
BARNWELL, FRANK SOWTER, Elcho house, Balfron,	18 Feb., 1902
BARNWELL, RICHARD HAROLD, Elcho house, Balfron,	18 Feb., 1902
BARTY, THOMAS PATRICK WILLIAM, c/o Messrs. Formans & M'Coll, 160 Hope street, Glasgow,	18 Dec., 1900
BELL, H. L. RONALD, Redargan, Drumoyne drive, Govan,	22 Mar., 1904
BERTRAM, R. M., 9 Walmer road, Toronto, Canada,	24 Jan., 1899
BINLEY, WILLIAM, Jun., Office of Superintendent Constructor, U.S.N., Gas Engine and Power Co., Morris Heights, New York, U.S.A.,	21 Mar., 1899
BISSET, JOHN, 35 Harriet street, Pollokshaws, Glasgow,	18 Dec., 1900
BLACK, JAMES, 3 Clarence street, Paisley,	18 Dec., 1900
BONE, QUINTIN GEORGE, 31 Elgin terrace, Dowanhill, Glasgow,	19 Dec., 1899
BROOM, WILLIAM A., M.A., Rothmar, Campbeltown,	20 Dec., 1904
BROWN, ALEXANDER TAYLOR, 1 Broomhill avenue, Partick, Glasgow,	26 Oct., 1897
BRYSON, WILLIAM,	24 Oct., 1899
BROWN WALTER GEORGE, 35 Burnbank gardens, Glasgow,	2 May, 1905
BUCHANAN, JOSHUA MILLER, 4 Eldon terrace, Partickhill, Glasgow,	21 Nov., 1899
BUNTEN, JAMES C., Anderston Foundry, Glasgow,	20 Nov., 1900

CALLANDER, WILLIAM, 130 Nithsdale road, Pollokshields, Glasgow,	24 Dec., 1901
CAMERON, CHARLES, 126 Paisley road, west, Glasgow,	25 Oct., 1904
CAMERON, IVAN JOHNSTONE, 5 Osborne place, Copeland road, Govan,	24 Jan , 1905
CLARK, WILLIAM W., 32 Grafton square, Glasgow,	20 Dec., 1904
CLOVER, MAT., Roselea, Willaston, near Chester,	22 Dec., 1903
COCHRANE, JOHN, 15 Ure place, Montrose street, Glasgow,	24 Dec., 1901
CORMACK, JAMES ALEXANDER, 149 Hill street, Garnethill, Glasgow,	24 Nov., 1903
CRAN, J. DUNCAN, 11 Brunswick street, Edinburgh,	21 Jan., 1902
CRAWFORD, ARCHIBALD, P.O. Box 558, Pretoria, S.A.,	18 Dec, 1900
CRICHTON, JAMES, B.Sc., c/o Hunter, 308 Byres road, Glasgow,	22 Mar., 1904
CRIGHTON, ARTHUR EDWARD, c/o Whitelaw, Jamestown, by Balloch,	21 Mar. 1905
CUBIE, ALEXANDER, Jun., 2 Newhall terrace, Glasgow,	23 Jan., 1900
CUTHBERT, JAMES G., Holmehouse, Ulleskeff, near York,	21 Nov., 1899
DE SOLA, JUAN GARCIA, Sacramento, 57, Cadiz, Spain,	20 Mar., 1900
DEWAR, ROBERT D., 4 Battlefield avenue, Langside, Glasgow,	21 Mar., 1905
DIAS, CHRISTOPHER, c/o Gow, 273 Dumbarton road, Glasgow,	16 Dec., 1902
DICKIE, DAVID WALKER, 3208 West avenue, Newport News, V.A., U.S.A.,	22 Mar., 1904
DICKIE, JAMES S., San Mateo, California,	19 Dec., 1899
DOBBIE, ROBERT B., 15 Leander Road, Brixton Hill, London, S.W.,	24 Oct., 1899
DORNAN, JAMES, 21 Minerva street, Glasgow,	20 Jan., 1903
DORNAN, JOHN D., 21 Minerva street, Glasgow,	22 Mar., 1904
DRYSDALE, WILLIAM, 3 Whittingehame gardens, Kelvinside, Glasgow,	16 Dec., 1902
DUNCAN, ALEXANDER, c/o E. G. Fraser Luckie, Esq., Hacienda, Andalusia, Huacho, Sayou, Peru,	23 Apr., 1901
DUNLOP, JOHN, 9 Oakfield terrace, Hillhead, Glasgow,	21 Mar., 1905
DUNSMUIR, GEORGE, Matheran, 27 Sherbrooke avenue, Pollokshields, Glasgow,	21 Apr., 1903
DYER, HENRY,	18 Dec., 1900
FAIRLEY, JOHN, 124 Pitt street, Glasgow	21 Nov., 1899

FAIRWEATHER, GEORGE A. E., Elmwood, Avon street, Motherwell,	26 Nov., 1901
FERGUSON, JOHN, Bellevue, Clydesdale street, Hamilton,	20 Dec., 1904
FERGUSSON, W. L., 48 Connaught road, Roath, Cardiff,	22 Dec., 1891
FISH, N., 69 Mayfair avenue, Ilford, Essex,	18 Feb., 1902
FLEMING, ARCHIBALD L, c/o Rankin, 280 Bath street, Glasgow,	20 Dec., 1904
FRASER, JOHN ALEXANDER, 959 Govan road, Govan,	26 Jan., 1904
FREER, ROBERT M'DONALD, 14 India street, Glasgow,	27 Oct., 1903

GALBRAITH, HUGH, 2 Hillside villa, Kentish road, Belvidere, Kent,	20 Dec., 1898
GARDNER, HAROLD THORNBY, Thorncliffe, Skermorlie,	26 Apr., 1904
GIBB, JOHN, 17 Thornwood drive, Partick, W.,	24 Jan., 1899
GRAHAM, JOHN, 16 Summerfield cottages, Whiteinch, Glasgow,	26 Apr., 1904
GRANT, WILLIAM, Croft park, High Blantyre,	24 Oct., 1899
GRENIER, JOSEPH R., c/o Mrs M'Master, 307 St. Vincent street, Glasgow,	3 Mar., 1903

HALLEY, MATTHEW WHITE, 48 Lawrence street, Partick,	22 Mar., 1904
HANNAH, JOHN A., 112 Govanhill street, Glasgow,	26 Nov., 1901
HENDERSON, JOHN ALEXANDER, c/o Glen, 5 Gt. George street, Glasgow,	22 Mar., 1904
HARVEY, WILLIAM BARNETT, B.Sc., 7 Marchmont ter., Kelvinside, Glasgow,	22 Nov., 1904
HENRICSON, JOHN A., c/o A. B. Sandoikens, Skeppsdocka, och Mek, Varkstad, Helsingfors, Finland,	19 Dec., 1899
HERSCHEL, A. E. H., 23 Wilson street, Hillhead, Glasgow,	19 Dec., 1899
HODGART, MATTHEW, Linnsburn, Paisley,	22 Dec., 1903
HOLLAND, HENRY NORMAN, Metropolitan Electric Supply Co., Willesden Works, London, N.W.,	22 Nov., 1898
HOLLAND, JOHN C., 50 Gibson street, Hillhead, Glasgow,	20 Dec., 1904
HOLMES, JAMES, 25 St. James street, Paisley,	17 Feb., 1903
HOTCHKIS, MONTGOMERY H., Crookston house, near Paisley,	24 Dec., 1901
HOUSTON, DAVID S., 83 Kilmarnock road, Shawlands, Glasgow,	27 Oct., 1903
HOWIE, JOHN, 110 Camperdown road, Scotstoun, Glasgow,	25 Oct., 1904
HOYT, CHARLES S., B.A.,	22 Mar., 1904
HUTTON, W. R., 97 Queensborough gardens, Hyndland, Glasgow,	23 Apr., 1901

IRONS, JAMES HAY, 4 Albert drive, Crosshill, Glasgow, 19 Feb., 1901

JANKINS, GARNET EDWARD, N.B.R. Station, Springburn, Glasgow, 3 May, 1904

JENKINS, CHARLES C., 3 Mar., 1903

JOHNSTON, HECTOR, Roselea cottage, Drumoyne road, South Govan, 22 Dec., 1903

KIMURA, N., Marine Inspector's Office, H.I.J.M.'s Consulate-General, Shanghai, 23 Apr., 1901

KING, CHARLES A., 9 Spring gardens, Kelvinside, Glasgow, 25 Apr., 1893

KINGHORN, DAVID RICHARD, Ardoch, Prenton, Cheshire, 23 Oct., 1900

KINROSS, CECIL GIBSON, 25 Katherine drive, Govan, 22 Dec., 1903

KIRBY, WILLIAM HUBERT TATE, 35 Duncan avenue, Scotstoun, Glasgow, 26 Apr., 1904

LEMON, ERNEST J. H., c/o Rutherford, 49 Barcaple street, Springburn, 20 Dec., 1904

LIEPKE-RÖED, CARL, 9 Grosvenor terrace, Glasgow, 20 Dec., 1904

LLOYD, HERBERT J., Brecon road, Builth, Wells, 21 Dec., 1897

LOADER, EDMUND T., Y.M.C.A. Club, 100 Bothwell Street, Glasgow 20 Nov., 1900

LOCHHEAD, JAMES M'CULLOCH, Brenfield, Scotstounhill, Glasgow, 25 Oct., 1904

LOW, ARCHIBALD N., Dunlea, Partickhill, Glasgow, 20 Dec., 1904

M'AULAY, ALEX., 1 Leven Grove terrace, Dumbarton, 20 Dec., 1904

M'CLELLAND, HAROLD R., 3 Caird drive, Partick, 22 Mar., 1904

M'CLURE, WILLIAM, 48 Claremont street, Glasgow, 20 Dec., 1904

M'CRACKEN, WILLIAM, Craigneil, Lower Queen street, Onehunga, Auckland, New Zealand, 27 Oct., 1903

M'DONALD, CLAUDE KNOX, Lennoxvale, Maryland drive, Craigton, Glasgow, 22 Mar., 1904

M'FARLANE, JOHN K., 20 Kelvinside gardens, N., Glasgow, 20 Dec., 1904

M'GENN, HENRY HAMILTON, 46 Claremont street, Glasgow, W. 21 Mar., 1905

M'GREGOR, ROBERT, 22 Westminster terrace, Sauchiehall street, Glasgow, 25 Oct., 1904

MACGREGOR, J GRAHAM, 4 West George street, Glasgow,	18 Feb., 1902
M'HARG, W. S., The Grove, Ibrox, Glasgow,	19 Mar., 1901
M'INTOSH, GEORGE, Dunglass, Bowling,	22 Jan., 1895
MACKAY, HARRY, J. S., 53 Deansgate Arcade, Manchester,	22 Feb., 1898
M'KEAN, JAMES, 3 Buchanan terrace, Paisley,	22 Dec., 1903
M'KEAN, JOHN G., c/o Riddell, 19 Stanley street, West, North Shields,	23 Oct., 1900
M'LACHLAN, CHARLES ALEX., Kia-Ora, Bogston avenue, Cathcart, Glasgow,	21 Apr., 1903
MACLAREN, JAMES ERNEST, 3 Porter street, Ibrox, Glasgow,	23 Oct., 1900
M'LAURIN, JAMES H., 34 Park circus, Ayr,	18 Dec., 1900
M'LAY, J. A., Rose Lea, Uddingston,	17 Feb., 1903
M'MILLAN, DUNCAN, 174 Paisley road west, Glasgow,	27 Oct., 1903
M'MILLAN, DUNCAN MURRAY, Millbrae, Milngavie,	2 May, 1905
MACNICOLL, DONALD, 190 Langlands road, South Govan,	23 Apr., 1901
M'WHIRTER, ANTHONY C., 1009 State street, Schenectady, N.Y., U.S.A.,	21 Dec., 1897
MARSHALL, ALEXANDER, Brightons, Polmont station,	18 Mar., 1902
MAITLAND, JOHN M., 13 Rosslyn terrace, Glasgow,	22 Jan., 1901
MATHER, JOHN BOYD, Kirkhill, Mearns,	20 Mar., 1894
MAY, ANDREW, Woodbourne, Minard avenue, Partickhill, Glasgow,	20 Dec., 1904
MELVILLE, ALEXANDER, c/o Messrs J. A. Millen & Somerville, King street, Tradeston, Glasgow,	20 Feb., 1900
MERCER, JOHN, c/o M'Neish, 4 Craignethen gardens, Partick,	22 Oct., 1895
MILLAR, ALEX. SPENCE, Towerlands, Octavia terrace, Greenock,	16 Dec., 1902
MILLIKEN, GEORGE, Milton house, Callander,	18 Feb., 1902
MITCHELL, JOHN MACFARLAN, 37 West Princes street, Glasgow,	25 Oct., 1904
MORE, THOMAS, 595 Cathcart road, Glasgow,	24 Jan., 1905
MORISON, THOMAS, 23 St. Andrew's drive, Pollokshields, Glasgow,	21 Nov., 1899
MORLEY, JAMES STEEL, 4 Gloag place, West Calder,	20 Feb., 1900
MORLEY, THOMAS B., B.Sc., 5 Walmer terrace, Ibrox, Glasgow,	27 Oct., 1903
MORTON, W., REID, 124 Great Victoria street, Belfast,	26 Oct., 1897
MUIR, JAMES H., Prospecthill, Gourock,	26 Jan., 1892
MUNDY, H. L., Ormsby Hall, Alford, Lancs.,	24 Oct., 1899
MUNRO, GEORGE W., 5 Osborne place, Copeland road, Govan,	24 Jan., 1905

NEIL, ROBERT, 1 Carmichael place, Langside, Glasgow,	20 Mar., 1900
NIVEN, JOHN, c/o Messrs Lynch, Basreh, Persian Gulf,	22 Nov., 1898
ORR, Prof. JOHN, B.Sc., South African College, Cape Town,	26 Mar., 1895
O'SULLIVAN, ANTHONY, 54 Daisy street, Govanhill, Glasgow,	23 May, 1905
PARR, FREDRIK, 16 Eton place, Hillhead, Glasgow,	22 Mar., 1904
PATERSON, A. STANLEY, Maryville, Bearsden,	24 Jan., 1905
PATERSON, JOSEPH BARR, c/o Henry, 38 White street, Partick,	22 Mar., 1898
PATON, THOMAS, Ravenswood, Port-Glasgow,	20 Dec., 1892
PRENTICE, HUGH, Box No. 105, Postal Station B., Cleveland, Ohio, U.S.A.,	26 Apr., 1898
PRESTON, JOHN C., 343-5 Sussex street, Sydney, New South Wales,	6 Apr., 1887
RAMSAY, JOHN C., 72 Norse road, Scotstoun, Glasgow,	19 Feb., 1901
REID, HENRY P., 12 Grantly gardens, Shawlands, Glasgow,	20 Dec., 1898
RICHMOND, TOM, 71 Kintone road, Newlands, Glasgow,	20 Feb., 1900
ROBERTSON, ROBERT M., 3 Charles street, Kilmarnock,	15 Apr., 1902
ROSS, FRANCIS CECIL, Beech Lawn, Hessle, R.S.O., Yorks.,	20 Dec., 1904
SADLER, JOHN, 551 Sauchiehall street, Glasgow,	23 Oct., 1900
SAYERS, W. H.,	19 Mar., 1901
SCOTT, G. N., 7 Corunna street, Glasgow,	17 Feb., 1903
SELLERS, FREDERICK WREFORD BRAGGE,	26 Apr., 1904
SEMPLE, JOHN SCOTT, 44 Brayburne avenue, Clapham, London, S.W.,	26 Apr., 1904
SEMPLE, WILLIAM, Coral Bank, Bertrohill road, Shettleston,	21 Jan., 1902
SERVICE, WILLIAM, 173 West Graham street, Glasgow,	26 Nov., 1901
SEXTON, GEORGE A., c/o Prof. Sexton, G. & W. of S. Technical College, Glasgow,	24 Nov., 1896
SHARP, JAMES R.,	24 Oct., 1899

SHARPE, WILLIAM, B.Sc., Engineer-in-Chief's office, Natal Government Railway, Maritzburg, Natal,	24 Dec., 1895
SHEARDOWN, HAROLD E., 109 Beverley road, Hull,	20 Dec., 1904
SIBBALD, THOMAS KNIGHT, c/o Messrs Cook & Son, Ltd., Cairo, Egypt,	26 Oct., 1897
SIMPSON, ADAM, 12 Rupert street, Glasgow, W.,	3 May, 1904
SMITH, ALEXANDER, 77 High street, Kinghorn,	24 Dec., 1901
SMITH, CHARLES, 3 Rosemount terrace, Ibrox, Glasgow,	24 Apr., 1894
SMITH, JAMES, 44 Cleveland street, Glasgow,	31 Oct., 1902
SMITH, JAMES, Jun., Darley, Milngavie,	27 Oct., 1903
SMITH, WILLIAM, 13 Minerva street, Glasgow,	28 Apr., 1903
SPENCE, JAMES, Jun., c/o Larg, 34 Rupert street, Glasgow,	20 Dec., 1904
SPIERS, ERNEST J., 76 Stepney green, London, E.,	20 Dec., 1904
SPROUL, JOHN, 13 Greenlaw avenue, Paisley,	3 Mar., 1903
STEVEN, DAVID M., 9 Princes terrace, Dowanhill, Glasgow,	15 June, 1898
STEVENS, CLEMENT H., c/o Messrs Blandy Bros. & Co., Las Palmas, Grand Canary,	22 Dec., 1891
STEVENSON, ALLAN, 108 Dundrennan road, Langside, Glasgow,	26 Nov., 1901
STEVENSON, WILLIAM, 1 Mosley street, Newcastle-on-Tyne,	25 Jan., 1881
SUTHERLAND, ALEX , 12 Regent park terrace, Strathbungo, Glasgow,	24 Jan., 1905
TAYLOR, ANDREW P., 47 St. Vincent crescent, Glasgow,	19 Dec., 1899
TAYLOR, JOHN DOUGLAS, Jeanieslea, Oxhill road, Dumbarton,	26 Apr., 1904
THOMAS, NEVILL SENIOR, c/o Messrs Topham, Jones & Railton, H.M.'s Dockyard, Gibraltar,	24 Mar., 1903
THOMSON, GRAHAME H., Jun., 2 Marlborough terrace, Glasgow,	22 Feb., 1898
THOMSON, JOHN A., British Linen Bank house, Moffat,	20 Dec., 1904
TOD, WILLIAM, 948 Sauchiehall street, Glasgow,	22 Feb., 1898
VICK, HENRY HAMPTON, 23 Broomhill terrace, Partick,	25 Oct., 1904
WADDELL, ROBERT, 19 Kelvinside terrace, S., Glasgow,	20 Dec., 1904

WALLACE, HUGH,	24 Oct., 1899
WARD, G. K., Rockvilla, Dumbarton,	23 Apr., 1901
WARD, JOHN, Jun., Rockvilla, Dumbarton,	23 Apr., 1901
WATSON, JAMES, 35 Regent Moray street, Glasgow,	24 Dec., 1901
WILLIAMSON, GEORGE TAYLOR, Craigbarnet, Greenock,	22 Mar., 1904
WILLIAMSON, EDWARD H., 214 Langlands road, South Govan,	27 Oct., 1903
WILSON, THOMAS, 12 Barrington drive, Glasgow,	20 Feb., 1900
WILSON, ROWAND, 3 Cecil street, Ibrox, Glasgow,	25 Oct., 1904
WITHY, VIVIAN, Kenmore, Bowling Green terrace, Whiteinch, Glasgow,	31 Oct., 1902
WOOD-SMITH, GEORGE F., Union Switch & Signal Co., Swissvale, Pennsylvania, U.S.A.,	26 Oct., 1897
WORK, JOHN C.,	22 Mar., 1904

YOUNG, GEORGE M., B.Sc., 268 Kenmure street, Pollokshields, Glasgow,	24 Dec., 1901
YOUNG, JAMES M., Auldfield place, Pollokshaws, Glasgow,	22 Jan., 1901
YOUNG, J. M., Ravenscraig, Ardrossan,	17 Feb., 1903
YOUNGER, JOHN, 264 Plumstead Common road, Plumstead, Kent,	3 Mar., 1903

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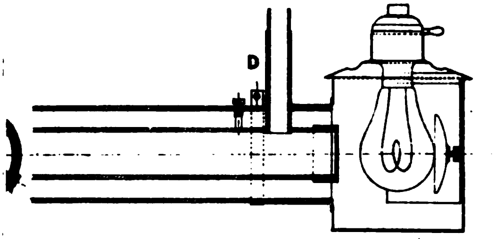
PLATE I.



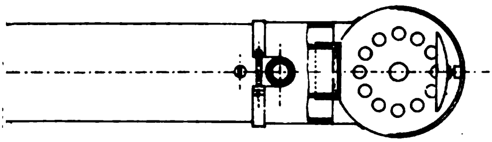
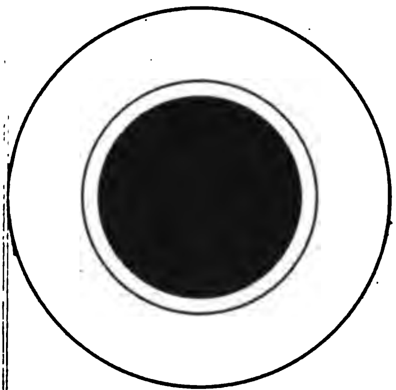


Fig. 13.



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IE SMOK

PLATE II.

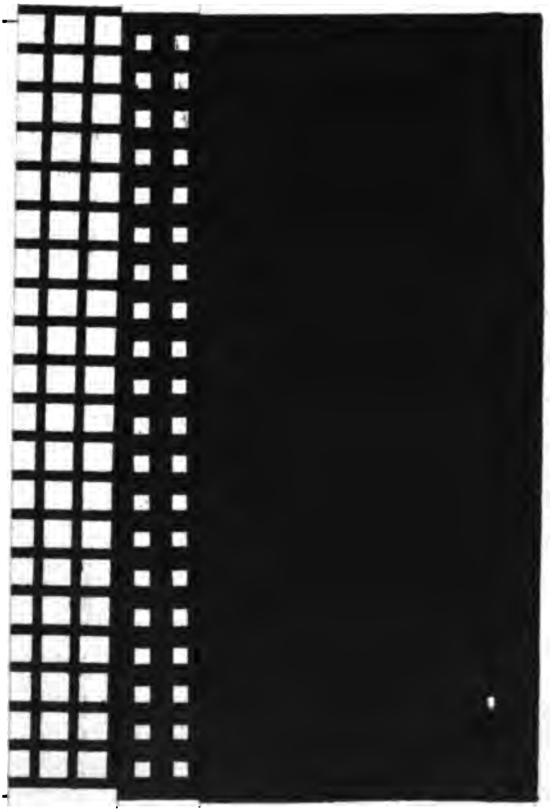

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PLATE III.

Fig. 5.

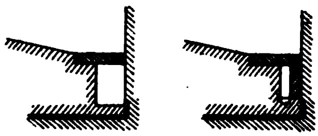


Fig. 4.

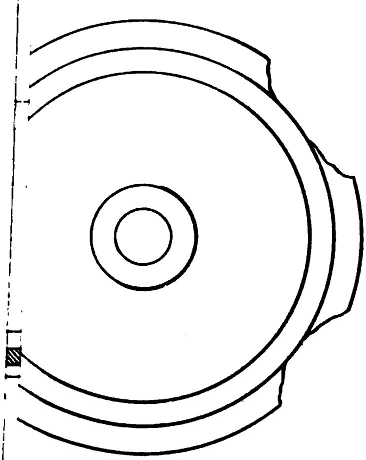
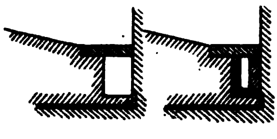


Fig. 6.



Leggat Bros.
Engineering Lithographers, Glasgow

PLATE IV.

Fig. 10.

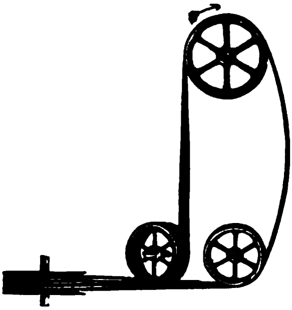


Fig. 11.

Fig. 28.

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PLATE V.

Fig. 36.

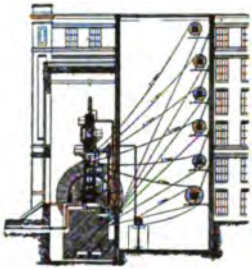

Fig. 42.

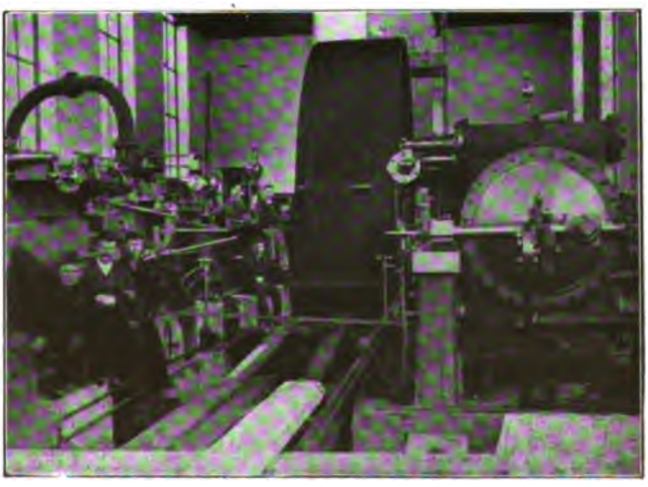

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Fig. 6

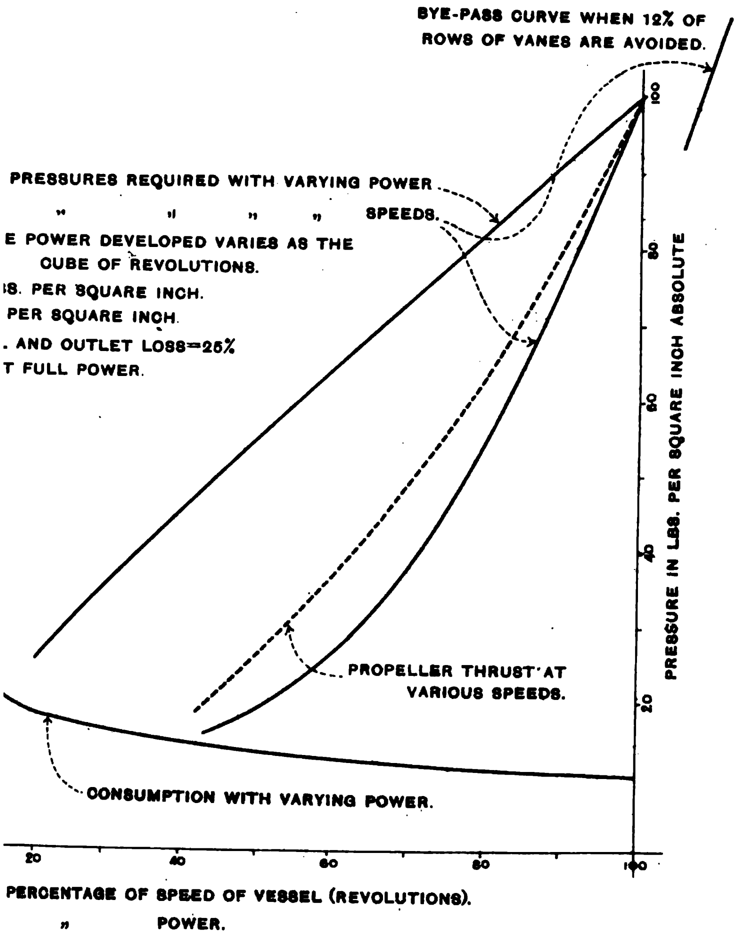

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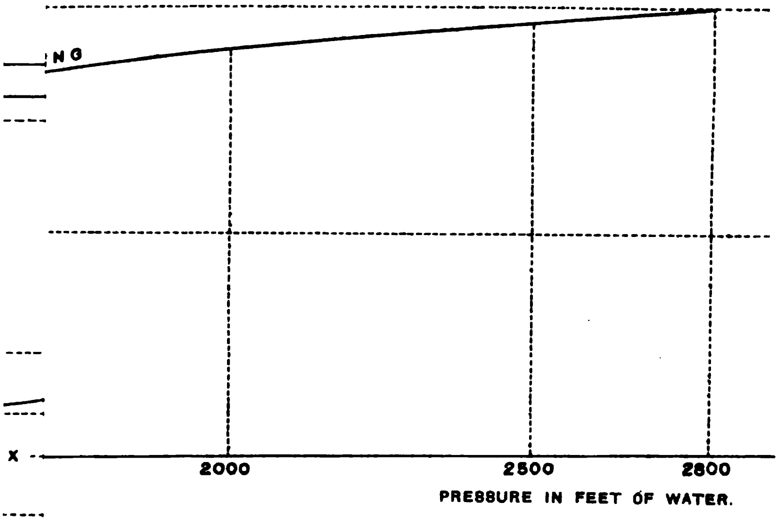
PLATE VII.



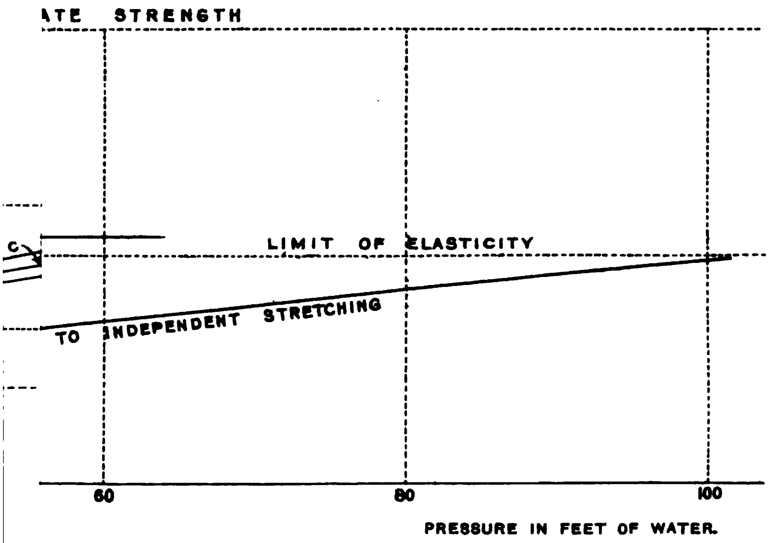


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PLATE VIII.

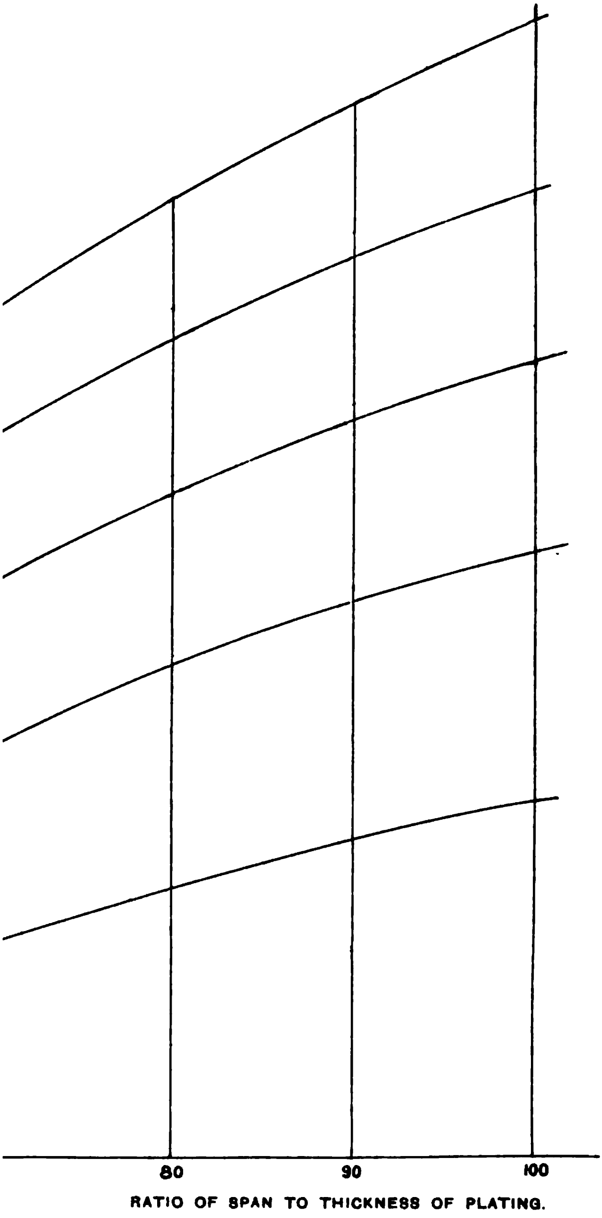

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PLATE IX.

Fig. 9.

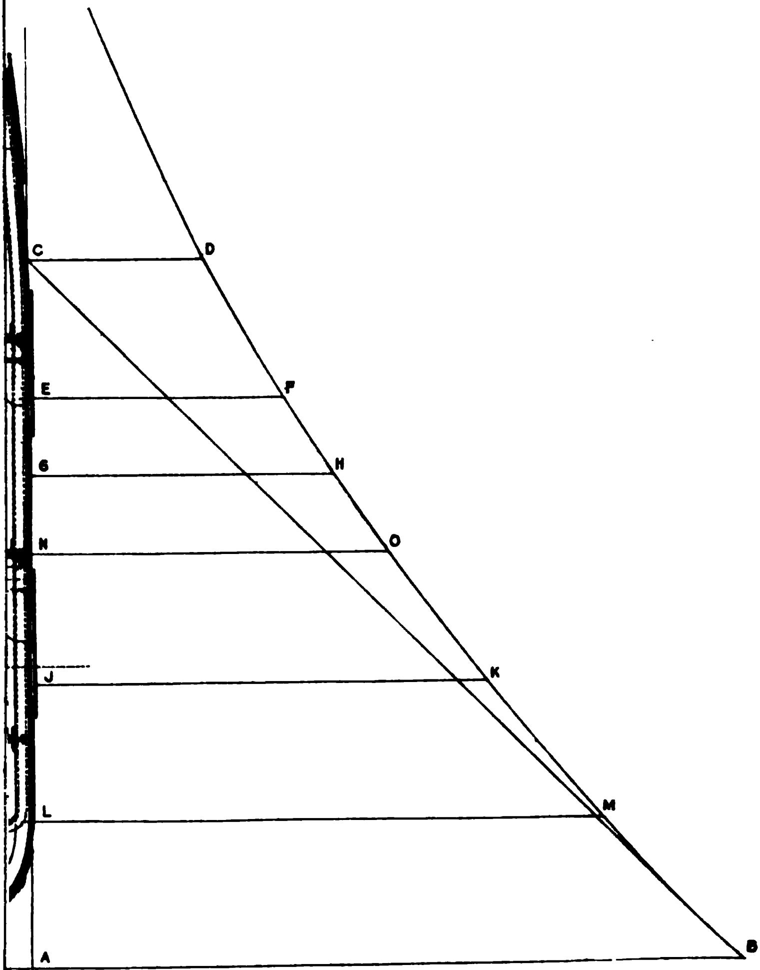

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PLATE X.

I LOCOMOTIVE

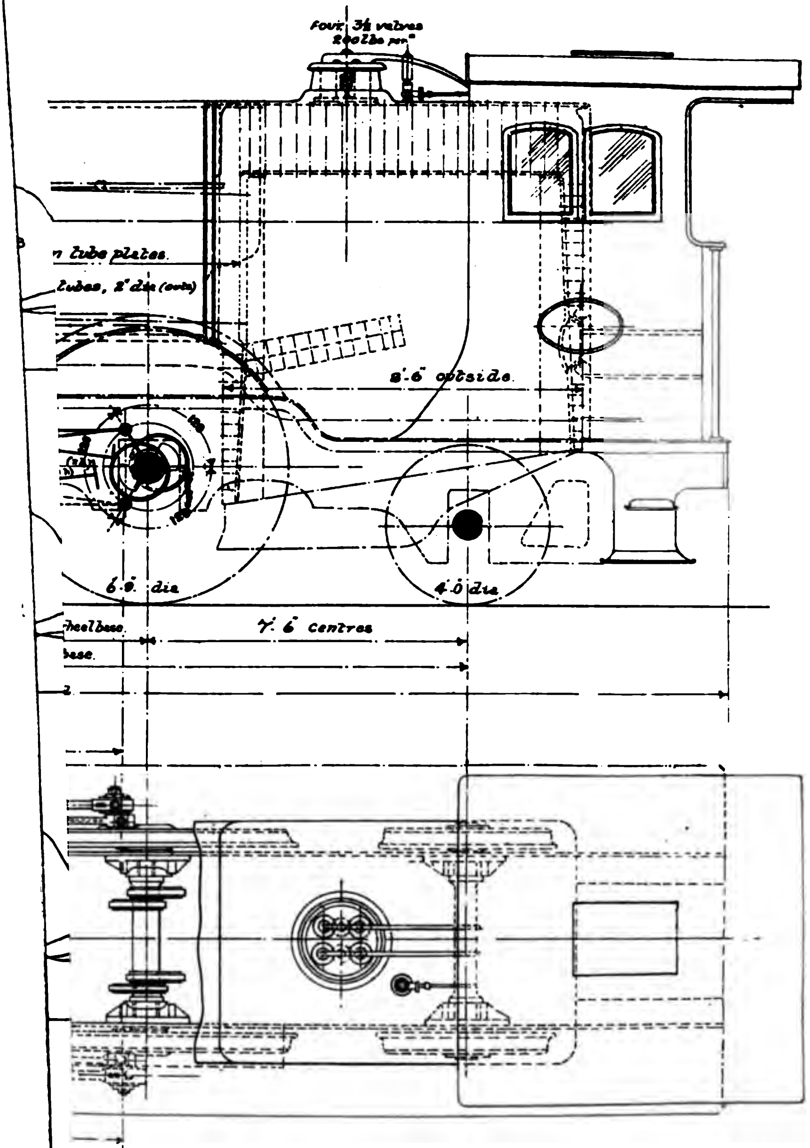

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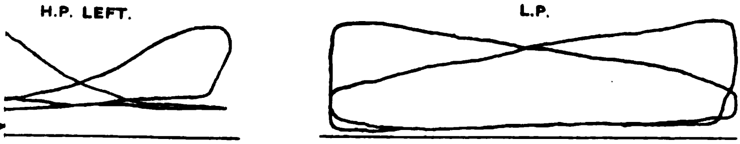
PLATE XI.

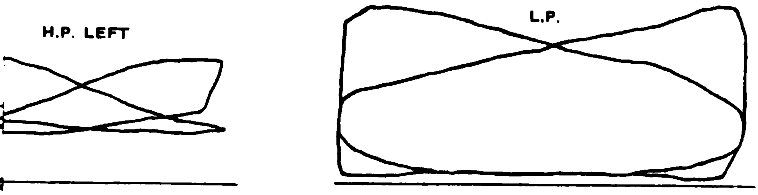
Fig. 12.

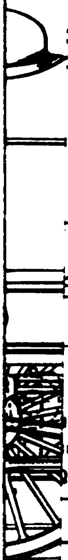
…EPRESENTATIVE OF THE MEANS ON TRIAL NO. 1.

…NDER …



REPRESENTATIVE OF THE MEANS ON TRIAL NO. 2.





REPRESENTATIVE OF THE MEANS ON TRIAL NO. 3.

…DERS, 7½". 7½". 12" X 14" STROKE.
…8 TUBES 2¼" DIA. X 7' 7" LONG. GRATE AREA 92 SQ. FEET.
…. FEET BOILER PRESSURE 125 LBS. PER SQ. INCH.

	TRIAL NO. 1	TRIAL NO. 2	TRIAL NO. 3
	610	1040	1450
	36·85		
	42·84	61·23	80·28
	172	172	170
	1019·5	1323	
HOUR	23·17	20·8	
MINUTE	401·33	401·33	396·6
RIGHT	23·812	31·075	32·37
LEFT	22·467	28·78	32·105
	13·68	21·94	33·88

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PLATE XII.

Fig 4.

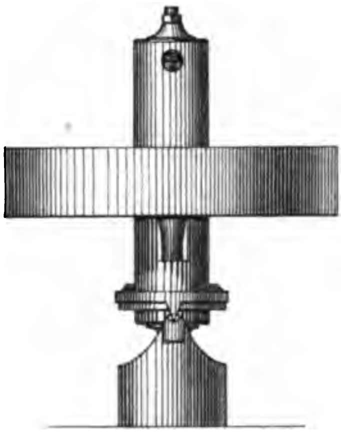

Fig. 9.

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