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P.99/LXXIV

The Journal of the
**INSTITUTE OF
METALS**

and
METALLURGICAL ABSTRACTS



In this Issue :

PAGE

1117. Recent Developments in Corrosion-Resistant Aluminium-Magnesium Alloys.
P. Brenner and W. Roth 159
1118. The Constitution of Aluminium-Copper-Magnesium-Zinc Alloys at 460° C. *D. J. Strawbridge, W. Hume-Rothery, and A. T. Little* 191

DECEMBER 1947

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you
asked
these
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yet?**

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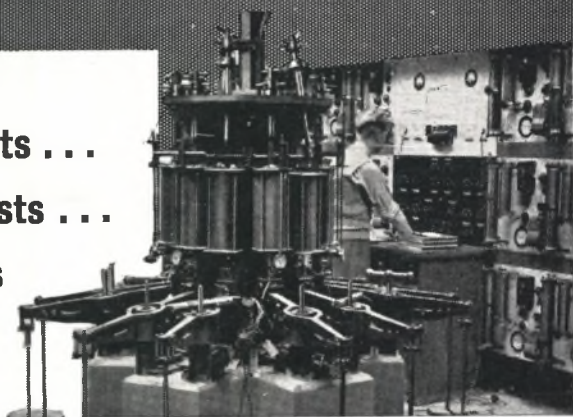
***HOW can I benefit
from this work ?***

You can make use not only of existing information, but of the technical service behind it. If you have a heat or fuel problem get into touch with your local Gas Undertaking for further details. This is well worth while, even if only to make sure that your gas equipment is being used to the best possible advantage.



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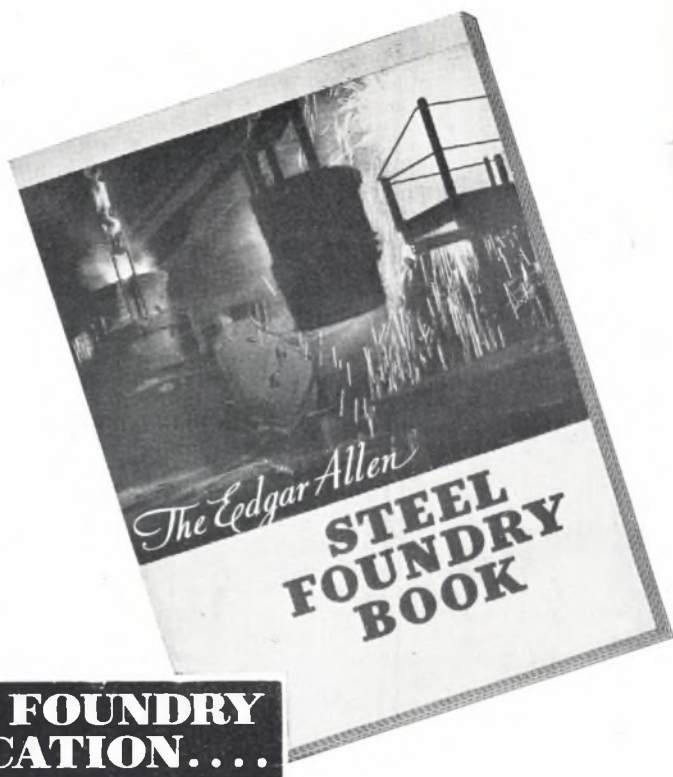
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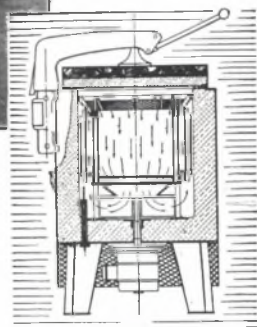
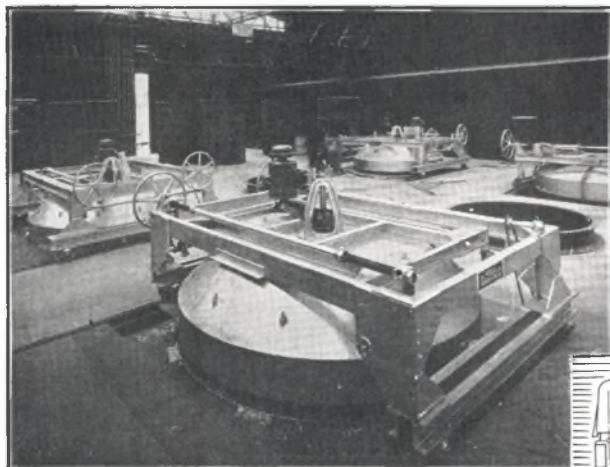
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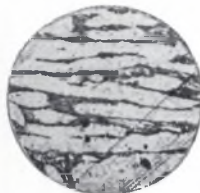
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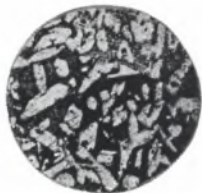
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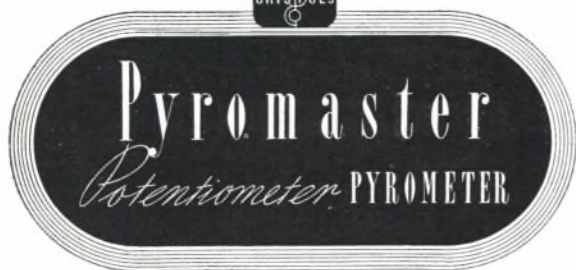
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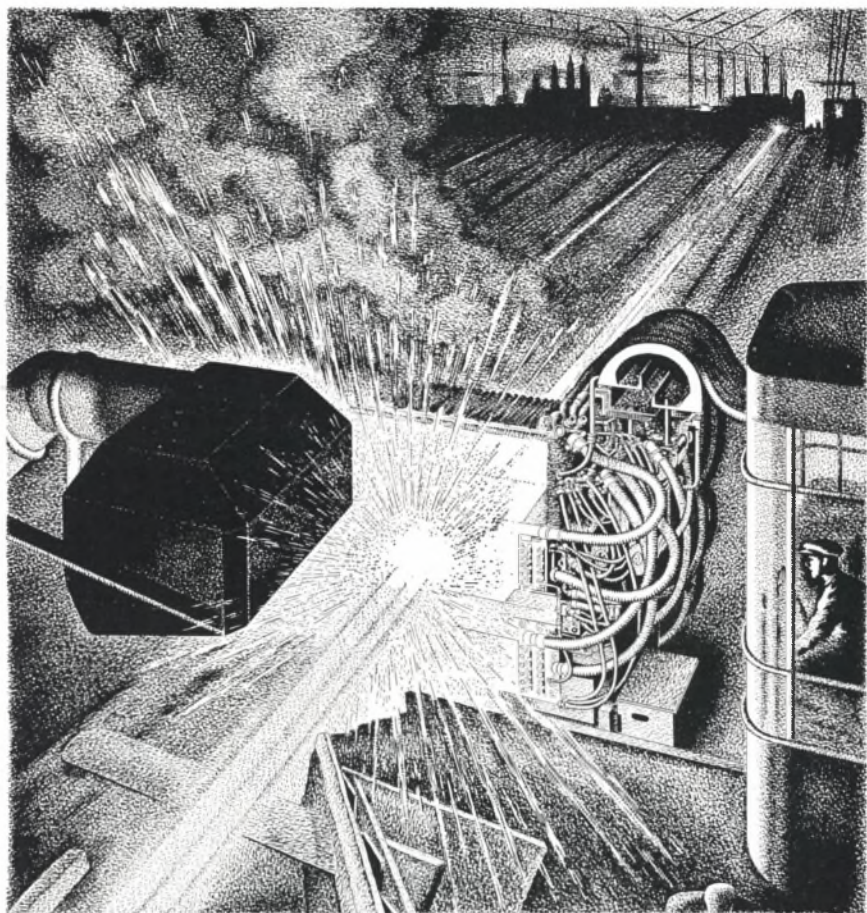
A series of lectures with particular emphasis on the theoretical side of cast-iron metallurgy. A great deal remains to be learned about this plebeian among metals, for the common grey iron is an alloy of great complexity and one which has been somewhat neglected by physical metallurgists in favour of the more aristocratic members of the alloy domain.

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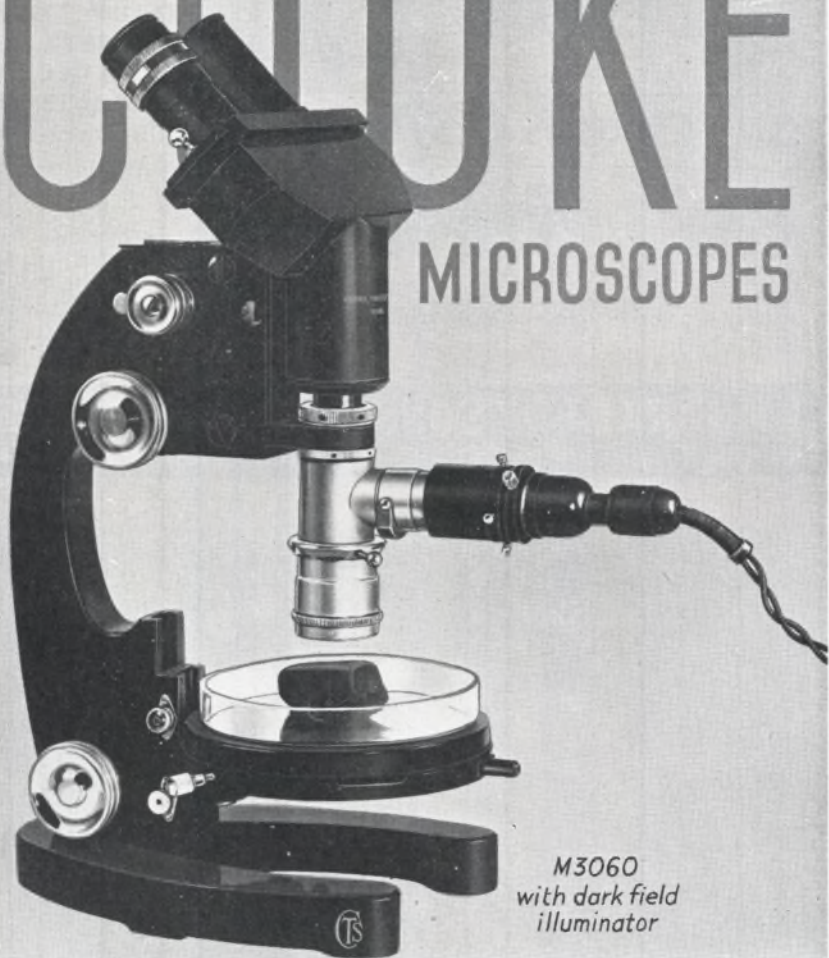
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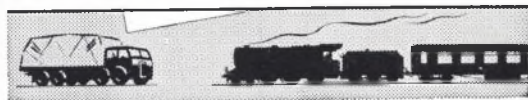
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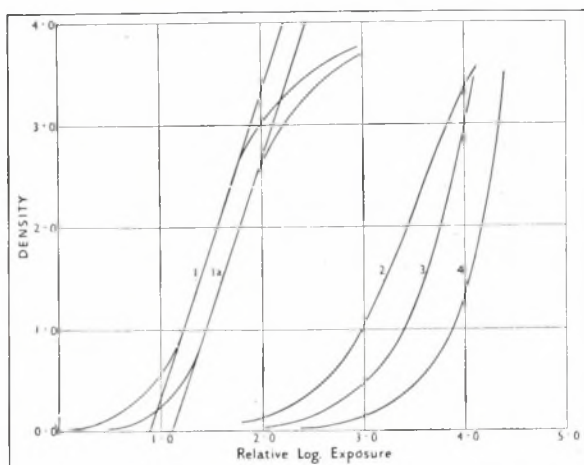
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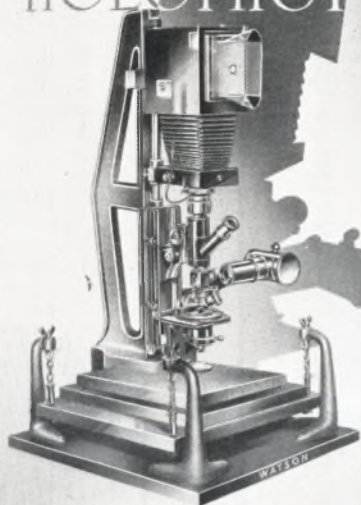
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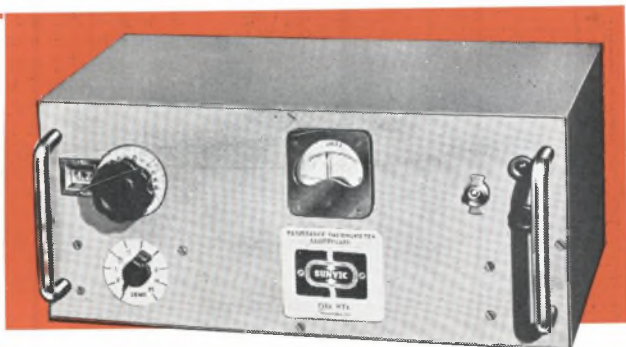
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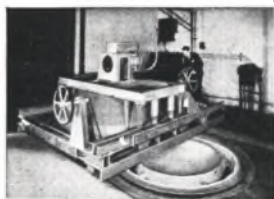
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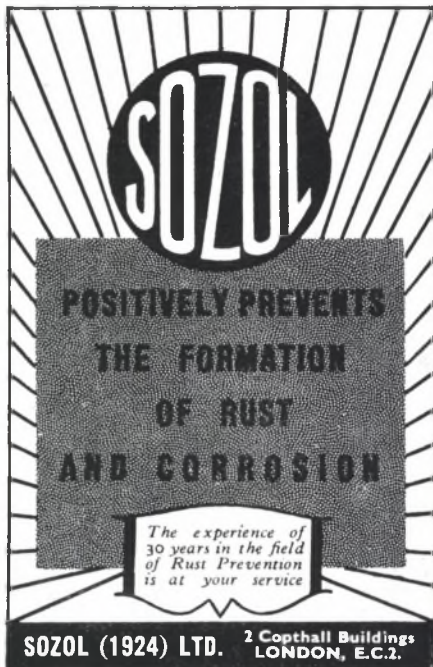
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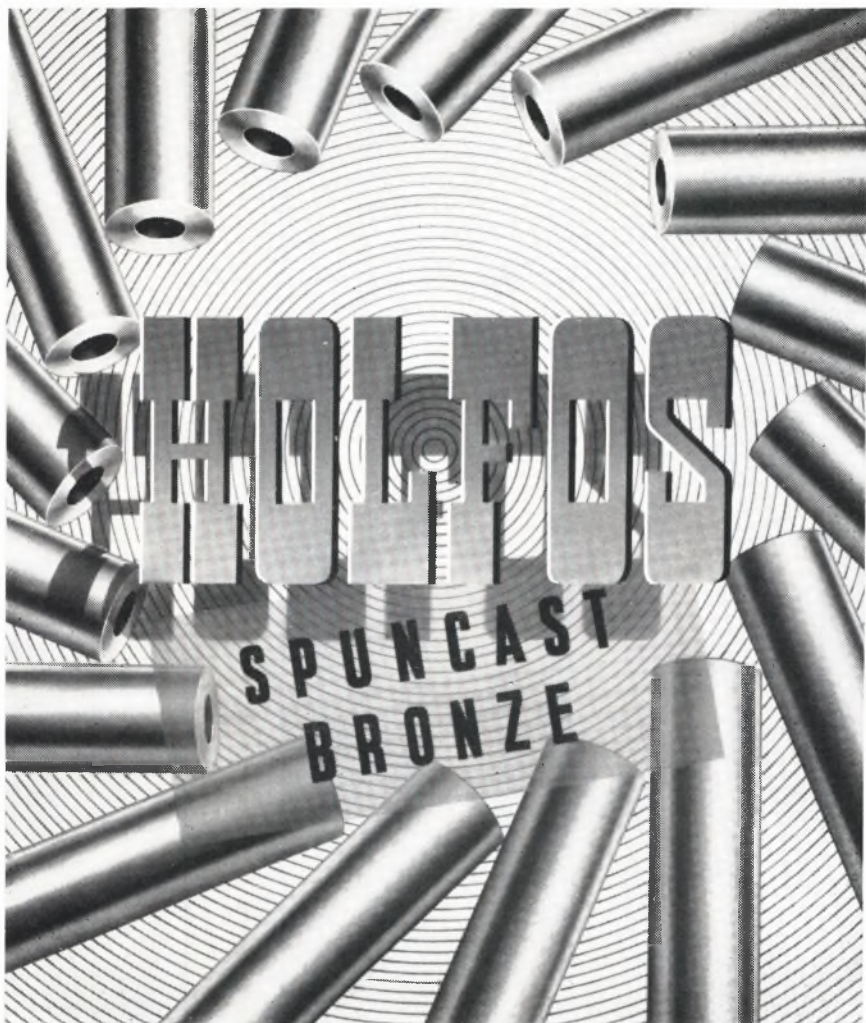
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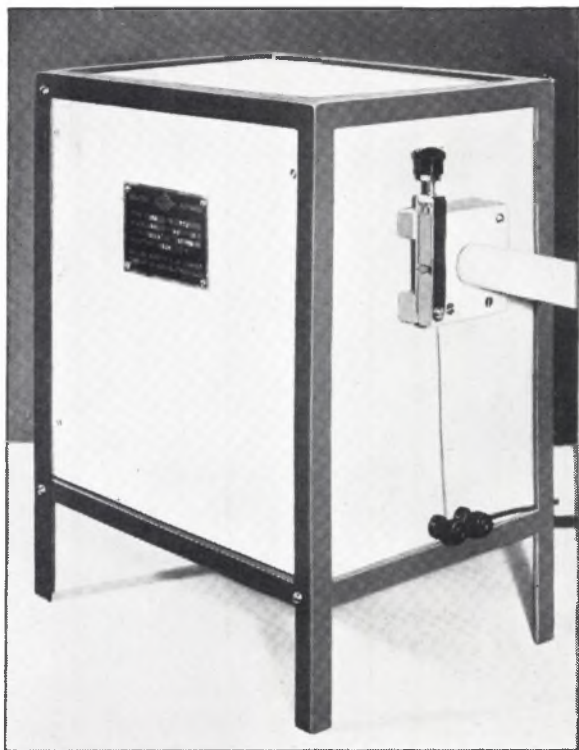
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Contents

| | PAGE |
|---|-------|
| Institute News and Announcements | xxvii |
| Local Sections News | xxxiv |
| University News | xxxvi |
| Other News | xli |
| Appointments Vacant | li |
| II17. Recent Developments in Corrosion-Resistant Aluminium-Magnesium Alloys. By P. Brenner and W. Roth | 159 |
| II18. The Constitution of Aluminium-Copper-Magnesium-Zinc Alloys at 460° C. By D. J. Strawbridge, W. Hume-Rothery, and A. T. Little | 191 |
| Metallurgical Abstracts | 137 |

INDEX TO ADVERTISEMENTS

| | Page | | Page |
|--|----------------------|--|----------------------|
| Allen, Edgar, & Co., Ltd. | iv | Ilford, Ltd. | xv |
| Almin, Ltd. | — | Imperial Chemical Industries, Ltd. | ix |
| Aluminium Union, Ltd. | — | Imperial Chemical Industries (Metals) Co., Ltd. | (Outside back cover) |
| American Society for Metals | x | Imperial Smelting Corporation, Ltd. | — |
| Avimo, Ltd. | — | International Alloys, Ltd. | — |
| Baird & Tatlock (London), Ltd. | — | International Electrolytic Plant Co., Ltd., The. | — |
| Baker Platinum, Ltd. | viii | Johnson, Matthey & Co., Ltd. | xxiv |
| Barnard, H. B., & Sons, Ltd. | xviii | Kodak, Ltd. | — |
| Bausch & Lomb Optical Co., Ltd. | — | Lewis, H. K., & Co., Ltd. | xxii |
| Beryllium Smelting Co., Ltd. | xx | Llewellyn Ryland, Ltd. | (Inside back cover) |
| Birkett, T. M., & Sons, Ltd. | xiv | McGraw-Hill Publishing Co. | — |
| Birlec, Ltd. | xix | McKee Bros., Ltd. | xxvi |
| Bolton, Thos., & Sons, Ltd. | xvi | Manganese Bronze & Brass Co., Ltd., The | — |
| Booth, James, & Co., Ltd. | xviii | Mellows & Co., Ltd. | xii |
| Bowen Instrument Co., Ltd. | — | Metallisation, Ltd. | xx |
| Bristol's Instrument Co., Ltd. | vii | Ministry of Fuel & Power | xxi |
| British Aluminium Co., Ltd., The | — | Mond Nickel Co., Ltd., The | iii, xxvi |
| British Gas Council | (Inside front cover) | Mullard Wireless Service Co., Ltd., The | — |
| British Insulated Callender's Cables, Ltd. | — | Northampton Polytechnic | — |
| British Oxygen Co., Ltd., The | xi | Northern Aluminium, Co., Ltd. | — |
| British Rototherm Co., Ltd., The | — | Park & Paterson, Ltd. | xx |
| Bureau of Analysed Samples, Ltd. | xxii | Ridsdale & Co., Ltd. | xxii |
| Capper Pass & Son, Ltd. | — | Sheffield Smelting Co., Ltd., The | — |
| Cooke Troughton & Simms, Ltd. | xiii | Siemens-Schukert (Great Britain), Ltd. | — |
| Copper Development Association | — | Sozol (1924), Ltd. | xxii |
| Derby & Co., Ltd. | viii | Spear & Jackson, Ltd. | xiv |
| Earle Bourne & Co., Ltd. | — | Stone, J., & Co., Ltd. | — |
| Eclipse Tool Co., The | — | Sunvic Controls, Ltd. | xvii |
| Electric Furnace Co., Ltd. | — | Temple Press | vii |
| Electric Resistance Furnace Co., Ltd. | — | Tyseley Metal Works, Ltd. | vi |
| Entores, Ltd. | xii | Vinten, W., Ltd. | — |
| Fisher & Ludlow, Ltd. | — | Watson, W., & Sons, Ltd. | xxvii |
| Foster Instrument Co., Ltd. | xviii | Wiggin, Henry, & Co., Ltd. | — |
| Foyle, W. & G., Ltd. | — | Wild-Barfield Electric Furnaces, Ltd. | v |
| Gallenkamp, A., & Co., Ltd. | — | Wolverhampton Die-Casting Co., Ltd. | — |
| Gibbons Bros., Ltd. | — | | |
| Heffer, W., & Sons | — | | |
| High Duty Alloys, Ltd. | — | | |
| Hind, E. (South Bank), Ltd. | — | | |
| Holroyd, John, & Co., Ltd. | xxiii | | |
| Hughes, F. A., & Co., Ltd. | — | | |

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December 1947.

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4 GROSVENOR GARDENS, LONDON, S.W.1

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INSTITUTE NEWS AND ANNOUNCEMENTS

HONORARY MEMBERS OF COUNCIL

THE Council has elected Captain (E.) J. G. C. GIVEN, C.B.E., R.N., Engineer-in-Chief's Department, The Admiralty, to be an Honorary Member of Council, representing the Lords Commissioners of the Admiralty.

BALLOT LIST FOR ELECTION OF COUNCIL FOR 1948-49

A ballot list has been circulated to all Fellows and Ordinary Members, who are requested to complete and return it in accordance with the instructions accompanying the document. Honorary Members, Associate Members, and Student Members are not entitled to vote in this election.

STUDENT MEMBERSHIP

The Council has resolved that, with effect from 27 November 1947, full-time students at universities and technical colleges and schools who are taking recognized courses of study may be permitted to pay, for the duration of their courses, though over the present age limit for Student Membership, a membership fee equal to the current rate of subscription for student members.

This special arrangement will be reviewed at 30 June 1949.

METALLURGICAL ABSTRACTS, 1946

The title page, contents, and indexes of *Metallurgical Abstracts*, 1946, vol. 13, were despatched with the November issue of the monthly *Journal* to all members who were members of the Institute in the year 1946.

The index of the 1947 volume is nearing completion and it is hoped to issue it to members early in 1948.

CHRISTMAS HOLIDAYS

The Joint Library at 4 Grosvenor Gardens, London, S.W.1, and also the offices of both the Institute of Metals and Iron and Steel Institute, will be closed on 24-28 December.

PAYMENTS TO THE INSTITUTE

Members who desire to pay their subscriptions by Banker's Order are requested to send these orders completed to the offices of the Institute, for registration, and *not* direct to their bankers.

NEWS AND ANNOUNCEMENTS

It is also particularly requested that members shall make all other payments to the Institute and not direct to the Institute's bankers. Much avoidable work is caused both to the staff and to the auditors in attempting to identify such payments from the pass-book sheets, and members may, in consequence, either receive requests for the payment of accounts that have been settled by direct payment to the bank, or else not receive publications or services for which they have paid, and which it is desired that they shall obtain promptly.

PERSONALITIES

Dr. J. F. Thompson

DR. JOHN FAIRFIELD THOMPSON, who was recently elected an Honorary Member of the Institute, was born at Portland, Me.,

U.S.A., on 8 March 1881, and received his technical education at the School of Mines, Columbia University, where he graduated, B.S., in 1903. In 1906 he was awarded the degree of Ph.D.



On leaving Columbia University, where he had been an Assistant in Metallurgy, he joined the International Nickel Company, Inc., in 1906, to develop the Company's first research laboratory at the Orford works. From 1906 to 1918 he was in charge of all research and technical activities on Monel metal and malleable nickel, and was head of all field and outside plant operations.

Dr. Thompson established, and became manager of, the firm's first technical department, which was a forerunner of the Company's present Development and Research Division, and in 1921 he was appointed Manager of Operations and was the executive responsible for the Huntington Works at Huntington, W.Va. He became Assistant to the President, and has been Executive Vice-President of the International Nickel Company of Canada, Ltd., since 1935.

Dr. Thompson is a Director of the American Bank Note Company, American Metal Company, Ltd., Brooklyn Bureau of Charities, Tube Reducing Corporation, and the Texas Gulf Sulphur Company, Inc., in addition to being a Director of the Canadian Nickel Products Company, Ltd., International Sales, Ltd., Ontario Refining Company, Ltd., and Gap Farm, Ltd., which are subsidiaries of the International Nickel Company. He

NEWS AND ANNOUNCEMENTS

is also a Trustee of the Bank of New York, First National Bank and Trust Company (New Canaan, Conn.), and the Packer Collegiate Institute, and a Regent of the Long Island College Hospital.

In 1944, Dr. Thompson was awarded the Thomas Egleston Medal of the Columbia Engineering Schools Alumni Association, in recognition of his distinguished engineering achievements. He is a Past-President of the Mining and Metallurgical Society of America, and a member of the American Institute of Mining and Metallurgical Engineers and of the American Society for Testing Materials. He is a member of the Advisory Committee on Metals and Minerals of the National Research Council, and is the author of papers on nickel and on corrosion, published by the American Institute of Mining and Metallurgical Engineers, the American Electrochemical Society, and the International Congress of Mining, Metallurgy, and Applied Geology.

Dr. Thompson was elected a member of the Institute of Metals in 1937, and is now honoured by the Institute for his very distinguished services to the science and practice of non-ferrous metallurgy.

ELECTION OF ORDINARY MEMBERS AND STUDENT MEMBERS

The undermentioned 20 Ordinary Members and 27 Student Members were elected on 17 November 1947.

Ordinary Members

- BEARD, James Willis Nassau, Senior Technical Representative, Measurement, Ltd. (Parkinson and Cowan Group), Sale, Cheshire.
- CHEVIGNY, Raymond André, Chef du Service de Recherches et Essais Physiques de la Compagnie Alais Froges et Camargue, 23 rue Balzac, Paris, France.
- CLIFFORD, Sydney Carton, Chief Chemist and Metallurgist, Humber, Ltd., Coventry.
- DREVER, George, B.Sc., Ph.D., Metallurgist, 4 Naples Street, Stratford, London, E.15.
- FENTON, Wilfrid David Drysdale, B.Sc., Commercial Engineer, North of Scotland Hydro-Electric Board, 16 Rothesay Terrace, Edinburgh 3.
- GOMEZ-BAEZA, Pedro, Commandante de Artilleria, Escuela Politecnica del Ejercito, Apartada Oficial, Madrid, Spain.
- JENKINS, John Campbell, B.Met.E., Chief Metallurgist, Electrolytic Refining and Smelting Company Pty., Ltd., Collins House, 360 Collins Street, Melbourne, C.1, Australia.
- MILLER, J. A., Doctor of Chemistry, Chief Chemist, Buenos Aires Great Southern and Buenos Aires Western Railways, Liniers, Buenos Aires, Argentina.
- MONTGOMERY, Allen Marshall, M.S., Librarian and Head of the Metallographic Laboratory, Aluminum Company of America, 2210 Harvard Avenue, Cleveland 5, O., U.S.A.
- MUMFORD, L. Quincy, Assistant Director, Cleveland Public Library, 325 Superior Avenue, Cleveland 14, O., U.S.A.

NEWS AND ANNOUNCEMENTS

- PODCZASKI, Professor Brunon, Met.Ing., Assistant Professor of Metallurgy, Polish University College, 5 Princes Gardens, London, S.W.7.
- RAMACHANDRAN, Erode Ganapati Iyer, M.Sc., Lecturer in Physical Metallurgy, Indian Institute of Science, Bangalore, India.
- RAUDEBAUGH, Professor Robert J., Ph.D., B.S., Associate Professor, University of Rochester, Rochester 3, N.Y., U.S.A.
- RUTHERFORD, Neville Bowman, B.Sc., Metallurgist, British Non-Ferrous Metals Research Association, Euston Street, London, N.W.1.
- SCHUETZ, Edwin, Managing Director, Oederlin and Company, Limited, Baden, Switzerland.
- SEXTON, (Miss) Lena, Technical Secretary, F. A. Hughes and Company, Ltd., Abbey House, Baker Street, London, N.W.1.
- THOMAS, Oswald, Superintendent of the Laboratories, Imperial Smelting Company, Ltd., Bloxwich, Walsall, Staffordshire.
- VERBEEK, Leo Henricus, Chem.Eng., Head of the Lamp Development Department, N.V. Philips' Gloeilampenfabrieken, Eindhoven, Holland.
- WILLIAMS, Cyril, B.Sc., Research Metallurgist, Royal Arsenal, Woolwich, London, S.E.18.
- WILSON, Archibald Hammond, Managing Director, Evered and Company, Ltd., Smethwick 40, Staffordshire.

Student Members

- ADAMSON, Kenneth Cecil, Student, Battersea Polytechnic, London, S.W.11.
- BLADE, John Clements, B.Sc., Research Bursar, British Non-Ferrous Metals Research Association, Euston Street, London, N.W.1.
- BOXALL, John M., Student of Metallurgy, Royal School of Mines, London, S.W.7.
- BRICKNELL, Roy Richard, Student of Metallurgy, Royal School of Mines, London, S.W.7.
- CARTWRIGHT, Donald Roy, Student of Metallurgy, Liverpool University.
- CHATTERJEE, Pranab Kumar, Government of India Overseas Scholar, University of Sheffield.
- CLARK, Peter, Student of Metallurgy, Royal School of Mines, London, S.W.7.
- COCKCROFT, Maurice George, B.Sc., Research Student in Metallurgy, University of Manchester.
- DENYER, George Douglas, B.Sc., Bursar, British Non-Ferrous Metals Research Association, Euston Street, London, N.W.1.
- DYBALL, Herbert Thomas, Student of Metallurgy, Birmingham University.
- EDGE, Dennis Albert, Student, Birmingham University.
- HEAD, Michael David, Student of Metallurgy, Royal School of Mines, London, S.W.7.
- HULL, William Griffin, Metallurgist, Southern Forge, Ltd., Langley, Buckinghamshire.
- HUMPHREYS, David, Student of Metallurgy, Royal School of Mines, London, S.W.7.
- JAYES, William Gregory, Student of Metallurgy, Royal School of Mines, London, S.W.7.

NEWS AND ANNOUNCEMENTS

- MASLIN, Harold George, Student of Metallurgy, Royal School of Mines, London, S.W.7.
- MENDS, David, Student of Metallurgy, Battersea Polytechnic, London, S.W.11.
- MINCHER, Albert Leslie, B.Sc., Research Metallurgist, British Non-Ferrous Metals Research Association, Euston Street, London, N.W.1.
- MOORE, Peter Thomas, Student of Metallurgy, Royal School of Mines, London, S.W.7.
- MORGAN, Eric Raymond, Student of Metallurgy, Birmingham University.
- OPPENHEIMER, Hans, Student of Metallurgy, Royal School of Mines, London, S.W.7.
- OTTLEY, Derek John, Student of Metallurgy, Royal School of Mines, London, S.W.7.
- PAXTON, Harold William, B.Sc., Research Student in Metallurgy, Manchester University.
- SAYERS, John Brian, Student, Battersea Polytechnic, London, S.W.11.
- TOLLEY, Roderick James, Student of Metallurgy, Royal School of Mines, London, S.W.7.
- TOWN, Arthur W., Student of Metallurgy, Pembroke College, Cambridge University.
- WARNER, John Pelham, Student of Metallurgy, Royal School of Mines, London, S.W.7.

PERSONAL NOTES

MR. T. A. ALEXANDER has resigned his appointments with the Alexander Metal Company, Ltd., Copper Alloys, Ltd., and West Bromwich Metal Refiners. He remains Managing Director of the West Smethwick Metal Company, Ltd., Old Bury Road, Smethwick.

MR. A. W. BRACE, L.I.M., has left Rotol, Ltd., Gloucester, to take up a post as Foundry Metallurgist with Douglas (Kingswood), Ltd., of Bristol.

MR. WILLIAM B. BROOKS has resigned his position with Alloys Development Company, Pittsburgh, Pa., U.S.A., and has established a consulting practice, specializing in stainless and alloy steels.

MR. DAVID BROWN has bought the goodwill, designs, and work in progress of Lagonda, Ltd.

MR. H. CAUSER has left Serck Radiators, Ltd., Birmingham, to take up an appointment as Works Metallurgist at the Clarendon Park Road Works of J. W. Lawrence, Ltd., Leicester.

PROFESSOR P. A. J. CHEVENARD was elected *Ingénieur honoris causa* of Liège University on 11 October 1947.

MR. D. K. COUTTS, M.Sc., A.R.I.C., has left the Inspectorate of Metals and Steel (M.G.O. Services), Ishapore, and is now Chief Metallurgist, Indian Iron and Steel Company, Ltd., Kueti Works, Kueti, E.I. Railway, Bengal, India.

NEWS AND ANNOUNCEMENTS

MR. BERNARD D. CULLITY has left the Massachusetts Institute of Technology, Cambridge, Mass., U.S.A. His present address is c/o Prof. Crussard, Ecole des Mines, 60 boulevard Saint Michel, Paris 6e, France.

MR. JAMES L. ERICKSON has left Mansfield, O., and is now with the Lukens Aluminium Company, Dayton, O., U.S.A.

MR. E. J. EVANS, B.Sc., L.I.M., has left Stewarts and Lloyds, Ltd., to take up an appointment as Works Metallurgist and Chemist to the Welsh Tinplate and Metal Stamping Company, Ltd., Llanely.

MR. E. GATHERCOLE, B.Sc., has left Switzerland. His new address is c/o Aluminium Company of South Africa Pty., Ltd., P.O. Box 74, Pietermaritzburg, Natal, South Africa.

MR. FRED HARGREAVES, B.Met., has left the Armament Research Department, Woolwich, to take up an appointment as Metallurgist with Philips Blackburn Works, Ltd.

MR. H. G. HOSKINS is now with the Aluminium Company of South Africa, Pietermaritzburg, South Africa.

MR. E. HUNTER, F.I.M., has joined the Incandescent Heat Company, Smethwick, as Manager of the foundry equipment department.

MR. GEORGE T. HYSLOP received presentations at a meeting of the Council of the Association of Bronze and Brass Founders in appreciation of the services that he has rendered as President of the Association during the past two years.

DR. P. H. JENNINGS, B.Sc., has left Birmingham University and has taken up an appointment as Metallurgist in the Research Laboratories of the English Electric Company, Ltd., Stafford.

MR. D. M. KERR is visiting Sweden to study welding practice in that country.

MR. H. KNIGHT, B.Sc., has left Sun Engineering (Crowle), Ltd., and has taken up an appointment with Tractor Spares, Ltd., Willenhall Road, Wolverhampton.

MR. K. KORNFELD has left the Polish Resettlement Corps and has accepted a temporary post as teacher in the Polish Merchant Navy College, Landywood, near Walsall, Staffs.

MR. M. KRISHNA, B.A., has left his appointment as Assistant Foreman in the Inspectorate of Metal and Steel, Bombay, to take up a post as Foreman in the Die-Casting Department of the Indian Standard Metal Company, Ltd., Bombay.

MR. E. A. LANGHAM has relinquished his appointment as Sales Manager in the Sales Division of the British Aluminium Co., Ltd., to take up a new appointment as General Manager of the Company in India, and left England for India in November.

MR. J. McMULLEN, A.I.M., has relinquished his appointment with Omes, Ltd., and is now Chief Metallurgist to the English Resistance Furnace Company, Ltd., Weybridge, Surrey.

MR. GEORGE MANN, B.Sc., A.I.M., has left England. His address is South African Bureau of Standards, Private Bay 191, Pretoria, South Africa.

NEWS AND ANNOUNCEMENTS

MR. A. J. MURPHY, M.Sc., while on a two-weeks' visit to Sweden, in November, delivered an address to the Mining and Metallurgy Division of the Svenska Teknologföreningen on "Recent Developments in Non-Ferrous Metallurgy in Great Britain".

MR. G. G. MUSTED obtained a \$100 award from the James F. Lincoln Arc Welding Foundation for his description of a method for repairing cast-iron sections by welding without pre-heating.

MR. R. N. PARKINS, B.Sc., obtained a \$250 award from the James F. Lincoln Arc Welding Foundation for his paper on the determination of the cause of stress-corrosion cracking of metals.

MR. V. A. PHILLIPS, B.Sc., A.R.S.M., L.I.M., who resigned his appointment as Metallurgist with British Insulated Callender's Cables, Ltd., Prescott, Lancs., in July 1947, has now commenced work as a graduate research student in the Hammond Metallurgical Laboratory, Yale University, New Haven, Conn., U.S.A.

MR. MAO-HWA PO was awarded the M.Sc. (Metallurgy) degree of Birmingham University last January. His thesis dealt with the production of high-strength aluminium sheet of the Duralumin type and the influence of variations of composition on production and properties. He has returned to China, and has taken up an appointment on the Senior Technical Staff of the National Resources Commission of the Chinese Government, Nanking.

DR. J. R. RAIT, B.Sc., has been appointed research controller of Messrs. Hadfields, Ltd.

MR. K. N. RAO is now at University College, Cardiff.

MR. J. A. ROBERTS has graduated from Swansea University with honours in metallurgy.

DR. GEORGE SACHS has been appointed Director of the recently-established Research Laboratory for Mechanical Metallurgy, Case Institute of Technology (formerly Case School of Applied Science), University Circle, Cleveland 6, O., U.S.A.

MR. M. SIGMUND, Managing Director of Sigmund Pumps (Great Britain), Ltd., Gateshead, left this country on 4 October to visit the principal cities of India, and also Ceylon, Burma, Siam, and Malaya. He will investigate the future requirements of the mining industry and make a general study of manufacturing conditions.

MR. A. J. NICOL SMITH, B.Sc., has left Birmingham and is now at the Ministry of Supply, W.R. (D) 2, 10th Floor, Shell-Mex House, Strand, London, W.C.2.

MR. R. A. SMITH has been awarded the degree of B.Sc. (First Class Honours) in Metallurgy of Birmingham University.

MR. D. E. J. TALBOT has been awarded the degree of B.Sc. (2A Honours) in Metallurgy of Swansea University. He has been called up for military service and is now in the Royal Army Ordnance Corps.

MR. A. W. TAYLOR, A.I.M., is now with the Arc Manufacturing Co., Ltd., 529 Goldhawk Rd., Shepherd's Bush, London, S.W.12.

MR. JOHN WALKER, B.Sc., A.R.S.M., has been appointed a Director of the Morgan Crucible Company, Ltd., London.

NEWS AND ANNOUNCEMENTS

MR. L. H. WALKER, B.Sc., L.I.M., has left King's College, University of Durham, and has taken up an appointment with Reynolds Light Alloys, Ltd., Birmingham.

FLYING-OFFICER H. H. WILKINSON is now in the Middle East. His address is Officers Mess, R.A.F., Kasfareet, M.E.F.

MR. G. H. H. WILLIAMS has left the English Electric Company, Ltd., Stafford, and returned to the University College of Swansea, where he is undertaking research work.

MR. JOHN G. YOUNG left Birmingham University on attaining his degree, and is at present serving in the Army.

DEATH

GREER. The Editor regrets to announce the death, on Saturday, 22 November 1947, of MR. H. H. A. GREER, J.P., who was recently elected a Fellow of the Institute. The Institute was represented at the funeral by Mr. A. B. Graham and Mr. Matthew Hay.

Mr. Greer was Honorary Local Secretary of the Scottish Local Section from 1918 to 1928, Chairman of the Section in 1931 and 1932, and was a Member of Council of the Institute from 1928 to 1936. A biographical notice and a photograph of Mr. Greer were published in the October issue of the *Journal*, pp. xxxvi-xxxvii.

Note : Will members (in addition to informing the Institute's administrative department of changes of address, occupation, &c.) kindly notify the Editor, separately, of all changes of occupation, appointments, awards of honours and degrees, &c., as these are matters which interest their fellow members? Such notes should reach the Editor not later than the 21st day of each month for publication in the next month's issue.

LOCAL SECTIONS NEWS

PRESIDENT'S VISIT TO LEEDS

The President, accompanied by the Secretary, paid a visit to the Leeds Metallurgical Society on Wednesday, 3 December 1947, when Mr. H. G. Warrington gave a lecture on "Aluminium Alloys". Light refreshments were served after the lecture, when the President had the opportunity to meet many members resident in the area.

JOINT MEETING WITH IRON AND STEEL INSTITUTE AND MANCHESTER METALLURGICAL SOCIETY

Mr. John Cartland, M.C., M.Sc., Vice-President of the Institute of Metals, took the Chair at a Joint Meeting of the Manchester Metallurgical Society with the Iron and Steel Institute and Institute of Metals, on Wednesday, 26 November 1947, at the Engineers' Club, Albert Square, Manchester, when Mr. E. W. Colbeck, M.A., delivered an address on "Some Metallurgical Problems in the Field of Atomic Energy".

NEWS AND ANNOUNCEMENTS

LOCAL SECTIONS COMMITTEE

A meeting of the Local Sections Committee, which was attended—by invitation—by officers of the Leeds Metallurgical Society and Manchester Metallurgical Society, was held at the offices of the Institute on 27 November 1947, when problems associated with the development of the activities of the Sections were discussed.

SOUTH WALES LOCAL SECTION

The President of the Institute was present at a meeting of the Section held in the Guildhall, Swansea, on Wednesday, 19 November 1947, when Sir Arthur Smout, J.P., President-Elect, addressed the Section on "The Place of the Metallurgist in Industry". Prior to the meeting, the Mayor of Swansea gave a dinner party, to meet Sir Arthur, at which the President, the Secretary, and the Chairman and Officers of the Section were present. Those who accepted invitations included former Mayors of Swansea.

The Place of the Metallurgist in Industry

In his address, Sir Arthur stressed the importance of South Wales, and particularly Swansea, as a centre of metallurgical activity. He said that it had often been levelled against the British metallurgical industry that the capitalist was reluctant to "chance his arm". He could detect no trace of timidity in the great enterprises carried out at Ebbw Vale and Waunarlwydd and the developments in progress in the Port Talbot area. He was convinced that the metals industry was as progressive as any in the country, and British metallurgy as any in the world.

In the past, he said, the metallurgical industry had suffered from the fact that the academic metallurgist and the works man had, as it were, existed in mutually hostile camps. He believed that the time had come when it might be desirable to set up an advisory board, drawn from both sides, to look ahead and to think out problems for the future in their broadest aspect. The success of modern business would depend largely on how successfully the interlocking between industry and science could be carried out, and he fully subscribed to the late Mr. Gluckstein's edict that the business man of the future would have to be a scientist or at least to have some scientific training.

Sir Arthur said that he had little or no sympathy with complaints that the metallurgical profession was not adequately remunerated—these generally emanated from those who had neglected their own interests when young and taken little or no opportunity to improve themselves. He urged young men with industrial ambitions not to leave their choice too late if they wished to bridge successfully the wide gap between the lecture room and the works. If the metallurgist entering industry was not prepared to tackle the hard work of the factory and live alongside his men, he would be well advised to leave the manufacturing side alone.

Sir Arthur said that he considered that the metallurgist's sphere lay in two particular branches of industry. The first was production and manufacture, for industry was becoming so highly technical that adequate metallurgical knowledge behind all its operations was a necessity for commercial success. The second sphere was in control, research, and development. This called for a certain amount of "detachment", but the industrial metallurgist could

NEWS AND ANNOUNCEMENTS

not remain within the locked doors of his laboratory. Even in research, the closest possible contact with the works should be established early and maintained throughout.

The profession, he continued, was an honourable one, full of interest and growing daily in importance. It was not overcrowded, and needed four times the annual intake of trained men compared with 1925-1935. This was due not only to the much extended employment of metallurgists in industry, but also to the increased opportunities provided by their frequent promotion to posts of management and responsibility.

On the subject of coal exports, which were so vital to the economy of South Wales, Sir Arthur said that thirty million tons of coal exported from British ports at current prices would almost close the gap between exports and imports. To the metallurgist, coal was the life-blood of his industry. Without it no metallurgical product could be produced, and without supplies for shipment overseas we could not import the copper, aluminium, nickel, and zinc on which the non-ferrous industries of the whole country depended.

UNIVERSITY NEWS

BIRMINGHAM UNIVERSITY

Course of Lectures on Theory of Sheet and Strip Rolling

A course of six lectures will be given in the School of Industrial Metallurgy by Dr. A. R. E. Singer on "An Introduction to the Theory of Sheet and Strip Rolling, and its Application to Industrial Problems". They will be delivered in Lecture Room 7 at the University, Edgbaston, Birmingham, at 10.30 a.m. on successive Saturday mornings, commencing 31 January 1948. The fee for the whole course is £1 10s. Those wishing to enrol should notify the Registrar, The University, Edgbaston, Birmingham 15, before 15 January.

These lectures are planned to meet the requirements of senior executive officers, metallurgists, engineers, and technicians in the metal producing and consuming industries. They will also constitute a refresher course for metallurgical graduates. A basic knowledge of metallurgy will be assumed.

The lectures will deal with: theories applicable to the rolling of strip and sheet; the effect of variations in the coefficient of friction, rate of work hardening, draught, roll diameter, front and back tension on pressure distribution, forward slip and spread; calculations of rolling load, torque, and power consumption in some simple cases of rolling; the effect of rolling speed, idling time, lubricants, coolants, and roll neck bearings on efficiency, output, and quality; and the factors governing the development and choice of rolling mill plant.

MELBOURNE UNIVERSITY

At a meeting of the Rosenhain Club on 17 November 1947, opportunity was taken to welcome Dr. D. W. Davison, who had just arrived from England to work in the Baillieu Laboratory.

Chief guest of the evening was Dr. J. W. Mitchell from the School of Physics in Bristol. Dr. Mitchell gave an interesting

NEWS AND ANNOUNCEMENTS

outline of the views being developed in Bristol relating to mechanism of plastic flow. A good discussion followed. Dr. Mitchell has been visiting New Zealand and Australia and has given a series of informative lectures.

NATIONAL CERTIFICATES IN METALLURGY

REPORT BY THE JOINT COMMITTEE ON THE PROGRESS OF THE
SCHEME FOR THE AWARD OF NATIONAL CERTIFICATES IN
METALLURGY, 1946-1947

The Scheme for the award of Ordinary and Higher National Certificates in Metallurgy, established by the Iron and Steel Institute, the Institution of Mining and Metallurgy, and the Institute of Metals, in co-operation with the Ministry of Education, has continued to make good progress during the year 1946-47.

Schemes for *Senior and Advanced* Courses submitted by the following *Examining Body* have been agreed as suitable for submission to the Ministry by Colleges and Schools under the arrangements and conditions governing the award of National Certificates in Metallurgy :

CITY AND GUILDS OF LONDON INSTITUTE.

Schemes for a *Senior* Course submitted by the following *Examining Bodies* have been agreed as suitable for submission to the Ministry by Colleges and Schools under the arrangements and conditions governing the award of National Certificates in Metallurgy :

EAST MIDLANDS EDUCATIONAL UNION.

NORTHERN COUNTIES TECHNICAL EXAMINATIONS COUNCIL.

UNION OF LANCASHIRE AND CHESHIRE INSTITUTES.

Schemes submitted by the following *Technical Colleges* for a Senior Course leading to an Ordinary National Certificate in Metallurgy have been approved and are in operation :

BATTERSEA POLYTECHNIC, LONDON.

BIRMINGHAM CENTRAL TECHNICAL COLLEGE.

CHESTERFIELD TECHNICAL COLLEGE.

COVENTRY TECHNICAL COLLEGE.

CUMBERLAND TECHNICAL COLLEGE, WORKINGTON.

DUDLEY AND STAFFORDSHIRE TECHNICAL COLLEGE (Scheme is supplementary to that of County Technical College, Wednesbury).

ENFIELD TECHNICAL COLLEGE.

MERCHANT VENTURERS' TECHNICAL COLLEGE, BRISTOL.

MIDDLESBROUGH, CONSTANTINE TECHNICAL COLLEGE.

NEWPORT TECHNICAL COLLEGE.

ROTHERHAM TECHNICAL COLLEGE.

SCUNTHORPE TECHNICAL SCHOOL.

SMETHWICK, THE CHANCE TECHNICAL COLLEGE.

SWANSEA TECHNICAL COLLEGE.

WEDNESBURY, COUNTY TECHNICAL COLLEGE.

WOLVERHAMPTON AND STAFFORDSHIRE TECHNICAL COLLEGE.

NEWS AND ANNOUNCEMENTS

Schemes submitted by the following *Technical Colleges* for an Advanced Course leading to a Higher National Certificate in Metallurgy have been approved and are in operation :

WEDNESBURY, COUNTY TECHNICAL COLLEGE.

WOLVERHAMPTON AND STAFFORDSHIRE TECHNICAL COLLEGE.

Final Examinations have been held this year at the following Colleges for students who satisfied the conditions laid down in Ministry of Education Rules III under which the scheme is operated :

Ordinary Certificate

BATTERSEA POLYTECHNIC, LONDON.

BIRMINGHAM CENTRAL TECHNICAL COLLEGE.

CHESTERFIELD TECHNICAL COLLEGE.

COVENTRY TECHNICAL COLLEGE.

MERCHANT VENTURERS' TECHNICAL COLLEGE, BRISTOL.

ROTHERHAM TECHNICAL COLLEGE.

SCUNTHORPE TECHNICAL SCHOOL.

SMETHWICK, THE CHANCE TECHNICAL COLLEGE.

SWANSEA TECHNICAL COLLEGE.

WEDNESBURY, COUNTY TECHNICAL COLLEGE.

WOLVERHAMPTON AND STAFFORDSHIRE TECHNICAL COLLEGE.

Higher Certificate

WEDNESBURY, COUNTY TECHNICAL COLLEGE.

WOLVERHAMPTON AND STAFFORDSHIRE TECHNICAL COLLEGE.

The Committee is pleased to report that distinctions have been awarded to thirteen candidates who have shown an exceptional grasp of their subjects, indicating a high degree of training and knowledge in the particular subject in which the distinction has been gained.

The Joint Committee wishes to take this opportunity of again thanking the Assessors for their valuable assistance in the operation of the scheme for National Certificates in Metallurgy, particularly in connection with the first two years' examinations.

Prize Fund. As previously reported, the Iron and Steel Institute, the Institution of Mining and Metallurgy, and the Institute of Metals have contributed to a Prize Fund, and it is the intention of the Joint Committee to award prizes to students of sufficient merit. Prizes, taken in books and distributed by the Colleges concerned, were awarded to seven successful candidates in the final examinations for the Ordinary Certificate in 1946.

Signed on behalf of the Joint Committee
for National Certificates in Metallurgy.

H. S. TASKER,
Chairman.

Pass List, Year 1946-1947

Senior Part-time Course for Ordinary National Certificate

| <i>Name of Candidate.</i> | <i>Distinctions awarded.</i> |
|---------------------------|------------------------------|
|---------------------------|------------------------------|

BATTERSEA POLYTECHNIC, LONDON.

| | |
|--------------------------------|---------------------|
| Casling, William Henry | *** |
| Graham, John Alastair | General metallurgy |
| James, Victor Leonard | Chemistry and |
| | physical metallurgy |
| Proffitt, Henry Joseph | *** |

NEWS AND ANNOUNCEMENTS

Name of Candidate. *Distinctions awarded.*

BIRMINGHAM CENTRAL TECHNICAL COLLEGE.

| | | | | |
|--------------------------|---|---|---|-----------|
| Burnard, David Chance | . | . | . | Chemistry |
| Lee, Raymond Frederick | . | . | . | ... |
| Pester, Dorothy Margaret | . | . | . | ... |
| Storer, Roy Alan | . | . | . | ... |
| Thomas, John Leslie | . | . | . | ... |
| Toach, Shirley Alan | . | . | . | ... |
| Warwick, Leslie Vincent | . | . | . | ... |

CHESTERFIELD TECHNICAL COLLEGE.

| | | | | |
|---------------------------|---|---|---|--------------------|
| Lynch, John James | . | . | . | ... |
| Meakin, John | . | . | . | ... |
| Moss, John Barry | . | . | . | Physical chemistry |
| Pugh, Jack Fisher | . | . | . | ... |
| Sutherland, John McKellar | . | . | . | ... |

MERCHANT VENTURERS' TECHNICAL COLLEGE, BRISTOL.

| | | | | |
|------------------------|---|---|---|-----|
| Atherton, Norman James | . | . | . | ... |
| Murlis, Douglas Harry | . | . | . | ... |
| Phillips, Esme Gladys | . | . | . | ... |
| Robson, Alfred Wayman. | . | . | . | ... |

ROTHERHAM TECHNICAL COLLEGE.

| | | | | |
|-------------------------|---|---|---|-----|
| Bond, Leslie | . | . | . | ... |
| Broadbent, Peter Robert | . | . | . | ... |
| Graves, Geoffrey Basil | . | . | . | ... |
| Mayo, George Victor | . | . | . | ... |

SMETHWICK, THE CHANCE TECHNICAL COLLEGE.

| | | | | |
|--------------------------------|---|---|---|--------------------------------|
| Allen, Gordon Leonard | . | . | . | General metallurgy |
| Brett, Alan Samuel | . | . | . | ... |
| Burton, James | . | . | . | ... |
| Cornes, Leslie George | . | . | . | ... |
| Davis, Derrick Sydney | . | . | . | ... |
| Dunning, Malcolm John | . | . | . | General metallurgy |
| Forsyth, Richard Victor Walter | . | . | . | ... |
| Harris, Leslie Howard William | . | . | . | General metallurgy |
| Harvie, Kenneth Ryder | . | . | . | ... |
| Laker, Gordon Patrick | . | . | . | ... |
| McManus, William George | . | . | . | General metallurgy |
| Salmon, Clifford Gerald | . | . | . | Physics |
| Scott, John Edward | . | . | . | Physics and chemistry |
| Taylor, Alan John | . | . | . | ... |
| White, John Harold | . | . | . | Physics and general metallurgy |

SWANSEA TECHNICAL COLLEGE.

| | | | | |
|----------------------|---|---|---|-----|
| Lewis, Ogwyn | . | . | . | ... |
| O'Connor, James John | . | . | . | ... |
| Rees, George Philip | . | . | . | ... |

NEWS AND ANNOUNCEMENTS

Name of Candidate. *Distinctions awarded.*

WEDNESBURY, COUNTY TECHNICAL COLLEGE.

| | |
|--------------------------------|--------------------|
| Elson, Gladys | ... |
| Feasey, Raymond James | ... |
| Harrison, Jim | ... |
| Meadows, Albert William | ... |
| Richards, Charles John Godfrey | General metallurgy |
| Tyler, Arthur William | ... |
| Vaughan, Geoffrey Raymond | ... |
| Wakeman, Peter John | ... |

WOLVERHAMPTON AND STAFFORDSHIRE TECHNICAL COLLEGE.

| | |
|----------------------------|--------------------|
| Baker, Joan Theresa | ... |
| Crowe, Stanley Frederick | ... |
| Firm, Iris | ... |
| Fisher, Kevin | ... |
| Holgate, Sheila Marjory | ... |
| Meachem, Frederick Arthur | General metallurgy |
| Wicks, Clive William Harry | ... |
| Williams, Edward | ... |
| Williams, John Randall | ... |

The above candidates have also passed in the additional and optional Final Year subject—engineering drawing.

Advanced Part-time Course for Higher National Certificate

Name of Candidate. *Distinctions awarded.*

WEDNESBURY, COUNTY TECHNICAL COLLEGE.

| | |
|-------------------------------|-----|
| Beebe, Trevor | ... |
| Bickley, Alan Geoffrey | ... |
| Burkin, Derek | ... |
| Cattell, Dorothy Mary | ... |
| Dugard, Stanley Edward | ... |
| Hartill, Albert E. | ... |
| Holloway, John Douglas | ... |
| Kitson, Harold Edward | ... |
| Lloyd, Rex | ... |
| London, Derek Wilfred | ... |
| Mercer, Geoffrey Henry Ernest | ... |
| Morgan, Edward Llewellyn | ... |
| O'Connor, Denis | ... |
| Parton, John Thomas | ... |
| Phipps, Kenneth James | ... |
| Vaughan, Charles Stanley | ... |
| Whitehouse, Richard William | ... |

WOLVERHAMPTON AND STAFFORDSHIRE TECHNICAL COLLEGE.

| | |
|-------------------------|-----|
| Tansley, Anthony Victor | ... |
|-------------------------|-----|

Prizes

Prizes (to be taken in books) will be awarded to the following candidates in respect of the Final Examinations for the Ordinary and Higher Certificate held in June 1947 :

NEWS AND ANNOUNCEMENTS

ORDINARY CERTIFICATE.

Battersea Polytechnic, London.

| | |
|---------------------------------|--------------|
| Graham, John Alastair | One guinea |
| James, Victor Leonard | Four guineas |

Birmingham Central Technical College.

| | |
|---------------------------------|------------|
| Burnard, David Chance | One guinea |
|---------------------------------|------------|

Chesterfield Technical College.

| | |
|----------------------------|-------------|
| Moss, John Barry | Two guineas |
|----------------------------|-------------|

Rotherham Technical College.

| | |
|-----------------------------------|------------|
| Broadbent, Peter Robert | One guinea |
|-----------------------------------|------------|

Smethwick, The Chance Technical College.

| | |
|--|---------------|
| Allen, Gordon Leonard | One guinea |
| Dunning, Malcolm John | Three guineas |
| Forsyth, Richard Victor Walter | Two guineas |
| Harris, Leslie Howard William | One guinea |
| McManus, William George | Three guineas |
| Salmon, Clifford Gerald | One guinea |
| Scott, John Edward | Four guineas |
| White, John Harold | Four guineas |

Swansea Technical College.

| | |
|-------------------------------|------------|
| Rees, George Philip | One guinea |
|-------------------------------|------------|

Wednesbury, County Technical College.

| | |
|--|------------|
| Richards, Charles John Godfrey | One guinea |
| Wakeman, Peter John | One guinea |

Wolverhampton and Staffordshire Technical College.

| | |
|-------------------------------------|---------------|
| Meachem, Frederick Arthur | Three guineas |
|-------------------------------------|---------------|

HIGHER CERTIFICATE.

Wednesbury, County Technical College.

| | |
|----------------------------------|------------|
| Bickley, Alan Geoffrey | One guinea |
|----------------------------------|------------|

OTHER NEWS

SURVEY OF SCIENTIFIC AND TECHNOLOGICAL MAN-POWER

The Report on Scientific Man-Power (Cmd. 6824), which was based on the work of a Committee presided over by Sir Alan Barlow, received widespread attention in the technical and daily press; it emphasized the vital need for increasing the output of qualified scientists and technologists, in view of the increasing demands which will be made on scientific knowledge following the development of scientific discoveries and their conversion from war-time to peace-time use.

In order that the part which Universities and Technical Colleges will be called on to play in this connection may be estimated with greater accuracy than hitherto, the Government's Advisory Council on Scientific Policy has requested the help of the Technical and Scientific Register of the Ministry of Labour and National Service in estimating the existing man-power in the fields of science and technology. In consequence, a questionnaire has been circulated to all British scientific and technical men and women so that as complete an analysis as possible may be made of the existing British scientific and technological man-power in the United Kingdom and overseas in respect of its distribution in age-groups

NEWS AND ANNOUNCEMENTS

between Government, industry, university, and school teaching. This analysis will be used as a basis for estimating in which sciences it will be necessary to take special steps for increasing the output of the Universities and Technical Colleges. In view of the international developments of science, it is also important for information to be compiled regarding the knowledge and experience of foreign languages and countries and of British territories overseas which is possessed by British scientists and technologists.

Any members or subscribers of British nationality who have not yet received a copy of the questionnaire are requested to apply for one to the offices of the Institute.

NATIONAL FOUNDRY COLLEGE

The College is now in being and its Board of Governors, representing all the bodies concerned—trade associations, technical institutions, and research associations in the industry, has been established by the Ministry of Education.

The first task of the Board of Governors was to re-establish the full-time Diploma Course on the lines so successfully carried out by the British Foundry School during 1935-1939. This Course will, in general, be for one academic year from September to July, and is intended for those whose practical and technical qualifications and abilities in leadership mark them out for responsible positions in the industry. It is hoped that the Course will help to overcome the dearth of qualified foundry executives.

The Course for the first year will be abbreviated somewhat. It is anticipated that it will open on 5 January 1948 at the National Foundry College within the Wolverhampton and Staffordshire Technical College, and run until August 1948.

The new Head of the National Foundry College, Mr. James Bamford, B.Sc., was in charge of the British Foundry School from 1935 to 1939. Particulars of the College and copies of its prospectus and curriculum, &c., may be obtained from the Director, British Cast-Iron Research Association, Alvechurch, Birmingham.

POWDER METALLURGY

Those interested in powder metallurgy may apply to Powder Metallurgy, Ltd., Commonwealth House, 1-19 New Oxford St., London, W.C.1, for a specimen copy of the "Metal Powder Report". This 16-page monthly abstracts journal is edited by Dr. W. D. Jones and Mr. R. A. Hetzig. The September issue contains full summaries of recent B.I.O.S. reports, British, French, U.S., and Canadian patents, as well as a number of important scientific papers on the manufacture and uses of metal powders.

NON-FERROUS DIRECTORATE (DISPOSALS)

The address of the Non-Ferrous Directorate (Disposals) is now 2 Hyde Park Street, London, W.C.2. (Ambassador 1290.)

SCIENTIFIC AND TECHNICAL RESEARCH IN BRITISH INDUSTRY

A statistical survey carried out by the Industrial Research Secretariat of the Federation of British Industries has recently been published, and may be obtained, price 1s., from the Federation at 21 Tothill Street, London, S.W.1.

NEWS AND ANNOUNCEMENTS

420 firms supplied material for the questionnaire sent out by the F.B.I., and it is estimated that the facts set out in the survey cover 75 % of the total research work now being carried out by British industry.

SWISS SPECTROSCOPISTS' CLUB

The Schweizerische Arbeitsgemeinschaft für Spektralanalyse was founded as an informal club in 1938, meeting twice yearly, and held its twentieth meeting on 20 October this year. For the first time they invited a foreign speaker to address them, and they chose Mr. Ernest van Someren, the Honorary Secretary of the Industrial Spectroscopic Group of the British Institute of Physics. The meeting was held at the old head office of the A.I.A.G. works where the first aluminium was made in Europe, and Professor von Zeerleder, one of the founders of the Swiss Club, was present. In the afternoon members divided into two parties, to visit either the Research Laboratories of the A.I.A.G. or those of the Amsler factory.

Mr. van Someren, who spoke in English, reviewed the present position of spectroscopic analysis in Great Britain, with special reference to light sources, methods of sample preparation, and microphotometry. Two other shorter papers were given in German and in French, dealing with colorimetric methods and with spectrographic methods of steel analysis, respectively.

On his return journey, Mr. van Someren also visited the officers of the corresponding French Group, the G.A.M.S., who hold conferences on spectroscopy in the last week of January and of June each year, in Paris. Metallurgists with an interest in spectroscopy who may be in Paris next year at one of these periods are invited to approach Mr. van Someren for an introduction to the French Group.

BRITISH COUNCIL'S SHORT-TERM BURSARY SCHEMES

The British Council has inaugurated a scheme for the award of short-term bursaries to candidates from overseas, to enable them to see something of British industrial technique and machinery. The majority of the candidates will be technical workers, and each bursary will cover travel to and from the United Kingdom and will include a maintenance grant during the three or four months they will spend in this country.

Some of the trades which have so far been included are water engineer, tractor engineer, electrical fitter, road construction engineer, wagon shop and carriage foreman, and librarian.

COMMONWEALTH FUND FELLOWSHIPS

The Commonwealth Fund of New York has established for British subjects a number of Fellowships tenable in the United States. In creating these Fellowships, the Directors of the Fund have been impelled by their belief in the value of international opportunities for education and travel, and by a conviction that mutual amity and understanding between Great Britain and the United States will thereby be promoted. None of these Fellowships is open to women. Full particulars of the Fellowships may be obtained from the Commonwealth Fund Fellowships, 35 Portman Square, London, W.1. Some details are given below.

NEWS AND ANNOUNCEMENTS

Ordinary Fellowships. Not more than 20 will be offered during 1948. Candidates must be persons of British descent who are domiciled in the United Kingdom and are degree graduates of recognized universities therein; they must be over 23 and not have reached the age of 35 on 1 September of the year of the award; or they may be persons of British descent who have studied, but not necessarily graduated, at a university in the U.K. and are degree graduates of a recognized university in Australia, New Zealand, and South Africa, and who fulfil the age requirements mentioned above. Such candidates need not show a permanent domicile in the U.K., but must be available for interview in London in May.

Service Fellowships. Candidates of British descent who hold appointments overseas under the British Government in Australia, New Zealand, and South Africa, or Governments of the British colonies, protectorates, or mandated territories. Not more than 5 such Fellowships will be awarded in 1948.

Home Civil Service Fellowships. Candidates holding appointments in the Home Civil Service. Not more than 3 such Fellowships will be awarded in 1948.

QUANTUM CHEMISTRY

A special course of six lectures by Professor H. S. W. Massey, B.A., M.Sc., Ph.D., F.R.S., will be held at the Sir John Cass Technical Institute, Jewry Street, Aldgate, London, E.C.3, on Tuesday evenings from 6 to 7 p.m., commencing on Tuesday, 3 February 1948. The fee for the course will be 10s., and applications should, if possible, be made to the Principal prior to the opening date of the course.

The course is intended for post-graduate and advanced students and will be addressed chiefly to those who do not possess the mathematical equipment which is necessary for the usual treatment of these problems.

The syllabus of lectures is: 1.—The electronic structure of atoms according to the quantum theory; 2.—The quantum picture of the simplest molecules—the new interpretation of valency; 3.—Quantum theory and organic chemistry; 4.—The theory of metals; 5.—The nature of crystal binding—electrode phenomena; 6.—Nuclear structure.

TELECOMMUNICATIONS RESEARCH

The Department of Scientific and Industrial Research is to take over the fundamental radio side of the Telecommunications Research Establishment, the Services' biggest war-time radio station, at Malvern, to develop and use techniques for industrial purposes. Sir Edward Appleton, Secretary of the Department, told the Select Committee on Estimates, whose minutes of evidence were published recently, that the establishment was too large for peace-time.

The D.S.I.R. had proposed assuming responsibility for those working on fundamental research, at a cost of £80,000 per annum, and of another group working on electronics and their applications to industry up to about £60,000 per annum. Ultimately, the sections will form part of the Department's central radio-research establishment.

NEWS AND ANNOUNCEMENTS

AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Professor Arthur B. Bronwell, of the North-western University, has been appointed Secretary of the Society, the address of the offices of which has been changed from the University of Pittsburgh to North-western University, Evanston, Ill.

PHYSICO-CHEMICAL SYMBOLS AND CO-ORDINATION OF SCIENTIFIC TERMINOLOGY

Dr. H. J. Ellingham has been appointed to succeed Professor A. Findlay as President of the International Union of Chemistry on Physico-Chemical Symbols and Co-ordination of Scientific Terminology.

MECHANICAL HANDLING EXHIBITION AND CONVENTION

The First National Mechanical Handling Exhibition and Convention will be held at the National Hall, Olympia, London, from 12 to 21 July 1948. Particulars may be obtained on application to "Mechanical Handling", Dorset House, Stamford Street, London, S.E.1.

TECHNICAL INFORMATION AND DOCUMENTS UNIT

B.I.O.S. Information Service will now become T.I.D.U. Information Section. With a view to centralizing the work and offering an improved service to industry on both reports and documents, B.I.O.S. and the Documents Unit have now been integrated and will be known as the Technical Information and Documents Unit (T.I.D.U.), German Division, Board of Trade, 40 Cadogan Square, London, S.W.1.

SCIENCE LIBRARY PHOTO-COPYING SERVICE

The Science Library has announced that it will commence a photo-copying service in the early part of next year. A readable copy of an article in a periodical of up to 20 pages will be printed for 2s.

This low price is only possible because the service has been planned on mass-production lines. All copies will be photostat negatives reduced to about 80% of the original size on sheets either $9\frac{1}{2} \times 8$ in. or $13\frac{3}{8} \times 9$ in. Publications which cannot be satisfactorily copied in this way will not be copied. To eliminate accounting costs the service will only be available to purchasers of requisition forms. Books of 50 forms will be available for £5.

Full details of the copying service are to be issued about the beginning of January 1948; at first, requisitions for copies of British publications published since 1850 must be accompanied by the written approval to copy from the publisher. The Science Library has made tentative approaches to some learned societies to obtain general approval to copy their publications and, pending the revision of the Copyright Act, it is hoped that this approach to the problem will be successful.

To assist the Science Library in making adequate provision for the introduction of the service, organizations which are likely to utilize it have been asked to forward an estimate of their annual requirements as soon as possible.

NEWS AND ANNOUNCEMENTS

NATIONAL CERTIFICATES IN CHEMISTRY (ENGLAND AND WALES)

The Report of the Assessors for the year 1946-47 states that the number of entries in the Senior Grade was 426, of whom 254 passed, as compared with 358 entries in 1946, of whom 247 passed.

In the Advanced Grade there were 148 candidates, of whom 110 passed (as compared with 112 and 83, respectively, in 1946). Of the 148 candidates, 117 had previously obtained the Ordinary Certificate, and of the 110 successful candidates 90 had previously obtained the Ordinary Certificate.

SUPPLEMENTARY ENDORSEMENT AND COUNTERSIGNATURE OF NATIONAL CERTIFICATES IN MECHANICAL ENGINEERING

Agreement has been reached by the Ministry of Education, in conjunction with the Institution of Mechanical Engineers, and the Institution of Chemical Engineers, to arrangements providing for the supplementary endorsement of Ordinary and Higher National Certificates in Mechanical Engineering in respect of special supplementary courses in chemical engineering and in respect of Higher National Certificates for countersignature by the Institution of Chemical Engineers.

In order to qualify for supplementary endorsement and countersignature the following considerations will apply:

(a) *Supplementary Endorsement of Ordinary National Certificates in Mechanical Engineering.* It will be a necessary preliminary to consideration for supplementary endorsement of Ordinary National Certificates in Mechanical Engineering that the student's course for that certificate shall have included heat engines as one of the assessed subjects. In addition to satisfying the conditions for the Ordinary National Certificate including the above provision, the student will be required to spend a further minimum 180 hours covering physical, organic, and inorganic chemistry. The certificates of successful candidates will be endorsed by the Institution of Mechanical Engineers with the titles of the subjects taken at the supplementary course.

(b) *Supplementary Endorsements of Higher National Certificates in Mechanical Engineering and Countersignature by the Institution of Chemical Engineers.* It will be a necessary preliminary to consideration for supplementary endorsement and countersignature of a Higher National Certificate in Mechanical Engineering that the student's course for that certificate shall have covered the following—mathematics, strength of materials, heat engines, hydraulics, metallurgy or electro-technology. In addition to satisfying the conditions for the Higher National Certificate including the above provision, the student will be required to spend a further 180 hours on a course in chemical engineering and chemistry. The certificates of successful candidates will be endorsed by the Institution of Mechanical Engineers with the titles of the subjects taken at the supplementary course and will then be countersigned on behalf of the Institution of Chemical Engineers.

Application for Supplementary Endorsement and Countersignature. Special courses for supplementary endorsement and countersignature referred to above need not necessarily be taken at the same establishment or at the same establishment as the

NEWS AND ANNOUNCEMENTS

original course for the National Certificate, but may be held at any Further Education Establishment approved, or which may be approved, for the purpose. It will be necessary, however, for forms of application in respect of such courses to be submitted in the first instance to the Ministry of Education for consideration by the Joint Committee. Forms 275 F.E. relating to National Certificates in Mechanical Engineering should be used. In completing the forms of application, particulars of the special course in question should be clearly stated, e.g. it is suggested that Head I of the form should show an entry on the following lines: "Special supplementary senior part-time course in chemical engineering for endorsement of Ordinary National Certificate in Mechanical Engineering", or "Special supplementary advanced part-time course in chemical engineering for endorsement of Higher National Certificate in Mechanical Engineering and for countersignature by the Institution of Chemical Engineers".

Assessors. The subjects of the special supplementary courses in Chemical Engineering will be assessed by Assessors appointed with full agreement of both the Institution of Mechanical Engineers and the Institution of Chemical Engineers.

DIARY FOR JANUARY

LOCAL SECTIONS MEETINGS

Birmingham Local Section.—Symposium on Chain Making. (James Watt Memorial Institute, Great Charles Street, Birmingham, Thursday, 22 January 1948, at 6.30 p.m.)

London Local Section.—Dr. L. B. Hunt: "Silver". (4 Grosvenor Gardens, London, S.W.1, Thursday, 8 January 1948, at 7 p.m.)

Scottish Local Section.—Mr. J. Stuart Scott: "Metal Spraying". (Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow, C.2, Monday, 12 January 1948, at 6.30 p.m.)

Sheffield Local Section.—Mr. E. W. Colbeck, M.A.: "Some Metallurgical Problems in the Field of Atomic Energy". (Royal Victoria Hotel, Sheffield, Friday, 23 January 1948, at 6.15 p.m.)

South Wales Local Section.—Display of industrial films. (Metallurgy Department, University College, Swansea, Tuesday, 13 January 1948, at 6.30 p.m.)

OTHER MEETINGS

Birmingham University Metallurgical Society.—Symposium on Current Departmental Research, Part II. (The University, Edgbaston, Birmingham, Thursday, 22 January 1948, at 5 p.m.)

British Institution of Radio Engineers, Scottish Section.—Dr. W. D. Oliphant: "Atomic Energy". (Heriot Watt College, Edinburgh, Wednesday, 21 January 1948, at 6.30 p.m.)

Chemical Society.—Dr. P. Gross: "The Physical Chemistry of Some Vacuum Metallurgical Processes". Joint Meeting with the University of Swansea Students' Chemical Society. (University College, Swansea, Monday, 19 January 1948, at 6 p.m.)

NEWS AND ANNOUNCEMENTS

Cleveland Institution of Engineers.—E. F. Brown: "Desilicization". (Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, Monday, 5 January 1948, at 6.30 p.m.)

Electrodepositors' Technical Society.—K. Langford: "Dyeing of Anodized Aluminium". (James Watt Memorial Institute, Great Charles Street, Birmingham, Tuesday, 6 January 1948.)

Electrodepositors' Technical Society.—R. C. L. Eveleigh: "Paints on Metallic Surfaces". (Northampton Polytechnic, St. John Street, Clerkenwell, London, E.C.1, Monday, 19 January 1948, at 5.30 p.m.)

Geological Society of London.—Ordinary Evening Meeting. (Burlington House, Piccadilly, London, W.1, Wednesday, 14 January 1948, at 5 p.m.)

Institute of British Foundrymen, Bristol and West of England Branch.—J. L. Howard: "Bronze Castings". (Grand Hotel, Broad Street, Bristol, Saturday, 24 January 1948, at 3 p.m.)

Institute of British Foundrymen, East Midlands Branch.—W. W. Braidwood: "The Constant Charge System of Cupola Operation". (Loughborough College, Wednesday, 28 January 1948, at 6 p.m.)

Institute of British Foundrymen, Lancashire Branch.—J. F. B. Jackson: "Centrifugally and Precision-Cast Ferrous Alloys for Aircraft Applications". (Engineers' Club, Albert Square, Manchester, Wednesday, 7 January 1948, at 7 p.m.)

Institute of British Foundrymen, Lincoln Section.—D. Killingworth: "Venting of Cores and Moulds". (Technical College, Lincoln, Thursday, 15 January 1948, at 7.15 p.m.)

Institute of British Foundrymen, London Branch.—H. Evans, Assoc. Met., P. S. Cotton, B.Sc., and J. Thexton, Assoc. Met.: "Precision Casting of High Melting Point Alloys Containing Nickel", with technicolour film. (Waldorf Hotel, London, W.C., Wednesday, 28 January 1948, at 7.30 p.m.)

Institute of British Foundrymen, Middlesbrough Branch.—Film presented by W. H. Salmon: "The Production of High-Quality Steel". (Cleveland Scientific and Technical Institute, Middlesbrough, Friday, 16 January 1948, at 7 p.m.)

Institute of British Foundrymen, Newcastle Branch.—Past-Presidents' Night. (Neville Hall, Newcastle-on-Tyne, Saturday, 10 January 1948, at 6 p.m.)

Institute of British Foundrymen, Scottish Branch.—R. S. M. Jeffrey, B.Sc.: "Mechanized Bath Production". (Royal Technical College, George Street, Glasgow, Saturday, 10 January 1948, at 3 p.m.)

Institute of British Foundrymen, Sheffield Branch.—L. Roy: "The Use of Fulbond in Foundries". (Royal Victoria Hotel, Sheffield, Monday, 12 January 1948, at 7.30 p.m.)

Institute of British Foundrymen, West Riding of Yorkshire Branch.—H. Berry: "Improvements in Conditions and Amenities in Foundries". (Chemistry Lecture Theatre, Leeds University, Tuesday, 13 January 1948, at 7 p.m.)

NEWS AND ANNOUNCEMENTS

Institute of Physics, Industrial Radiology Group.—F. P. Vickers: "Weld Radiography". (Institute of Physics, 47 Belgrave Square, London, S.W.1, Friday, 9 January 1948, at 6.30 p.m.)

Institute of the Motor Industry, Colwyn Bay Centre.—Beynon: "Oxy-Acetylene Welding for the Use of Vehicle Maintenance in All Aspects". (Co-operative Hall, Sea View Road, Colwyn Bay, Thursday, 22 January 1948, at 7.30 p.m.)

Institute of the Motor Industry, Newcastle-on-Tyne Centre.—P. P. Love: "Bearing Failure—Analysis and Prevention". (County Hotel, Neville Street, Newcastle-on-Tyne, Tuesday, 20 January, 1948, at 7.15 p.m.)

Institute of the Motor Industry, Stockton-on-Tees Centre.—Cobb: "Oxy-Acetylene Welding for the Use of Vehicle Maintenance in all Aspects". (Tuesday, 13 January 1948.)

Institute of Welding.—Sir William J. Larke Medal Paper. (Institution of Civil Engineers, Great George Street, London, S.W.1, Wednesday, 28 January 1948, at 6 p.m.)

Institute of Welding, Middlesbrough Branch.—Instructional film (sound): "Advanced Arc Welding Technique". (Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, Thursday, 8 January 1948, at 7.30 p.m.)

Institute of Welding, South London Branch.—G. L. Hopkin, B.Sc.: "The Practical Importance of Hydrogen in Welding Ferrous and Non-Ferrous Metals". (Institute of Marine Engineers, 85-88 The Minories, London, E.C.3, Thursday, 8 January 1948, at 6.30 p.m.)

Institute of Welding, West of Scotland Branch.—Film night. (Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow, C.2, Wednesday, 21 January 1948, at 6.45 p.m.)

Institution of Civil Engineers.—C. E. Dunton, M.A., and Keith Brinsmead, D.S.O.: "Design, Installation, and Maintenance of Long Welded Rails". (The Institution, Great George Street, London, S.W.1, Tuesday, 27 January 1948, at 5.30 p.m.)

Institution of Electrical Engineers.—Discussion (opened by C. S. Parsons, B.Sc.) on: "The British Patent System and Procedure". (The Institution, Savoy Place, London, W.C.2, Monday, 26 January 1948, at 5.30 p.m.)

Institution of Mechanical Engineers.—C. Eatough, B.Sc.Tech.: "Modern Cutting Tools and Machine Tool Design". (The Institution, Storey's Gate, London, S.W.1, Friday, 2 January 1948, at 5.30 p.m.)

Institution of Mining and Metallurgy.—General Meeting. (Geological Society, Burlington House, Piccadilly, London, W.1, Thursday, 15 January 1948, at 5 p.m.)

Institution of Structural Engineers, Midland Counties Branch.—R. G. Braithwaite: "Some Practical Considerations in Design of Welded Structures". (James Watt Memorial Institute, Great Charles Street, Birmingham, Friday, 23 January 1948, at 6 p.m.)

NEWS AND ANNOUNCEMENTS

Institution of Structural Engineers, Northern Counties Branch.—O. Bondy: "Recent Trends in Structural Welding". (Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, Tuesday, 6 January 1948, at 6.30 p.m.)

Institution of Structural Engineers, Northern Counties Branch.—O. Bondy: "Recent Trends in Structural Welding". (Neville Hall, Westgate Road, Newcastle-on-Tyne, Wednesday, 7 January 1948, at 6.30 p.m.)

Institution of Works Managers, Glasgow Branch.—A. Miller. (Bulls Metal and Melloid Co., Ltd.): "Costing as an Aid to Management". (Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow, C.2, Monday, 26 January 1948, at 7 p.m.)

Institution of Works Managers, Liverpool Branch.—Professor T. P. Hilditch: "Science in the Small Factory". (Exchange Hotel, Liverpool, Tuesday, 13 January 1948, at 6.45 p.m.)

Institution of Works Managers, Yorkshire Branch.—T. N. P. Burness: "Machine Tool Works Management". (White Swan Hotel, Halifax, Wednesday, 7 January 1948, at 7 p.m.)

Leeds Metallurgical Society.—Symposium on "Casting". (Main Lecture Theatre, Chemistry Department, The University, Leeds, Thursday, 8 January 1948, at 7 p.m.)

Manchester Association of Engineers.—Professor Sir Lawrence Bragg, F.R.S.: "Researches now in Progress in the Cavendish Laboratory". Fifth Manchester Association of Engineers Lecture. (Great Hall of the College of Technology, Sackville Street, Manchester, Friday, 9 January 1948, at 7.30 p.m.)

Manchester Literary and Philosophical Society.—Sir George P. Thomson, F.R.S., "Determinism in the Physical World". Joule Memorial Lecture. (Reynolds Hall, College of Technology, Manchester, Monday, 26 January 1948, at 5.30 p.m.)

Manchester Metallurgical Society.—E. Davis, M.Sc.: "Some Metallurgical Aspects of Jointing Non-Ferrous Materials". (Engineers' Club, Albert Square, Manchester, Wednesday, 28 January 1948, at 6.30 p.m.)

Royal Institute of Chemistry of Great Britain and Ireland, Bristol and South-West Counties Section.—G. H. Osborn: "Recent Developments in the Use of Organic Reagents in Chemical Analysis". (Chemistry Department, University of Bristol, Woodland Road, Bristol, Thursday, 15 January 1948, at 5.30 p.m.)

Sheffield Society of Engineers and Metallurgists.—E. W. Colbeck, M.A.: "Some Metallurgical Problems in the Field of Atomic Energy". Joint meeting with the Sheffield Local Section of the Institute of Metals. (Royal Victoria Station Hotel, Sheffield, Friday, 23 January 1948, at 6.15 p.m.)

Society of Chemical Industry, Chemical Engineering Group.—Dr. C. H. Desch, F.R.S.: "Abrasion, Erosion, and Corrosion". (Geological Society, Burlington House, London, W.1, Tuesday, 20 January 1948, at 5.30 p.m.)

NEWS AND ANNOUNCEMENTS

Swansea and District Metallurgical Society.—H. Edwards: "The Galvanizing of Sheets and Strips by the Hot-Dip Process". (Royal Institution, Swansea, Saturday, 10 January 1948, at 6.30 p.m.)

West of Scotland Iron and Steel Institute.—A. B. C. Rankin: "Flaw Detection by Supersonic and Other Non-Destructive Methods". (Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow, C.2, Friday, 16 January 1948, at 6.45 p.m.)

APPOINTMENTS VACANT

To conform to the requirements of the Control of Engagements Order, 1947, these advertisements are published for the information of those only who are "excepted persons" under the Order.

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 - (a) Papers recording the results of original research ;
 - (b) First-class reviews of, or accounts of, progress in a particular field ;
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3. Manuscripts and illustrations must be submitted in duplicate. MSS. must be typewritten (*double-line spacing*) on one side of the paper only, and authors are required to sign a declaration that neither the paper nor a substantial part thereof has been published elsewhere. MSS. not accepted will be returned within 6 months of receipt.
4. Synopsis. Every paper must have a synopsis (not exceeding 250 words in length), which, in the case of results of research, should state its objects, the ground covered, and the nature of the results. The synopsis will appear at the beginning of the paper.
5. References must be collected at the end of the paper, and must be numbered. Initials of authors must be given, and the Institute's official abbreviations for periodical titles (as used in *Met. Abs.*) must be used where known. References must be set out in the style :
 1. W. Hofmann and W. Jäniche, *Z. Metallkunde*, 1936, **28**, 1 (i.e. year, volume, page).
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No.....

Recd.....

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The INSTITUTE of METALS

4 Grosvenor Gardens, London, S.W.1.

Founded 1908. Incorporated 1910.

To the Secretary,
The Institute of Metals.

I, the UNDERSIGNED.....

being.....years of age and desirous of becoming a*.....

Member of the **Institute of Metals**, agree that if elected I will be governed by the Regulations and Bye-laws of the Institute from time to time extant and observe the obligations imposed on Members under the Articles of Association of the Institute, and that I will advance the interests of the Institute so far as may be in my power ; and we, the undersigned, from our personal knowledge, do hereby recommend the said.....for election.

Name of applicant in full.....

Address

Business or Profession†.....

Qualification

Degrees and/or honorific distinctions.....

Dated this.....day of....., 19.....

Signatures
of three
Members.

The Council, having approved the above recommendation, declare
the applicant to be duly elected as.....
Member of the **Institute of Metals**.

To be filled up
by the
Council.

Chairman.

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

* For **Qualifications of Members**, see other side. An applicant for Student Membership must state date of birth.

† Name and address of firm (or other body) should be stated as well as position held.
(It would be a convenience if the Candidate's Card were sent with this form.)

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The main objects for which the Institute was formed in 1908 are :

(a) To promote the science and practice of non-ferrous metallurgy in all its branches.

(b) To afford a means of communication between members of the non-ferrous metal trades upon matters bearing upon their respective manufactures, other than questions connected with wages, management of works, and trade regulations.

(c) To facilitate the exchange of ideas between members, and between members and the community at large, by holding meetings and by the publication of literature.

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RECENT DEVELOPMENTS IN CORROSION-RESISTANT ALUMINIUM-MAGNESIUM ALLOYS.*

By P. BRENNER,† Dr. Ing., and W. ROTH,‡ Dr. Ing.

SYNOPSIS.

The paper describes an extensive investigation on the influence of chemical composition and thermal treatment on the intercrystalline corrosion of aluminium-magnesium alloys containing 5-9% magnesium.

As a result of the investigation, a new method of heat-treatment, termed a "stabilizing treatment", is suggested in which the alloy is extremely slowly cooled from the homogenizing temperature at a rate of about 50° C./hr. Corrosion tests in the laboratory and in the North Sea, as well as long-term service trials, indicate that alloys treated by this method are immune to intercrystalline-corrosion and stress-corrosion failure even at the high temperatures encountered under tropical conditions.

While cold reduction generally increases the tendency to intercrystalline corrosion, small additions of copper, manganese, chromium, and zinc have very different effects. Some of these additions, e.g. copper, reduce the stress-corrosion-resistance in the homogenized state and improve it in the aged condition. The high stress-corrosion-resistance of alloys containing small additions of chromium instead of the usual manganese is of special interest.

The close correlation between the thermal treatment, the microstructure, and the susceptibility to intercrystalline corrosion and, especially, stress-corrosion of these alloys is clearly indicated.

I.—INTRODUCTION.

Of the aluminium alloys, those of the aluminium-magnesium type are of special interest, since in both the supersaturated-solid-solution and the aged states they show no marked age-hardening, although the solubility of magnesium is very large and decreases rapidly with decreasing temperature.^{1,2} In alloys of very high magnesium content (10%), more marked changes have, of course, been observed, especially in the proof-stress and elongation values in the temperature range 100°-300° C.³ These changes are preceded by grain-boundary precipitation and are accompanied later by precipitation within the grains. Despite this, the processes of solubility and decomposition of the solid solution in aluminium-magnesium alloys are connected with essentially much smaller changes of the mechanical and forming

* Manuscript received 14 March 1947.

† Metallurgy Department, Royal Aircraft Establishment, South Farnborough, Hants.

‡ High Duty Alloys, Ltd., Redditch, Worcester.

properties than in the case of the age-hardening aluminium alloys, e.g. aluminium-copper-magnesium, aluminium-magnesium-silicon, and aluminium-zinc-magnesium. For this reason, the aluminium-magnesium alloys are frequently referred to as "non-age-hardening".

For practical purposes this property is sometimes a disadvantage because these alloys cannot be adapted so easily to the manufacturing processes as can the usual age-hardening alloys, which can be used in a more-ductile and weaker state or in a stronger and less-ductile state by suitable choice of thermal treatment. For example, Duralumin sheets are formed in the annealed or "as-quenched" condition, while in service the finished parts are used in the age-hardened condition. It is well known that in the aircraft industry Duralumin sheets are formed in the fairly soft condition immediately after quenching, and that to obtain high strength without additional heat-treatment the finished parts are stored for some days at room temperature.

Since the mechanical and forming properties of aluminium-magnesium alloys are practically unchanged by thermal treatment, these alloys must be formed in the condition in which they are used in service. If high strength in the finished structural parts is required, a correspondingly highly alloyed material must be used, and all the disadvantages resulting from high magnesium content, especially the reduced formability, must be accepted.

On the other hand, this effect allows more freedom in the choice of the heat-treatment of the aluminium-magnesium alloys than is the case with the usual age-hardening aluminium alloys. For example, in alloys of the aluminium-magnesium-silicon type a choice has to be made between maximum strength or maximum corrosion-resistance, since the condition of highest strength does not correspond with that of maximum corrosion-resistance.^{4, 5} The fact that in the aluminium-magnesium alloys the mechanical properties are practically independent of the thermal treatment enables the heat-treatment to be selected so that other properties, such as corrosion-resistance, reach optimum values. This viewpoint is the basis of the investigations described in this paper.

II.—PREVIOUS INVESTIGATIONS.

Interesting observations on the influence of heat-treatment on the sea-water corrosion-resistance of aluminium-magnesium alloys with higher magnesium contents were published in 1933 by Sterner-Rainer.⁶ Cast, as well as rolled, specimens showed a considerable superiority of the homogeneous over the heterogeneous state. Bearing in mind

the limited stability of the homogeneous state at the high temperatures encountered in tropical service conditions, other authors ⁷ have recommended the use of supersaturated aluminium-magnesium alloys in a special heterogeneous state instead of the homogeneous state. This special state is produced preferably by annealing at a temperature

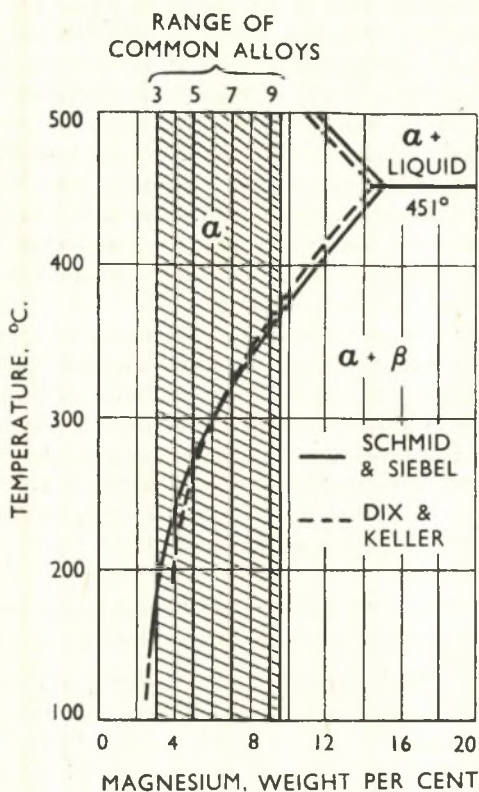


FIG. 1.—Aluminium-Rich Portion of Equilibrium Diagram of the Aluminium-Magnesium System.

just below the solid-solubility line in the aluminium-magnesium equilibrium diagram (Fig. 1). The purpose of this treatment is to precipitate a part (about 1%) of the magnesium contained in solid solution. Further investigations showed that the corrosion-resistance of alloys with higher magnesium contents depends not only on the quantity but also on the arrangement of the precipitated particles, especially at the grain boundaries. A minimum in the stress-corrosion-

resistance of these alloys was observed at low ageing temperatures (100°–150° C.), when very fine precipitation occurs.^{8, 9}

Other efforts have been made to increase the stability of the super-saturated aluminium-magnesium alloys by additions of manganese, chromium, titanium, calcium, silicon, and zinc. Favourable results are reported, especially with alloys containing about 1% zinc.¹⁰ The required stability at elevated temperatures was obtained only when the specimens were not quenched in water but were air cooled after a homogenizing treatment.^{11, 12} A valuable contribution by Sterner-Rainer¹³ gave results which indicated the influence of copper, iron, manganese, nickel, and silicon on the stress-corrosion of cast aluminium alloys containing 2.5% magnesium. Seemann and Wesch¹⁴ have investigated the effect of copper on the corrosion-resistance of aluminium-magnesium alloy sheets containing 7% magnesium. A study of the influence of grain-size on the corrosion-resistance of aluminium-magnesium alloys is also of interest.¹⁵

Another method of increasing the corrosion-resistance of aluminium-magnesium alloys is by cladding with magnesium-free aluminium alloys which are not affected by elevated temperatures, such as aluminium-zinc alloys containing up to 5% zinc, or aluminium-magnesium alloys with less than 3% magnesium.¹⁶ The same principle is the basis of proposals to reduce the magnesium content at the surface by diffusion, thus producing a zone at the surface which does not tend to form a precipitate, because of its low magnesium content.¹⁷

III.—INVESTIGATION OF THE CORROSION-RESISTANCE OF ALUMINIUM ALLOYS CONTAINING 5–9% MAGNESIUM.

Investigations were planned with the object of determining the most suitable heat-treatment for aluminium-magnesium alloys containing 5–9% magnesium and of observing the effect of some of the most promising additions of small amounts of other metals in combination with the heat-treatment. Since the results of previous investigations were frequently incomplete and were sometimes contradictory, experiments were carried out to check the anomalies reported. In addition, some fundamental questions as to the influence of the amount of magnesium and the purity of the original aluminium used for the manufacture of aluminium-magnesium alloys had to be resolved.

1. *Material Employed.*

The alloys were melted in the ordinary way, cast into 150-mm. (6-in.)-dia. chill moulds and extruded to bars of a cross-section of

100 × 20 mm. (4 × 0.8 in.) which were hot rolled to 6 mm. (0.24 in.) thickness and then cold rolled to the finished gauge. The cold reduction between annealing treatments at 380°–400° C. was 20–50%, depending on the magnesium content of the different alloys.

2. *Corrosion-Testing Methods.*

(a) *Corrosion Tests Without Stress.* The immersion method described in the German Specification D.I.N. E4853 was used. The electrolyte, which is stirred, is a solution of 3% sodium chloride containing 0.1% hydrogen peroxide.¹⁸ The immersed specimens (200 mm. long and 1.0 mm. thick) have the shape of the finished tensile test-pieces. The corrosion-resistance is measured by the loss of tensile strength and elongation after various periods of corrosion. Each of the established values is the average of 3 specimens.

This method has proved successful as an accelerated sea-water corrosion test for aluminium alloys and has been investigated in conjunction with extensive comparative corrosion tests in the North Sea.¹⁹ Because of its good reproducibility and accuracy and the uniformity of the corrosion attack over the whole surface of the specimens, this method appears to be particularly suitable for research work.²⁰

(b) *Stress-Corrosion Tests.* An immersion method described by the authors in an earlier paper⁸ was employed. The specimens are placed in a vertical position with the lower ends fixed at the bottom of a container, while the upper ends of the specimens bear levers loaded by weights. Any desired bending stress can be produced in the specimens by choice of a suitable weight. The applied bending stresses are 10 and 15-kg./mm.². The container is filled with a solution of 3% sodium chloride containing 1% by weight of hydrochloric acid. The stress-corrosion-resistance is measured by determining the time for which the specimens resist a certain bending stress. Failure occurs by fracture or by yielding. The type of failure is denoted in the Tables of results. Every result is based on tests of two specimens, which generally show good agreement.

The fractures always had a brittle appearance, caused by heavy intercrystalline attack (Fig. 4, Plate XVIII). The yielding occurred because of the increased stresses resulting from the reduction in thickness of the specimens by corrosion. The corrosion usually took the form of a general attack, which reduced the thickness of the specimen, but sometimes uniform penetration by intercrystalline corrosion occurred over the whole surface of the test-piece. Since failure is due to the gradual increase in deformation of the specimen, it is less serious than fracture occurring suddenly and without warning.

This method is a much accelerated test for aluminium alloys which are susceptible to intercrystalline corrosion because it gives a reliable indication of grain-boundary precipitation, which is one of the main causes of intercrystalline corrosion, particularly in aluminium-magnesium alloys. Though this method has not been so extensively proved as the standard corrosion methods, good results have been obtained in its application to research, as well as in the checking of material prior to delivery. Considerable quantities of aluminium-magnesium alloy sheets tested by this method and shown to be immune, did not fail in service.

In addition, a comparison between results obtained by this method after 6 days and those obtained by the standard method (D.I.N. E4853) after 450 days showed very good agreement in the case of an aluminium-7% magnesium alloy subjected to various heat-treatments²⁸; this supports the extensive use of this accelerated test in the work described in this paper. It appears from these investigations that stress-corrosion and stress-less intercrystalline corrosion of aluminium-magnesium alloys are closely related; the results differ mainly in degree, as a consequence of the acceleration of intercrystalline corrosion by the application of simultaneous stress.

Some of the most important results have been compared with stress-corrosion tests in the North Sea on similar specimens, exposed at the coast of the Isle of Sylt in such a manner that they were tidally immersed and dried.

Where other corrosion-testing methods have been used, further descriptions are given.

All specimens were cut out of the sheets transverse to the direction of final rolling.

3. Influence of Homogenizing and Ageing.

The term "homogenizing" implies heating the alloy, so as to obtain a completely homogeneous solid solution, and quenching in water in order to retain the alloy in a state of homogeneous solid solution.

First, the stress-corrosion-resistance of an aluminium-9% magnesium alloy in the homogenized state and after different ageing treatments was investigated. Sheet specimens 2.0 mm. thick were soaked at 460° C. for different times (1, 3, and 8 hr.) and water quenched. One set of these specimens was tested in this state and other sets after different ageing treatments (3 days at 75° C., 4 hr. at 100° C., 4 days at 100° C., 4 hr. at 150° C., and 4 hr. at 300° C.).

As shown in Table I, no effects of the soaking time at 460° C. could be detected after quenching. All homogenized specimens had a high

resistance to stress-corrosion (>12 days). The microstructure of these specimens was homogeneous, no grain boundaries being visible after etching by the method described (Fig. 2, Plate XVIII). The samples were carefully polished mechanically and etched for 20 min. in a solution of 9% orthophosphoric acid (H_3PO_4). Even ageing for 3 days at $75^\circ C$. or 4 hr. at $100^\circ C$. did not change this structure. Their stress-corrosion-

TABLE I.—*Influence of Homogenizing and Ageing Times on the Stress-Corrosion-Resistance of an Aluminium-9% Magnesium Alloy (2 mm. Sheet).*

| Time at $460^\circ C$, hr. | Ageing. | | Microstructure. | Stress-Corrosion-Resistance,* days. | Type of Failure. |
|-----------------------------|--------------|-----|---|-------------------------------------|------------------|
| | $^\circ C$. | hr. | | | |
| 1 | ... | ... | homogeneous, as Fig. 2 (Plate XVIII). | >12 | no failure |
| | | | | >12 | " |
| 3 | ... | ... | | >12 | " |
| | | | | >12 | " |
| 8 | ... | ... | | >12 | " |
| | | | | >12 | " |
| 8 | 75° | 72 | | >12 | " |
| | | | | >12 | " |
| 8 | 100° | 4 | | >12 | " |
| | | | | >12 | " |
| 8 | 100° | 96 | heterogeneous, as Fig. 3 (Plate XVIII). | 0.8 | fracture |
| | | | | 1.0 | " |
| 8 | 150° | 4 | | 0.4 | " |
| | | | | 0.4 | " |
| 8 | 300° | 4 | heterogeneous, as Fig. 5 (Plate XVIII). | 1.5 | " |
| | | | | 1.8 | " |

* Bending stress $\sigma = 15 \text{ kg./mm.}^2$.

resistance is therefore the same as that of the homogenized specimens not aged at elevated temperatures (>12 days). If the ageing time at $100^\circ C$. is increased to 4 days, the grain boundaries appear as a fine continuous network (Fig. 3, Plate XVIII). As a result of this change in the microstructure, the specimens failed with brittle fractures, with a resistance of less than 1 day. Specimens aged 4 hr. at $150^\circ C$., showing a similar structure, had a still shorter life (<0.5 day). The reason for the brittle fractures was severe intercrystalline corrosion (Fig. 4, Plate XVIII). After an ageing treatment of $300^\circ C$. for 4 hr., the pre-

precipitate at the grain boundaries coagulates and forms coarser particles, and the continuous network is replaced by "strings of pearls" (Fig. 5, Plate XVIII). In addition, precipitation occurs within the grains. Specimens with this microstructure failed also by intercrystalline corrosion, but had a longer life (1–2 days) than the specimens aged at 150° C. These results agree with the results of a metallographic examination of an aluminium–10% magnesium alloy by Fink and Smith.²³

In Fig. 8 (a), the stress-corrosion-resistance at 15 kg./mm.² of the 2-mm.-thick aluminium–9% magnesium alloy is plotted against the ageing temperature and ageing time. In the investigated range (50°–150° C., 3 hr.–27 days), the stress-corrosion-resistance decreases with increasing temperature and time. Fig. 8 (b) shows the same diagram, but determined from specimens cold rolled to 1.6 mm. (20%) before ageing. Generally, a lower stress-corrosion-resistance than without cold reduction is recorded. Some exceptions, especially at shorter ageing times, are probably due to internal stresses resulting from quenching or cold rolling. These stresses are reduced or eliminated at longer ageing times or higher ageing temperatures.

Similar results with an aluminium–7% magnesium alloy, but without consideration of the effect of cold reduction, have been published by the authors in an earlier paper.⁸ These investigations were extended to ageing temperatures up to 300° C. and showed an increase in stress-corrosion-resistance at ageing temperatures above 225° C.

The results obtained show that, under the test conditions described,

(a) homogenized aluminium–magnesium alloys are very resistant to stress-corrosion;

(b) the stability of the homogeneous state at elevated temperatures is limited and is decreased by cold deformation before ageing;

(c) minimum stress-corrosion-resistance occurs in the range of ageing temperatures 100°–200° C.; beyond this range the stress-corrosion-resistance increases with increasing temperature;

(d) the stress-corrosion-resistance of aluminium–magnesium alloys is connected with the decomposition of the solid solution and depends on the quantity, arrangement, and size of the precipitate, especially at the grain boundaries.

4. *Influence of Magnesium Content.*

Because the aluminium–magnesium alloys, even when of high magnesium content, are very resistant to stress-corrosion in the homogeneous state, the influence of magnesium content on the stress-corro-

sion-resistance was investigated, using low ageing temperature. Table II gives the results of stress-corrosion tests ($\sigma = 15 \text{ kg./mm.}^2$) on 2.0-mm.

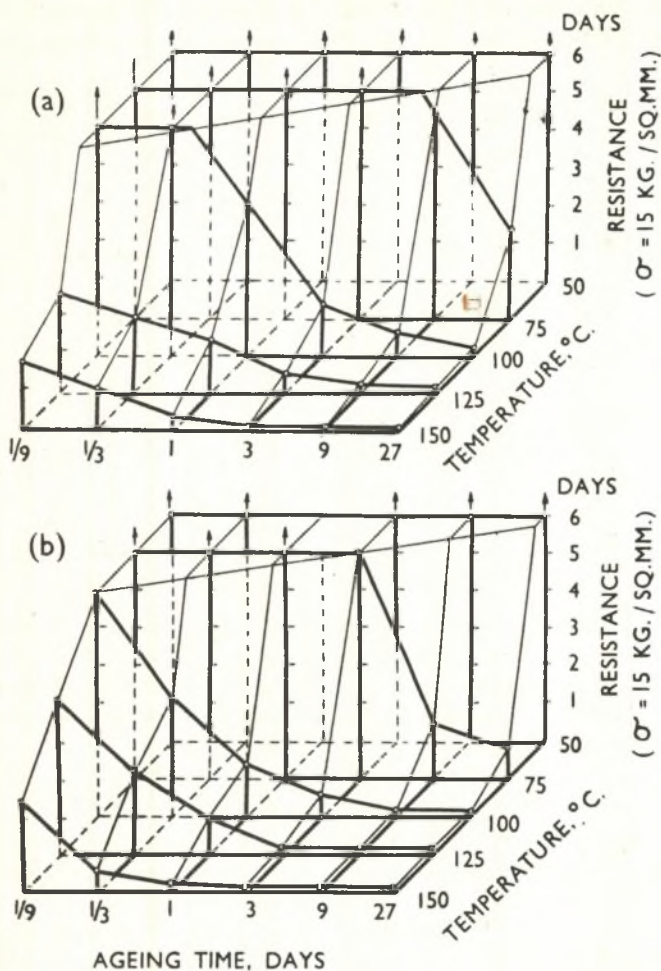


FIG. 8.—Influence of Ageing Temperature and Ageing Time on the Stress-Corrosion-Resistance of Aluminium-9% Magnesium Alloy Sheets.

(a) 2.0 mm. sheet, homogenized and aged.

(b) 1.6 mm. sheet, 20% cold rolled after homogenizing and before ageing.

sheet specimens of aluminium containing 5.2, 6.8, and 8% magnesium, homogenized (annealed 4 hr. at 450°C. and water quenched), and aged for 81 days at 50° – 55°C. The marked decrease in stress-corrosion-

resistance with increasing magnesium content is very striking. The specimens of the alloys containing 5.2 and 6.8% magnesium failed by yielding, while the alloy containing 8% magnesium gave brittle fractures. In addition, the 5.2- and 6.8%-magnesium-containing sheets

TABLE II.—*Influence of Magnesium Content on the Stress-Corrosion-Resistance of Aluminium-Magnesium Alloys.*

(After homogenizing, aged for 81 days at 50°–55° C.)

| Magnesium, %. | Cold Reduction, %. | Stress-Corrosion- Resistance,* days. | Type of Failure. |
|------------------|-----------------------|---|------------------|
| 5.2 | Nil | 10.0 | yielding |
| | | 9.8 | „ |
| 6.8 | Nil | 7.5 | yielding |
| | | 7.5 | „ |
| | 20 | 1.5 | fracture |
| | | 2.0 | „ |
| 8.0 | Nil | 0.8 | fracture |
| | | 1.4 | „ |
| | 20 | 0.4 | „ |
| | | 0.4 | „ |

* Bending stress $\sigma = 15 \text{ kg./mm.}^2$.

were cold rolled to 1.6 mm. between quenching and ageing, with the result that the stress-corrosion-resistance was further reduced and only brittle fractures obtained. Metallographic examinations indicated that the higher the magnesium content the earlier precipitation occurs at the grain boundaries.

5. *Influence of Manganese, Iron, Silicon, and Copper.*

The fact that nowadays the aluminium-magnesium alloys are manufactured from virgin aluminium of variable purity, raises the question of the influence of impurities on the stress-corrosion-resistance. For this purpose, 1.5-mm. sheets of an aluminium-7% magnesium alloy were manufactured from aluminium of different degrees of purity (99.99 and 99.5%). In addition, some alloys were made with and some without manganese. In one alloy, 0.06% copper was also added. The chemical compositions of the alloys are given in Table III.

Specimens of each alloy were heat-treated as follows:

- (a) homogenized (soaked 4 hr. at 460° C. and water quenched);
- (b) homogenized, and aged for 1 day at 100° C.;
- (c) homogenized, and aged for 3 days at 100° C.

TABLE III.—*Stress-Corrosion Resistance of Aluminium-7% Magnesium Alloys of Different Purities and Manganese Contents.*

| Alloy No. | Virgin Aluminium, %. | Chemical Composition. | | | | | Ageing Time at 100° C., days. | 0.2% Proof Stress,† kg./mm. ² . | Tensile Strength,† kg./mm. ² . | Elongation, 11.3√A,† %. | Stress-Corrosion Resistance,‡ days. | Type of Failure. |
|-----------|----------------------|-----------------------|--------|--------|--------|--------|-------------------------------|--|---|-------------------------|-------------------------------------|----------------------|
| | | Mg, %. | Mn, %. | Si, %. | Fe, %. | Cu, %. | | | | | | |
| 1 | 99.99 | 6.6 | Nil | 0.03 | 0.01 | Nil | 0 | 13.1 | 30.0 | 30.5 | >40 >40 | none |
| | | | | | | | 1 | 12.5 | 29.5 | 31.9 | 22 20 | yielding |
| | | | | | | | 3 | 12.7 | 29.3 | 31.0 | 7 6 | fracture |
| 2 | 99.99 | 7.1 | 0.35 | 0.03 | 0.01 | Nil | 0 | 13.3 | 30.6 | 27.0 | >40 >40 | none |
| | | | | | | | 1 | 13.7 | 30.8 | 29.2 | 9 9 | yielding |
| | | | | | | | 3 | 13.5 | 30.7 | 30.0 | 7 6 | fracture |
| 3 | 99.5 | 7.0 | Nil | 0.24 | 0.20 | Nil | 0 | 13.3 | 30.6 | 27.0 | >40 >40 | none |
| | | | | | | | 1 | 13.7 | 30.8 | 29.2 | 9 9 | yielding |
| | | | | | | | 3 | 13.5 | 30.7 | 30.0 | 5 2 | fracture |
| 4 | 99.5 | 6.8 | 0.36 | 0.29 | 0.24 | Nil | 0 | 14.4 | 33.6 | 25.5 | 10 9 | yielding |
| | | | | | | | 1 | 14.3 | 32.3 | 25.3 | 8 6 | " |
| | | | | | | | 3 | 14.1 | 32.4 | 24.5 | 5 5 | fracture |
| 5 | 99.5 | 6.9 | 0.45 | 0.23 | 0.26 | 0.06 * | 0 | 15.4 | 33.4 | 23.0 | 19 12 | yielding fracture |
| | | | | | | | 1 | 16.0 | 33.5 | 23.0 | 9 9 | yielding |
| | | | | | | | 3 | 16.2 | 33.1 | 21.0 | 5.0 5.5 | fracture |

* Upper limit of copper content in aluminium-magnesium alloys: 0.05% (see D.I.N. 1725).

† Average of 3 specimens.

‡ Bending stress $\sigma = 10$ kg./mm.².

The results of the stress-corrosion tests are collected in Table III. Considering first the *homogeneous state*, alloys 1 and 3 have the same high stress-corrosion-resistance (>40 days). The different purities of the virgin aluminium (99.99 and 99.5%), therefore, did not affect the results. While the higher-purity alloy containing 0.35% manganese (alloy No. 2) is as resistant as the same alloy without manganese (alloy No. 1), the stress-corrosion-resistance of the lower-purity alloy (alloy No. 3) seems to be reduced by the addition of manganese (alloy No. 4).

In the *aged state*, the alloys of higher purity (alloys No. 1 and 2) are definitely superior to the alloys of lower purity (alloys No. 3 and 4).

TABLE IV.—*Stress-Corrosion-Resistance of Aluminium-7% Magnesium Alloy Sheet, With and Without 0.9% Copper.*

| Alloy No. | Chemical Composition. | | | | | Ageing after Homogenizing.* | Stress-Corrosion-Resistance,† days. | Type of Failure. |
|-----------|-----------------------|--------|--------|--------|--------|-----------------------------|-------------------------------------|-------------------|
| | Mg, %. | Mn, %. | Si, %. | Fe, %. | Cu, %. | | | |
| 6 | 7.0 | 0.4 | 0.2 | 0.1 | Nil | Room temp. | >20 >20 | none " |
| | | | | | | 3 days at 100° C. | 1.5 1.0 | fracture " |
| 7 | 7.0 | 0.4 | 0.15 | 0.15 | 0.9 | Room temp. | 6 5.5 | yielding fracture |
| | | | | | | 3 days at 100° C. | 7.5 7.5 | fracture " |

* 4 hr. at 460° C. and water quenched.

† Bending stress $\sigma = 10 \text{ kg./mm.}^2$.

In the manganese-containing alloys (2 and 4), this superiority is not as marked as in the manganese-free alloys (1 and 3). The small amount of copper impurity (0.06%) in the presence of manganese (alloy No. 5) has, apparently, no detrimental effect on the stress-corrosion-resistance, which is even higher than in the copper-free alloy (alloy No. 4).

Metallographic examination showed that the structure becomes finer grained with increasing quantities of impurities, and that the manganese content particularly affects the alloy in this way. There was no evidence that the purity of the aluminium or the manganese content of the alloy affected the rate and distribution of precipitation at the grain boundaries. Adding manganese increases the tensile strength and proof stress, but decreases the elongation. Ageing has no great effect on these properties (Table III).

The effect of a higher copper content is seen in Table IV. 1.5-mm.-

thick sheet specimens of aluminium-7% magnesium alloy, with and without 0.9% copper, were tested in the homogenized state (room-temperature aged), and after 3 days ageing at 100° C. The stress-corrosion-resistance of the homogenized specimens decreases very considerably with increasing copper content; however, after 3 days ageing at 100° C., the opposite effect is shown. The high resistance of the copper-free alloy in the homogeneous state decreased after the ageing at 100° C. to less than 2 days, but the copper-containing alloy showed an improvement rather than a deterioration under these conditions.

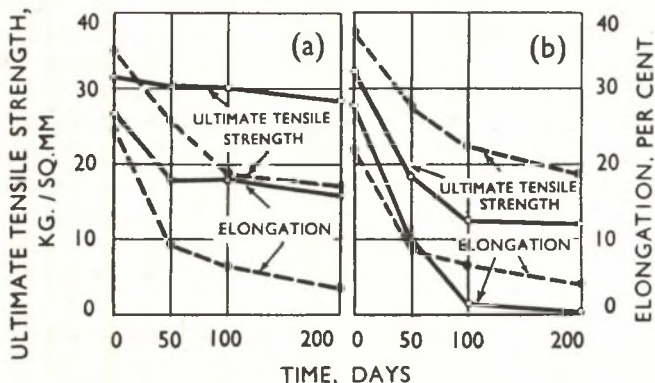


FIG. 9.—Effect of Corrosion on Strength and Elongation of an Aluminium-7% Magnesium Alloy with and without 0.9% Copper. Standard immersion test specimens (stirred solution of 3% NaCl containing 0.1% H_2O_2); specimens 1.5 mm. thick.

(a) Homogenized (room-temp. aged).

(b) Aged 3 days at 100° C.

KEY.

---●--- with 0.9% Cu.
—○— without Cu.

This surprising result was checked by the standard immersion test covered by the German Specification D.I.N. E4853 (see p. 163), and good agreement with the stress-corrosion tests was obtained. In Fig. 9, the tensile strength and elongation of both alloys are plotted against the corrosion time up to 200 days.

The increase in corrosion-resistance of aged aluminium-magnesium alloys caused by the addition of copper is difficult to understand because the potential of the solid solution becomes more noble when copper is added,²² and the potential difference between the solid solution and the precipitated magnesium-containing phase is therefore increased. A large potential difference also exists between the magnesium-containing and the copper-containing precipitates, which favours

the development of intercrystalline corrosion. But these factors are obviously of little consequence because the corrosion-resistance of the solid solution is markedly reduced by the addition of copper, as shown by the results obtained with the homogeneous specimens (Table IV). The difference between the rate of corrosion of the solid solution and the rate of intercrystalline penetration is, therefore, considerably decreased, and the corrosion attack becomes more general and less dangerous.

6. *Influence of the Cooling Rate.*

As in other supersaturated and (especially) age-hardening alloys, the cooling rate has a great effect on the corrosion-resistance of the aluminium-magnesium alloys. Since the homogeneous state produced by the usual water quenching is not stable if elevated temperatures are encountered in service, other methods of cooling have been proposed, such as air cooling and "interval cooling". The term "interval cooling" denotes cooling from the homogenizing temperature to a temperature just below the equilibrium curve of the solid solution, holding at this temperature for a certain time, and then water quenching.⁷

(a) *Interval Cooling.* Specimens of an aluminium-8.5% magnesium alloy sheet (1.5 mm. thick) were treated as follows :

(a) Soaked for 8 hr. at 460° C. and water quenched.

(b) Soaked for 1 hr. at 450° C., cooled to 295° C. and held for 1.5 hr. at this temperature, then water quenched.

The stress-corrosion-resistance of these specimens was tested "as quenched", as well as after ageing for 3 days at 100° C. and ageing for 1 day at 150° C. The results, given in Table V, show that the corrosion-resistance of the specimens not aged at elevated temperatures is seriously affected by interval cooling; they failed by yielding after 2 days. The specimens aged at 100° and 150° C. were, however, somewhat more resistant after interval cooling than after the normal quenching from the homogenizing temperature.

That the homogeneous state, in which the maximum supersaturation of the solid solution in the aluminium-8.5% magnesium alloy exists, is most susceptible to ageing at elevated temperatures, is easy to understand. By interval cooling, the supersaturation of the solid solution is reduced by the precipitation of part of the magnesium, so that its susceptibility to ageing at elevated temperatures may be approximately the same as that of a homogeneous alloy of a correspondingly lower magnesium content. It must also be mentioned that

it is very difficult to obtain the desired precipitation in all cases by the method of interval cooling. For example, one test failed because the specimens became homogeneous at 305° C., the temperature first selected for the interval cooling. Only when the test was repeated at 295° C. was the desired precipitation ("string of pearls" structure) obtained, as shown in Fig. 6 (Plate XVIII). If the alloy treated in this manner is aged at 100°–150° C., the microstructure changes to the dangerous continuous network (Fig. 7, Plate XVIII). For this

TABLE V.—*Stress-Corrosion-Resistance of Water-Quenched and Interval-Cooled Specimens of an Aluminium-8.5% Magnesium Alloy Sheet (1.5 mm. Thick).*

| Alloy No. | Chemical Composition. | | | | Cooling Treatment. | Ageing. | | Stress-Corrosion-Resistance,* days. | Type of Failure. |
|-----------|-----------------------|--------|--------|--------|--------------------|---------|-------|-------------------------------------|------------------|
| | Mg, %. | Mn, %. | Si, %. | Fe, %. | | ° C. | days. | | |
| 8 | 8.5 | 0.4 | 0.3 | 0.2 | Water quenched. | 20° | ... | >12 >12 | none " |
| | | | | | | 100° | 3 | 0.7 0.6 | fracture " |
| | | | | | | 150° | 1 | 0.5 0.4 | " " |
| | | | | | Interval cooled. | 20° | ... | 2 2 | yielding " |
| | | | | | | 100° | 3 | 1.5 1.5 | fracture " |
| | | | | | | 150° | 1 | 0.5 0.5 | " " |

* Bending stress $\sigma = 15 \text{ kg./mm.}^2$.

reason, the interval-cooled and aged specimens failed in the same way as the normally quenched and aged specimens, i.e. by intercrystalline fracture.

From these results, interval-cooled aluminium-magnesium alloys, after ageing at 100°–150° C., appear somewhat more resistant to stress-corrosion than alloys of the same magnesium content in the normal water-quenched and aged conditions. This slight improvement is, however, not great enough to encourage the application of this method in practice, particularly as the susceptibility to intercrystalline corrosion is not removed by this treatment. In addition, the normal water-quenched material is far superior to the interval-cooled material in the

un-aged condition, so that in all cases where elevated temperatures in service are not expected material manufactured by the first and more simple method may be preferred.

(b) *Air Cooling.* If air cooling is applied in practice, the cooling rate must largely depend on the size of the treated components, as thick parts cool much more slowly than thin ones. The movement of the air also affects the cooling rate, and an experiment was carried out to test this.

Six specimens of an aluminium-7% magnesium alloy sheet, 1.5 mm. thick, were heated for 5 hr. at 460° C. and then cooled as follows :

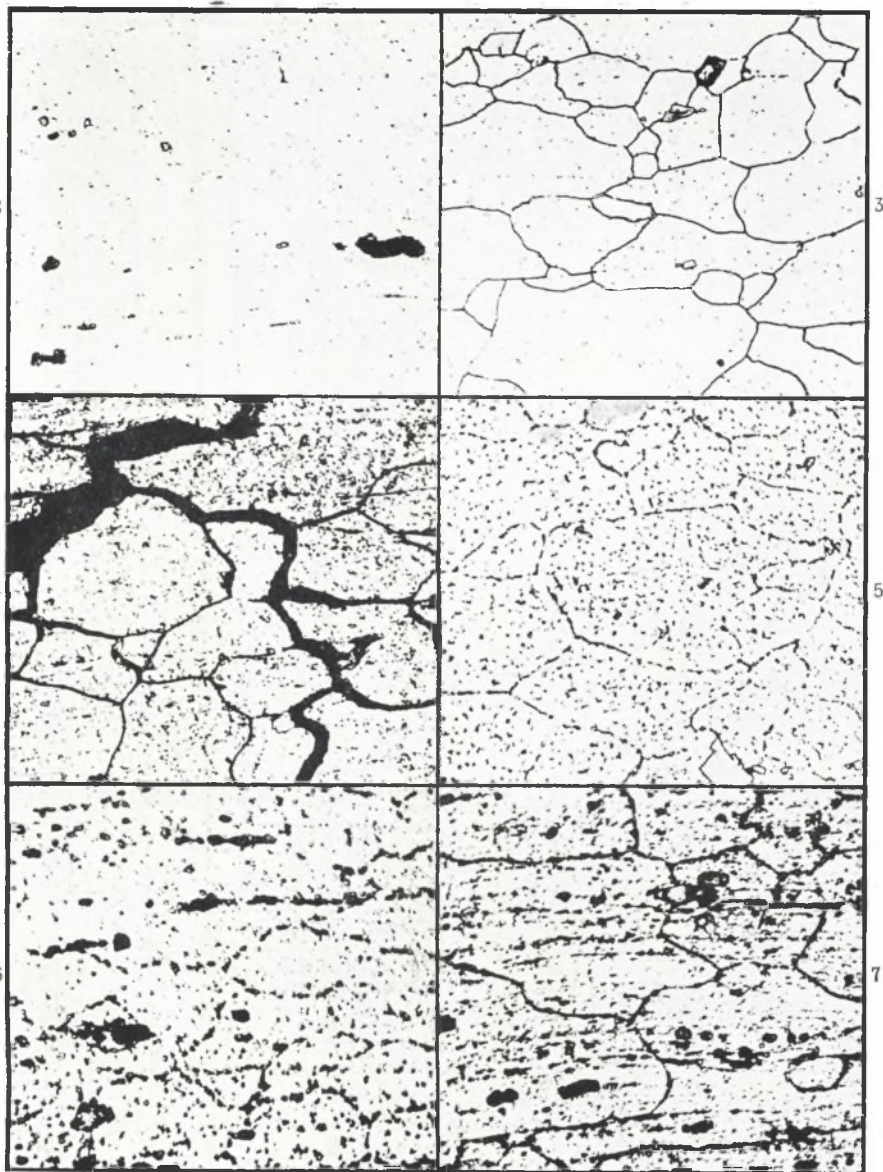
- (a) by quenching in water,
- (b) in moving air,
- (c) in calm air,
- (d) covered with 2-mm.-thick asbestos,
- (e) covered with 5-mm.-thick asbestos,
- (f) covered with 10-mm.-thick asbestos.

The cooling rate was measured by thermocouples fixed to the specimens, and the results shown in Table VI were obtained.

The results of the stress-corrosion test, carried out (i) without ageing, (ii) after ageing for 1 day, and (iii) after ageing for 3 days at 100° C., are also given in Table VI, and these demonstrate very clearly the improvement of stress-corrosion-resistance with decreasing cooling speed. If, for example, the cooling speed is reduced from 130° C./min. (moving air) to 12° C./min. (10-mm.-thick asbestos cover), the stress-corrosion-resistance is improved three times and more. The tendency for intercrystalline fracture to occur also decreases, and more specimens fail by yielding.

Micrographs of differently cooled specimens, without ageing and after ageing for 3 days at 100° C., are given in Figs. 10-15 (Plate XIX). The grain boundaries, which are not visible in the water-quenched specimen (Fig. 10) become increasingly apparent at lower rates of cooling, corresponding with the increased decomposition of the solid solution (Figs. 12 and 14). The precipitation is in both cases in the form of discrete particles, and does not take the form of a continuous network. After ageing for 3 days at 100° C., the microstructure changes in that the gaps which existed before ageing become filled with additional precipitate, and a more or less continuous network is formed (Figs. 11, 13, and 15). The tendency to form a continuous network is more pronounced in the specimens that have been cooled faster.

(c) *Furnace Cooling.* On the basis of the results obtained with the



FIGS. 2-7.—Typical Microstructure of Aluminium-Magnesium Alloy Sheet. All specimens etched in 9% orthophosphoric acid. $\times 500$.

FIG. 2.—Homogenized, water quenched.

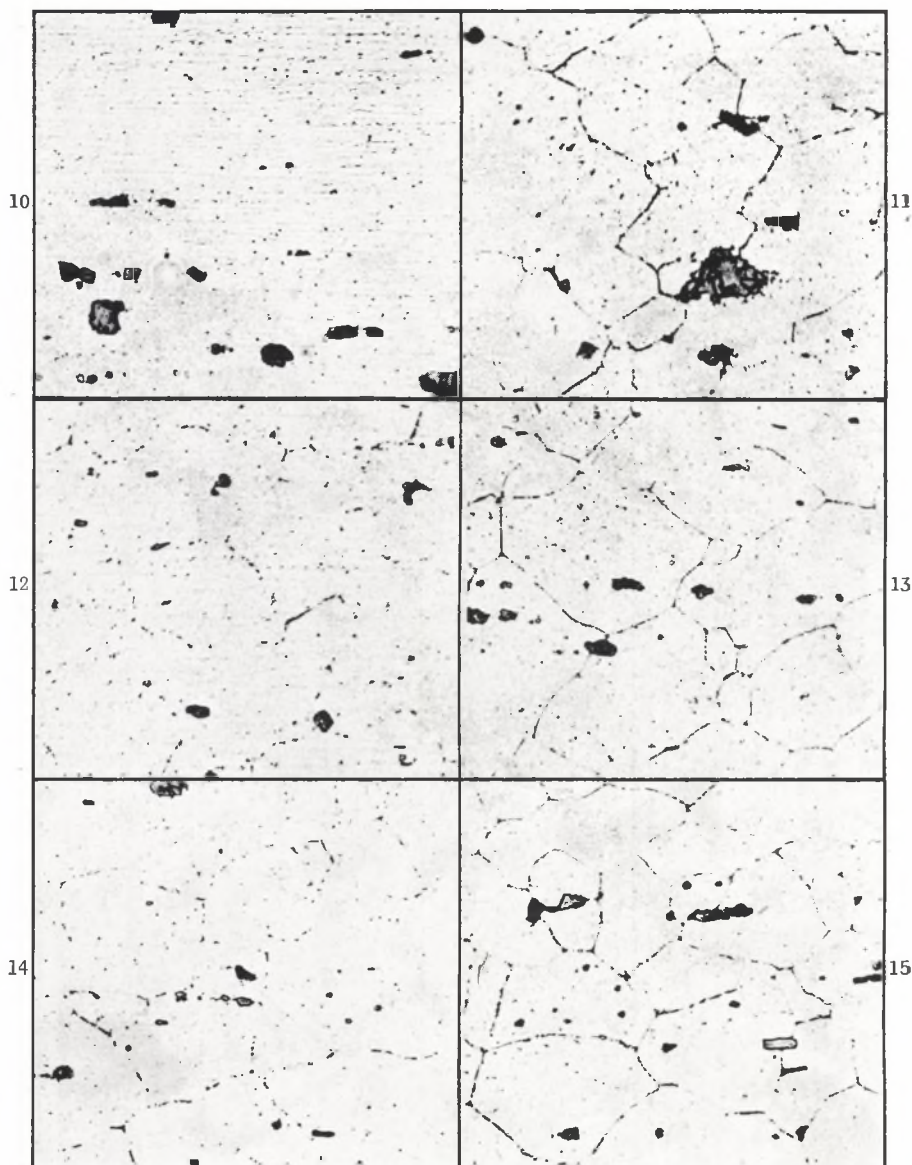
FIG. 3.—Homogenized, water quenched, and aged 4 days at 100°C .

FIG. 4.—Intercrystalline corrosion; heat-treatment same as Fig. 3.

FIG. 5.—Homogenized, water quenched, and aged 4 hr. at 300°C .

FIG. 6.—Interval cooled; string-of-pearls structure.

FIG. 7.—As Fig. 6, but aged 3 days at 100°C ; continuous network.



FIGS. 10-15.—Influence of the Cooling Rate on the Microstructure of Aluminium-7% Magnesium Alloy Sheet (1.5 mm. thick). Etched in 9% orthophosphoric acid. $\times 500$.

FIG. 10.—Water quenched.

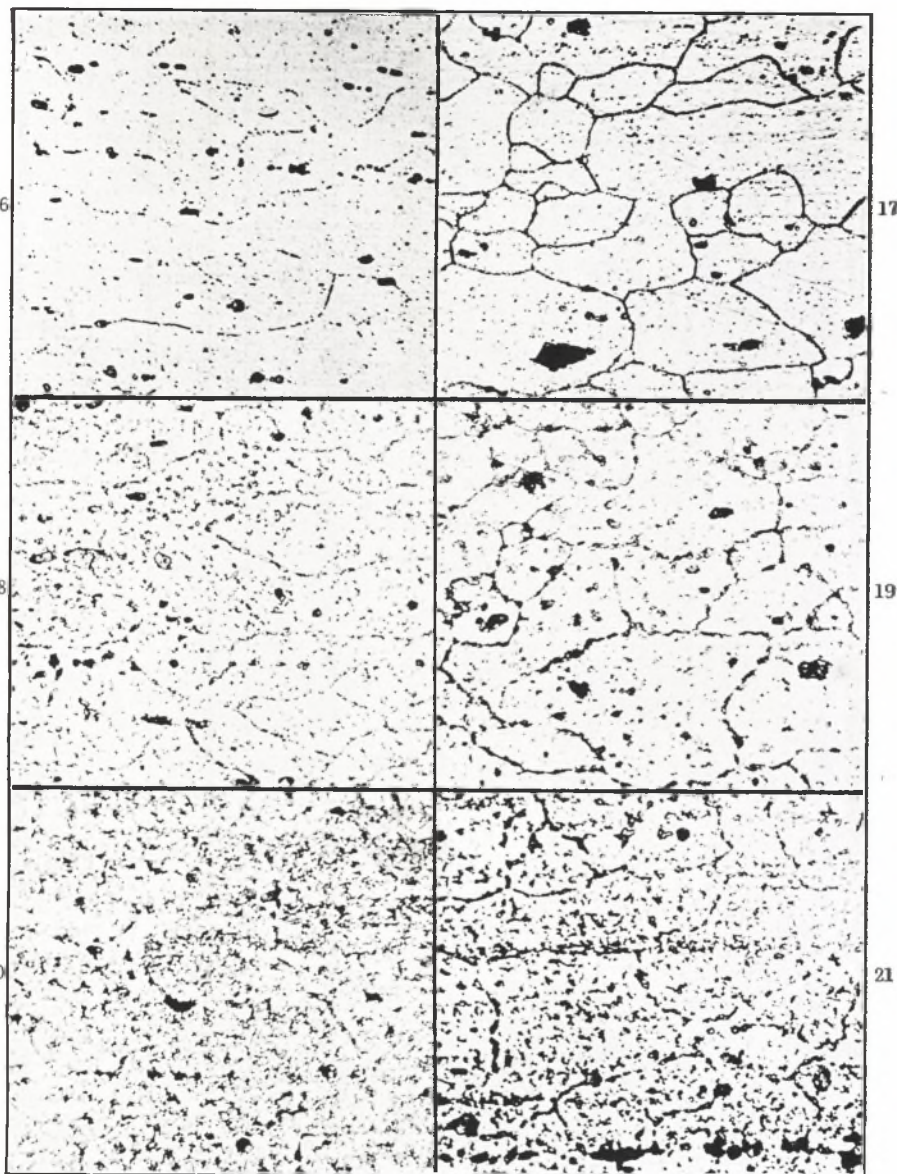
FIG. 11.—Water quenched and aged 3 days at 100° C.

FIG. 12.—Cooled in moving air.

FIG. 13.—Cooled in moving air and aged 3 days at 100° C.

FIG. 14.—Cooled with a 10-mm.-thick insulation.

FIG. 15.—Cooled with a 10-mm.-thick insulation and aged 3 days at 100° C.



FIGS. 16-21.—Micrographs of Aluminium-9% Magnesium Alloy Sheet (2.0 mm. thick) after Different Cooling and Ageing Treatments. Etched in 9% orthophosphoric acid. $\times 500$.

FIG. 16.—Air cooled.

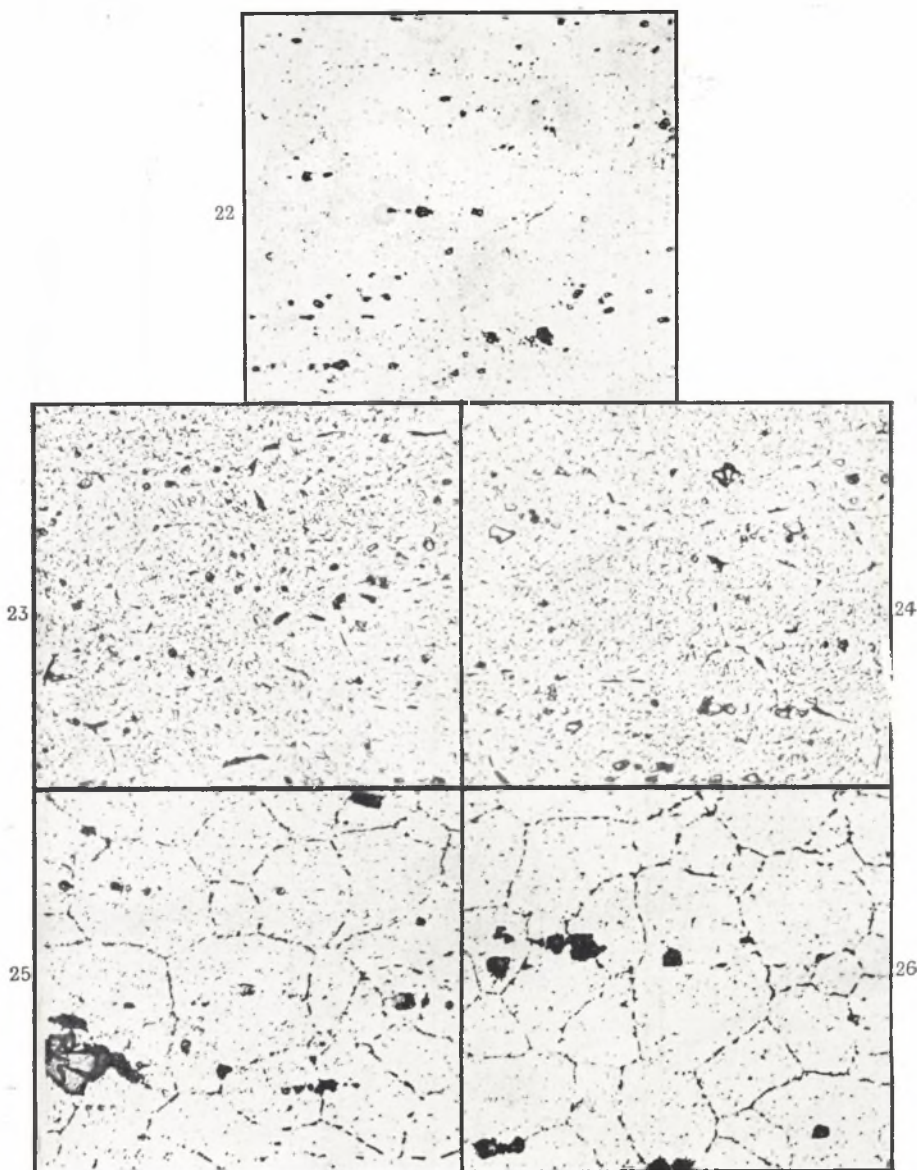
FIG. 17.—Air cooled and aged 3 days at 100° C.

FIG. 18.—Interval cooled.

FIG. 19.—Interval cooled and aged 3 days at 100° C.

FIG. 20.—Furnace cooled.

FIG. 21.—Furnace cooled and aged 3 days at 100° C.



FIGS. 22-26.—Influence of Zinc on the Microstructure of an Aluminium-7% Magnesium Alloy.
Etched in 9% orthophosphoric acid. $\times 500$.

FIG. 22.—Alloy with 1% zinc, air cooled.

FIG. 23.—Alloy with 1% zinc, furnace cooled.

FIG. 24.—Alloy with 1% zinc, furnace cooled and aged 3 days at 125° C.

FIG. 25.—Zinc-free alloy, furnace cooled.

FIG. 26.—Zinc-free alloy, furnace cooled and aged 3 days at 125° C.

TABLE VI.—*Influence of the Cooling Rate on the Stress-Corrosion of an Aluminium-7% Magnesium Alloy (1.5 mm. Sheet).*

| Cooling. | Cooling Rate, ° C./min. at 300° C.* | Ageing Time at 100° C., days. | Stress-Corrosion- Resistance, † days. | Type of Failure. |
|-----------------------------|---|----------------------------------|--|---------------------|
| Water. | 1800° | 0 | 9 9 | yielding |
| | | 1 | 4 4 | " |
| | | 3 | 2 2.5 | fracture |
| | | | | " |
| | | | | " |
| | | | | " |
| Moving air. | 130° | 0 | 7 7 | yielding |
| | | 1 | 5 5 | " |
| | | 3 | 3 3 | fracture |
| | | | | " |
| | | | | " |
| | | | | " |
| Calm air. | 34° | 0 | 15 17 | yielding |
| | | 1 | 8 12 | " |
| | | 3 | 6 6 | " |
| | | | | " |
| | | | | " |
| | | | | " |
| 2-mm. asbestos cover. | 22° | 0 | 14 14 | yielding |
| | | 1 | 12 13 | " |
| | | 3 | 6 7 | " |
| | | | | " |
| | | | | " |
| | | | | " |
| 5-mm. asbestos cover. | 16° | 0 | 18 18 | yielding |
| | | 1 | 13 13 | " |
| | | 3 | 9 9 | " |
| | | | | fracture |
| | | | | " |
| | | | | " |
| 10-mm. asbes- tos cover. | 12° | 0 | 21 22 | yielding |
| | | 1 | 17 17 | " |
| | | 3 | 12 12 | " |
| | | | | " |
| | | | | " |
| | | | | " |

* Specimens cooled from 460° C.
VOL. LXXIV.

† Bending stress $\sigma = 10$ kg./mm.².
O

differently cooled specimens, it would be expected that a further improvement in the stress-corrosion-resistance of aluminium-magnesium alloys might be possible if the rate of cooling could be reduced still further.

For this purpose, specimens of an aluminium-9% magnesium alloy sheet (2.0 mm. thick) were extremely slowly cooled in an air-circulating furnace. The cooling speed was about 0.5° C./min., as against 40° C./min. in the case of air cooling. These specimens were compared with corresponding specimens which had been water quenched, air cooled, and interval cooled. The different specimens were treated as follows :

- (a) soaked for 3 hr. at 460° C. and extremely slowly cooled in the furnace ("stabilizing treatment");
- (b) soaked for 5 hr. at 460° C. and water quenched;
- (c) soaked for 5 hr. at 460° C. and air cooled;
- (d) soaked for 1 hr. at 460° C., cooled to 295° C. and held for 1.5 hr. at this temperature, and water quenched (interval cooling).

The results of stress-corrosion tests on these specimens are given in Table VII. The unaged specimens had the highest stress-corrosion-resistance after air cooling (c) and water quenching (b). The furnace-cooled specimens (a) yielded after a resistance of 33 days, while the interval-cooled specimens (d) had the shortest life (4 days). After ageing for 3 days at 100° C., the stress-corrosion-resistance of the furnace-cooled specimens (a) showed no change (33 days); the air-cooled (c) and interval-cooled (d) specimens failed in a much shorter time, less than 19 and less than 5 days, respectively. The water-quenched specimens (b) failed after about 1.5 days, owing to intercrystalline fracture.

Micro-examination of the differently treated specimens showed that precipitation in the aluminium-9% magnesium alloy was more marked than in the aluminium-7% magnesium alloy, corresponding to the higher magnesium content. After ageing for 3 days at 100° C., the microstructure of the water-quenched and air-cooled specimens changes, as already described, to a continuous, or nearly continuous, network (Figs. 10, 11, 16, and 17, Plates XIX and XX). This tendency is less pronounced in the interval-cooled specimens (Figs. 18 and 19, Plate XX). In the case of furnace cooling, no change was detected in the microstructure after ageing. Both micrographs (Figs. 20 and 21, Plate XX) show a large amount of precipitation at the grain boundaries as well as within the grains. The grain-boundary precipitation consists of coarse isolated particles which do not form a continuous film.

There is a slight difference between the microstructures in Figs. 20 and 21, but this was not the case when originally viewed under the microscope. The difference now seen can be attributed to under-exposure of the print used for Fig. 20.

(d) *Effect of the Cooling Rate on Alloys Containing Manganese, Zinc, and Chromium.* In the course of the investigations described, the question arose of the effect of the cooling rate on alloys containing small additions of manganese, zinc, and chromium.

TABLE VII.—*Stress-Corrosion-Resistance of Aluminium-9% Magnesium Alloy Specimens (2.0 mm. Thick) Cooled by Different Methods.*

| Cooling Method.* | Ageing. | Stress-Corrosion-Resistance, † days. | Type of Failure. |
|------------------------------|-------------------|--------------------------------------|----------------------|
| Furnace cooled (stabilized). | Room temp. | 33 33 | yielding " |
| | 3 days at 100° C. | 33 33 | " " |
| Water quenched. | Room temp. | >33 27 | none yielding |
| | 3 days at 100° C. | 2 1.5 | fracture " |
| Air cooled. | Room temp. | >33 >33 | none " |
| | 3 days at 100° C. | 18 17 | fracture yielding |
| Interval cooled. | Room temp. | 2.5 3.0 | yielding " |
| | 3 days at 100° C. | 3.0 4.0 | " " |

* Specimens cooled from 460° C.

† Bending stress $\sigma = 13.5 \text{ kg./mm.}^2$.

To investigate the effects of zinc and chromium, four alloys were made, the chemical compositions of which are given in Table VIII. Sheet specimens of 1.5-mm. thickness of each alloy were soaked for 5 hr. at 460° C. and cooled (a) in water, (b) in air, and (c) in the furnace (cooling rate about 0.5° C./min.).

Two specimens of each set were aged at the temperatures and for the times given in Table VIII and then tested for stress-corrosion ($\sigma = 10 \text{ kg./mm.}^2$).

The results, collected in Table VIII, confirm that furnace cooling generally produces higher stress-corrosion-resistance than water

TABLE VIII.—*Influence of Zinc and Chromium on the Stress-Corrosion-Resistance of an Aluminium-7% Magnesium Alloy * Subjected to Different Cooling and Ageing Treatments.*

| Alloy No. | Chemical Composition. | | | | | | Cooling Method. | 0.2% Proof Stress,† kg./mm. ² . | Tensile Strength,† kg./mm. ² . | Elongation, 11.3√A,† %. | Stress-Corrosion-Resistance (days),‡ § After Ageing at : | | | | | | | | | |
|-----------|-----------------------|--------|--------|--------|--------|--------|-----------------|---|--|-------------------------------|--|------|------|------|------|------|------|------|------|-------------|
| | Mg, %. | Zn, %. | Cr, %. | Mn, %. | Si, %. | Fe, %. | | | | | 20° | 75° | 75° | 100° | 100° | 100° | 125° | 125° | 150° | 150° C. |
| | | | | | | | | | | | ... | 3 | 27 | 0.3 | 3 | 27 | 0.3 | 3 | 0.3 | for 3 days. |
| 9 | 6.8 | 0.5 | Nil | 0.4 | 0.3 | 0.2 | Water quenched. | 15.7 | 34.5 | 25.3 | 14 | 15 | 5 | 15 | 3 | 0.5 | 1 | 0.5 | 0.5 | 1 |
| | | | | | | | Air cooled. | 15.9 | 34.5 | 24.1 | 6 | 2 | 1.5 | 3 | 2 | 1.0 | 2 | 1.5 | 5 | 1.5 |
| | | | | | | | Furnace cooled. | 15.5 | 33.8 | 21.7 | 13 | 12.5 | 8.5 | 8.5 | 9.5 | 8.5 | 12.5 | 7 | 7.5 | 7 |
| 10 | 7.2 | 1.1 | Nil | 0.4 | 0.3 | 0.15 | Water quenched. | 16.5 | 34.9 | 23.3 | 2 | 2.5 | 3 | 3 | 3.5 | 0.2 | 1.5 | 0.2 | 1.5 | 1 |
| | | | | | | | Air cooled. | 16.1 | 34.8 | 23.9 | 3 | 3.5 | 4 | 4 | 3.5 | 3.5 | 4.5 | 6 | 4 | 3 |
| | | | | | | | Furnace cooled. | 15.2 | 33.7 | 19.8 | 8 | 10 | 10 | 10.5 | 11 | 10.5 | 9 | 10 | 11 | 10.5 |
| 11 | 6.5 | Nil | 0.25 | 0.4 | 0.3 | 0.2 | Water quenched. | 20.8 | 37.6 | 20.8 | 4 | 5 | 4 | 4.5 | 3.5 | 2 | 5 | 3 | 4 | 2.5 |
| | | | | | | | Air cooled. | 21.4 | 36.5 | 19.2 | 3 | 4 | 3.5 | 2 | 2 | 3.5 | 3.5 | 2.5 | 3 | 2.5 |
| | | | | | | | Furnace cooled. | 21.2 | 34.9 | 15.7 | 5 | 4.5 | 6 | 6 | 7.5 | 7.5 | 8 | 7 | 7 | 5 |
| 12 | 7.1 | Nil | Nil | 0.4 | 0.3 | 0.15 | Water quenched. | 15.4 | 32.8 | 27.5 | 8 | 8.5 | 1.5 | 7 | 1.5 | 1 | 2 | 1.5 | 1 | 1 |
| | | | | | | | Air cooled. | 14.7 | 32.0 | 25.3 | 17 | 9.5 | 5.5 | 9.5 | 3.5 | 1 | 3 | 1 | 1 | 1 |
| | | | | | | | Furnace cooled. | 14.5 | 32.6 | 25.3 | 16.5 | 15 | 18.5 | 19 | 16.5 | 11 | 14.5 | 13 | 15.5 | 6 |

* 1.5-mm.-thick sheet.

† Average of 3 specimens.

‡ Bending stress $\sigma = 10$ kg./mm.².

§ Average of 2 specimens.

quenching or air cooling. This is the case for all alloys and nearly all ageing treatments. The resistance of the water-quenched and air-cooled specimens differs very little. Only in the alloy containing 1% zinc and in the zinc-free and chromium-free alloy is an improvement in the stress-corrosion-resistance, compared with the water-quenched specimens, to be seen after air cooling. This agrees with results published by other investigators.^{10, 11} The chromium-containing alloy seems to be a little more resistant after water quenching than after air cooling.

If the various alloys are compared, their resistance to stress-corrosion differs very little; it cannot be said therefore that the additions of zinc and chromium have a very striking effect, except perhaps over a short range of cooling and ageing. Generally, the furnace-cooled alloy without zinc and chromium appears to be superior to the other alloys containing these additions.

The great influence of ageing temperature and ageing time on the stress-corrosion-resistance of some alloys under certain cooling and ageing conditions is very evident. The probable reason for contradictions occurring in the literature about the influence of additions such as zinc and chromium is that investigators have used different cooling and ageing treatments.

Metallographic examination showed that the *water-quenched* specimens of all alloys were homogeneous in the unaged condition as well as after low-temperature ageing (3 days at 75° C.; 0.3 days at 100° C.). With increasing ageing temperature and time, the structure became more and more heterogeneous, as already described. More evidence of precipitation, especially within the grains, was to be seen in the zinc-containing than in the zinc-free alloys.

In the *air-cooled* specimens, slight traces of precipitation in the grain boundaries could be observed in the unaged condition. Fig. 22 (Plate XXI) shows this structure in the alloy containing 1% zinc. The aged specimens had a structure similar to that of the water-quenched and aged specimens.

The *furnace-cooled* specimens showed precipitation in the grain boundaries as well as within the grains, but no continuous network was formed. Precipitation in the zinc- and chromium-containing alloys, especially within the grains, was very pronounced. This is particularly evident on comparing the alloy containing 1% zinc (Fig. 23, Plate XXI) with the zinc- and chromium-free alloy (Fig. 25, Plate XXI). The heavy precipitation doubtless resulted from the decrease in the solid solubility of magnesium in aluminium caused by the additions of zinc, especially at lower temperatures. For example, at

200° C. the solubility of magnesium in aluminium is reduced from about 3% to 1% by the addition of 0.5% zinc.²⁴

The most important observation of this investigation is that the microstructure of the furnace-cooled specimens was not changed by ageing (cf. Fig. 23 with Fig. 24 and Fig. 25 with Fig. 26, Plate XXI). This is contrary to observations on the water-quenched and air-cooled specimens, which always tend to form a continuous network on ageing at elevated temperatures.

The mechanical properties of the different alloys after water quenching, air cooling, and furnace cooling are also given in Table VIII. The zinc- and chromium-containing alloys possess a higher tensile strength and proof stress, but a lower elongation, than the alloy free from these additions. While the method of cooling has no detectable influence on the mechanical properties of the aluminium-7% magnesium alloy, the zinc and chromium-containing alloys show a somewhat lower tensile strength in the furnace-cooled condition.

Since all these alloys contained 0.4% manganese, it was of interest to investigate a manganese-free alloy, especially in combination with an addition of chromium. Such an alloy was therefore compared with a normal aluminium-magnesium alloy with the usual manganese content, with and without 20% cold reduction.

The chemical compositions of the 1.5-mm. sheets employed are given in Table IX.

Unfortunately, alloy 2 had a considerably higher silicon content than alloy 1, but it is to be expected that this would affect the corrosion-resistance of alloy 2 unfavourably rather than favourably.³⁵

After soaking for 4 hr. at 460° C., the specimens were treated as follows:

- (a) water quenched;
- (b) water quenched and aged for 3 days at 100° C.;
- (c) water quenched and cold rolled, 20% reduction;
- (d) water quenched, cold rolled (20% reduction), and aged for 3 days at 100° C.;
- (e) furnace cooled;
- (f) furnace cooled and aged for 3 days at 100° C.;
- (g) furnace cooled and cold rolled, 20% reduction;
- (h) furnace cooled, cold rolled (20% reduction), and aged for 3 days at 100° C.

The results, given in Table IX, show that the chromium-containing alloy has a considerably higher stress-corrosion-resistance than the manganese-containing alloy in all conditions of heat-treatment and

cold reduction. The superiority of furnace cooling to water quenching when followed by ageing is again confirmed, as well as the detrimental

TABLE IX.—*Stress-Corrosion-Resistance of a Manganese- and a Chromium-Containing Aluminium-7% Magnesium Alloy (1.5 mm. Sheet).*

| Alloy No. | Chemical Composition. | | | | | Cooling Method. | Cold Reduction, %. | Ageing. | Stress-Corrosion-Resistance,* days. | Type of Failure. |
|-----------|-----------------------|--------|--------|--------|--------|-----------------|--------------------|-------------------|-------------------------------------|------------------|
| | Mg, %. | Mn, %. | Cr, %. | Si, %. | Fe, %. | | | | | |
| 13 | 7.3 | 0.42 | Nil | 0.08 | 0.16 | Water quenched. | Nil | Room temp. | 27 27 | yielding |
| | | | | | | | | 3 days at 100° C. | 6 6.5 | fracture |
| | | | | | | | 20 | Room temp. | 26 28 | yielding |
| | | | | | | | | 3 days at 100° C. | 1 1.5 | fracture |
| | | | | | | Furnace cooled. | Nil | Room temp. | 27 27 | yielding |
| | | | | | | | | 3 days at 100° C. | 23 23 | " |
| | | | | | | | 20 | Room temp. | 24 24 | yielding |
| | | | | | | | | 3 days at 100° C. | 11 11 | " |
| 14 | 7.2 | Nil | 0.54 | 1.09 | 0.16 | Water quenched. | Nil | Room temp. | > 30 > 30 | none |
| | | | | | | | | 3 days at 100° C. | 10 12 | fracture |
| | | | | | | | 20 | Room temp. | > 30 > 30 | none |
| | | | | | | | | 3 days at 100° C. | 2 2 | fracture |
| | | | | | | Furnace cooled. | Nil | Room temp. | > 30 > 30 | none |
| | | | | | | | | 3 days at 100° C. | > 30 > 30 | " |
| | | | | | | | 20 | Room temp. | > 30 > 30 | none |
| | | | | | | | | 3 days at 100° C. | 27 27 | yielding |

* Bending stress $\sigma = 10 \text{ kg./mm.}^2$.

effect of cold reduction. After ageing for 3 days at 100° C., the water-quenched specimens failed by intercrystalline fracture, but the furnace-cooled specimens yielded after a considerably longer life.

7. *Comparison of Laboratory Tests with Stress-Corrosion Tests in the North Sea.*

The results so far given in this paper have been obtained from laboratory tests. To be more certain that these results are comparable with conditions in service, stress-corrosion tests in the North Sea were carried out. 2.0-mm. specimens of aluminium-7 and 9% magnesium alloys were exposed on the coast of the Isle of Sylt in such a manner that they were tidally immersed and dried. For comparison, corresponding specimens were tested by three different stress-corrosion methods in the laboratory.

The specimens were subjected to the following tests:

(a) *North Sea.* The test used was the loop test (*Schlaufenprobe*), into which the test-pieces were bent through an angle of 180° over a radius of 16 mm. The free ends of the strips were then fixed together like a spring.²⁵ The stresses produced were not determined.

(b) *Laboratory Test 1.* Loop test as in (a). The specimens were exposed to a wet and dry method of corrosion, which involved a cycle of 10 min. immersion in a solution of 3% sodium chloride and 50 min. drying in air at about 25° C. and at a relative humidity of 80–90%.¹⁸

(c) *Laboratory Test 2.* The specimens were 20 mm. long, 10 mm. wide, and 2.0 mm. thick. A bending moment was applied by means of two arms, in which were slots which fitted tightly over the ends of the specimen. The arms were at right angles to the longitudinal axis of the specimen, and the free ends of the arms were brought together by a load calculated to provide the required skin stress (30 kg./mm.²) in the specimen.

The arms were then locked in this position by means of a clamping bolt.²⁶ The corrosion conditions were the same as in laboratory test 1 (para. (b) above).

(d) *Laboratory Test 3.* Specimens were stressed in bending and immersed in a solution of 3% sodium chloride containing 1% by weight of hydrochloric acid, as described earlier (see p. 163). The stress produced in the specimens was in this case 60% of the 0.2% proof stress.

The sheets employed were manufactured in the factory and contained, apart from magnesium, about 0.45% manganese, 0.2% silicon, and 0.3% iron. After soaking for 5 hr. at 460° C., separate sets of specimens were water quenched (*W*), air cooled (*A*), and furnace cooled (*F*). The cooling in the furnace was at a rate of 460° to 100° C. in 8 hr. Specimens from each set were in addition cold rolled, 15% reduction, and aged for 3 days at 100° C. Three test specimens in each condition were then exposed to each corrosion test,

The results of tests on the aluminium-7% magnesium alloy are given in Table X. Without cold reduction and without ageing at 100° C., all specimens had a resistance of more than 140 days in the North Sea and in laboratory tests 1 and 2. In laboratory test 3, some air-cooled and some furnace-cooled specimens failed by yielding at between 15 and 20 days, but the water-quenched specimens were still resistant after 20 days. After 15% cold reduction and ageing for 3 days at 100° C., only the furnace-cooled specimens had a resistance of 140 days in the North Sea and laboratory tests 1 and 2, while the water-quenched and the air-cooled specimens failed by intercrystalline fracture, generally after less than 20 days. In laboratory test 3, the resistance of all cold-rolled and aged specimens was less than 15 days, but the superiority of the furnace-cooled specimens was very marked. This is in agreement with the results observed in tests (a), (b), and (c).

The aluminium-9% magnesium alloy behaved similarly, but its stress-corrosion-resistance was on the whole lower than that of the aluminium-7% magnesium alloy (see Table X).

These results confirm the high susceptibility of water-quenched and air-cooled aluminium-7 and 9% magnesium alloys to stress-corrosion after cold reduction and ageing, and the beneficial effect of slow cooling from the homogenizing temperature (furnace cooling).

The good agreement of the results of the North Sea tests with laboratory tests 1 and 2 is also of special interest. Laboratory test 3 is shown to be an extremely rapid method of stress-corrosion examination. In the experiments described, the classification of stress-corrosion-resistance is similar to that obtained from tests in the North Sea and in laboratory tests 1 and 2 after long periods of exposure.

8. Experience in Service.

During the past ten years, aluminium-magnesium alloys have been used in Germany to a greater extent than before, especially in the construction of seaplanes. At first, the alloys with 7 and 9% magnesium were heat-treated by the method referred to in this paper as interval cooling. In service, much trouble arose with this material after a comparatively short time. Intercrystalline cracks occurred preferentially at rivet holes and in sections cold formed from sheet or strip, as well as in other parts containing internal stresses. In addition, intercrystalline cracks were observed in rivet heads, as shown in the paper by Metcalfe.²⁷ Replacing these alloys by an alloy containing 8% magnesium and 1% zinc effected no improvement.

The troubles were cured by the introduction of the new method of furnace cooling described, and no case of intercrystalline failure was

TABLE X.—Stress-Corrosion-Resistance of Aluminium-7 and 9% Magnesium Alloy Sheets (2.0 mm. Thick), Determined by North Sea and Laboratory Tests.

| Method of Testing. | Cooling Method. | Cold Reduction, %. | Ageing. | 7% Magnesium. | | 9% Magnesium. | |
|--|-----------------|--------------------|-------------------|------------------------------------|--------------------|------------------------------------|----------------------|
| | | | | Stress-Corrosion-Resistance, days. | Type of Failure. | Stress-Corrosion-Resistance, days. | Type of Failure. |
| North-Sea test (loops tidally immersed in sea water and dried in air). | Water quenched. | Nil | Room temp. | >140 >140 >140 | none " " | >140 >140 >140 | none " " |
| | | 15 | 3 days at 100° C. | 8 10 5 | fracture " " | 2 2 3 | fracture " " |
| | | | | | | | |
| | Air cooled. | Nil | Room temp. | >140 >140 >140 | none " " | >140 >140 >140 | none " " |
| | | 15 | 3 days at 100° C. | 4 14 7 | fracture " " | 7 4 ... | fracture " ... |
| | | | | | | | |
| | Furnace cooled. | Nil | Room temp. | >140 >140 >140 | none " " | >140 >140 >140 | none " " |
| | | 15 | 3 days at 100° C. | >140 >140 >140 | " " " | >140 >140 >140 | " " " |
| | | | | | | | |
| Laboratory test 1 (wet and dry loop test in 3% NaCl solution). | Water quenched. | Nil | Room temp. | >140 >140 >140 | none " " | >140 >140 >140 | none " " |
| | | 15 | 3 days at 100° C. | 4 3 9 | fracture " " | 2 2 3 | fracture " " |
| | | | | | | | |
| | Air cooled. | Nil | Room temp. | >140 >140 >140 | none " " | >140 >140 >140 | none " " |
| | | 15 | 3 days at 100° C. | 3 3 3 | fracture " " | 3 3 3 | fracture " " |
| | | | | | | | |
| | Furnace cooled. | Nil | Room temp. | >140 >140 >140 | none " " | >140 >140 >140 | none " " |
| | | | | | | | |
| | | | | | | | |

| | | | | | | | |
|---|-----------------|-----|-------------------|----------------------|-----------------------|----------------------|---------------------------|
| Laboratory test 2 (wet and dry clamp test, bending stress 30 kg./mm. ² , 3% NaCl solution). | Water quenched. | 15 | 3 days at 100° C. | >140 >140 >140 | " " " | >140 >140 >140 | " " " |
| | | Nil | Room temp. | >140 >140 >140 | none " " | >140 >140 >140 | none " " |
| | | 15 | 3 days at 100° C. | >140 8 5 | " fracture " | 3 3 3 | " " " |
| | Air cooled. | Nil | Room temp. | >140 >140 >140 | none " " | >140 >140 >140 | none " " |
| | | 15 | 3 days at 100° C. | 3 2 1 | fracture " " | 3 3 2 | fracture " " |
| | | | | | | | |
| | Furnace cooled. | Nil | Room temp. | >140 >140 >140 | none " " | >140 >140 >140 | none " " |
| | | 15 | 3 days at 100° C. | >140 >140 >140 | " " " | >140 >140 >140 | " " " |
| | | | | | | | |
| Laboratory test 3 (const.-load test, bending stress 60% of 0.2% proof stress, 3% NaCl solution + 1% HCl). | Water quenched. | Nil | Room temp. | > 20 > 20 > 20 | none " " | > 20 18 17 | none yielding " |
| | | 15 | 3 days at 100° C. | 3 4 3 | fracture " " | 1 1.5 1.5 | fracture " " |
| | | | | | | | |
| | Air cooled. | Nil | Room temp. | 18 19 > 20 | yielding " none | 10 6 6 | fracture yielding " |
| | | 15 | 3 days at 100° C. | 3 3 2 | fracture " " | 1.5 1.5 1.5 | fracture " " |
| | | | | | | | |
| | Furnace cooled. | Nil | Room temp. | > 20 > 20 18 | none " yielding | 8 10 9 | yielding " " |
| | | 15 | 3 days at 100° C. | 6 16 13 | " " " | 3 4 4 | " " " |
| | | | | | | | |

encountered during 5 years experience in service of aluminium-7 and 9% magnesium alloys heat-treated by this method. These materials were tested for stress-corrosion-resistance in a solution of 3% sodium chloride containing 1% by weight of hydrochloric acid (laboratory test 3) before being delivered to the customers. Two specimens of each sheet were aged for 3 days at 100° C. and stressed at 60% of the 0.2% proof stress; if they broke in less than 3 days, the sheets were rejected.

IV.—DISCUSSION OF RESULTS.

The results confirm the close correlation between the microstructure and the susceptibility to intercrystalline corrosion and stress-corrosion of aluminium-magnesium alloys. The microstructure largely depends on the heat-treatment applied. The most pronounced changes in microstructure occur in water-quenched alloys during ageing at up to 300° C., and are due to water quenching from the homogenizing temperature, resulting in a maximum degree of supersaturation in the alloy. The decomposition of the solid solution progresses gradually with increasing ageing temperature. At low ageing temperatures, precipitation starts at the grain boundaries, forming a fine continuous network which corresponds to a minimum of stress-corrosion-resistance. At higher temperatures, the precipitate at the grain boundaries coagulates, and the continuous network transforms into a network of coarser isolated particles. Precipitation also starts within the grains in the form of fine and randomly distributed particles. As a result of these changes in the microstructure at higher ageing temperatures, a considerable increase in the stress-corrosion-resistance is observed. After air cooling or interval cooling, the changes in the microstructure and stress-corrosion-resistance resulting from ageing are less pronounced, because a part of the magnesium held in solid solution has already been precipitated during cooling. After this retarded cooling, the alloys investigated showed a microstructure characterized by more or less fine separate particles of precipitate, and as a result the alloys are generally fairly resistant to stress-corrosion. During ageing at elevated temperatures, however, a continuous network is formed which is caused by further precipitation taking place, with the result that the stress-corrosion-resistance is considerably reduced.

By extremely slow furnace cooling from the homogenizing temperature (about 50° C./hr.), all the magnesium in excess of that in solid solution at room temperature is precipitated from the α -crystals. The structure of alloys treated in this manner shows heavy precipitation in the form of coarse isolated particles at the grain boundaries

and numerous fine particles irregularly distributed within the grains. This structure has a high stress-corrosion-resistance and, as shown in this paper, is very stable up to 100° or 150° C. No transformation into a continuous network is possible, because no additional precipitation can occur. The method of furnace cooling is therefore also termed a "stabilizing treatment".

On the basis of these findings, the process of attack of aluminium-magnesium alloys by intercrystalline corrosion and stress-corrosion can be easily explained, bearing in mind that the precipitated phase (Al_3Mg_2) is anodic to aluminium as well as to the solid solution. As already mentioned in an earlier paper, published in 1940 by one of the authors²¹ in connection with an investigation into the stress-corrosion of aluminium-zinc-magnesium alloys, when the network is continuous (Fig. 27 (a)) the corrosion starts by dissolving the anodic precipitated phase at the surface and penetrates between the grains, following the continuous film of precipitate. The penetration may be accelerated by differences in aeration and in stress-corrosion caused by stress concentrations occurring at the ends of these channels, which resemble sharp notches.^{28, 29} In the case where precipitation occurs in the form of isolated particles, distributed at intervals along the grain boundaries (Fig. 27 (b)), only the particles at the surface are dissolved and then further penetration ceases. Obviously, there is a critical distance between the precipitated particles which the corrosion is not able to overcome, and therefore intercrystalline attack cannot develop.

The quantity of precipitation must also be considered, especially its effective anodic surface, which influences the attack owing to its effect on the current density. The current density, and therefore the corrosion rate, is higher the smaller the anodic surface in proportion to the cathodic surface, represented by the solid solution exposed to corrosion.³⁰ An increase in intercrystalline penetration in the case of very fine grain-boundary precipitation, and a decrease in the case of additional precipitation within the grains, is therefore to be expected.

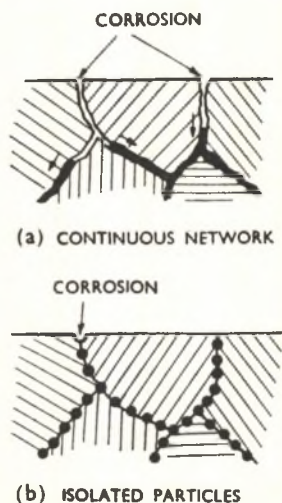


FIG. 27.—Corrosion Penetration for Different Types of Grain-Boundary Precipitation.

In the latter case, the structure approaches homogeneous precipitation, with a change from selective attack to a more general corrosion.

In this connection, an investigation by Lacombe and Chaudron³¹ on an aluminium alloy containing 11.8% magnesium is of interest. They found by X-ray examination that the decomposition of the solid solution starts at lower temperatures with the formation of an intermediate phase β' , which transforms at higher temperatures into the equilibrium phase β . Corrosion tests showed that the β -phase, having a potential near to that of the solid solution, is less electro-negative than the β' -phase. Compared with the results given in this paper, it is very significant that the range of the β' -phase covers the field of low stress-corrosion-resistance, while the range of the β -phase corresponds to higher stress-corrosion-resistance.

The question of the influence on stress-corrosion of internal stresses produced by the different cooling methods²¹ requires special consideration. For example, internal stresses up to 23 kg./mm.² have been measured in 12-mm.-dia. bars of an aluminium-10% magnesium alloy after water quenching.³² Decreasing the cooling rate reduces the amount of internal stress considerably, and the stresses are probably completely removed in the case of furnace cooling, the application of which in practice has the advantage that distortion of the heat-treated parts is avoided. On the other hand, the beneficial effect of such internal stresses should not be under-rated. Forrest³³ indicated that the fatigue strength in fluctuating bending of aluminium alloys is appreciably improved by quenching stresses. Similar conditions exist in the case of stress-corrosion, where the tensile stresses in the bent specimens are reduced or eliminated by the compression stresses produced in the external zones by quenching. It is supposed that this is also a reason for the high stress-corrosion-resistance generally found after water quenching, and for the decreased resistance of the aged or cold-rolled specimens, the quenching stresses of which have been partly or completely removed by the elevated temperatures or by plastic deformation.³⁴ Up to date, no systematic researches have been carried out on this question, which is certainly of fundamental importance in the field of stress-corrosion. In addition, nothing is known yet about the distribution of stresses in the grain boundaries and about the influence of stresses on the rate of precipitation.

It is difficult to give a reasonable explanation of the effect of small additions of, for example, manganese, zinc, and chromium on the stress-corrosion-resistance of aluminium-magnesium alloys. One of the most interesting facts is the marked changes sometimes observed in the microstructure, especially after furnace cooling, in alloys in

which these elements are present. Another interesting fact is the considerable improvement in the stress-corrosion-resistance of aluminium-magnesium alloys in all conditions of heat-treatment and cold reduction effected by additions of chromium instead of manganese. Further investigations on this problem would seem to be merited.

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190 Corrosion-Resistant Aluminium-Magnesium Alloys

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THE CONSTITUTION OF ALUMINIUM-1118 COPPER-MAGNESIUM-ZINC ALLOYS AT 460° C.*

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SYNOPSIS.

The equilibrium diagram of the quaternary system Al-Cu-Mg-Zn at 460° C. has been determined by the microscopic examination of alloys annealed for long periods. The range of composition investigated lies within the limits: zinc 0-8, copper 0-55, and magnesium 0-30%, and within this range the only phases encountered are the same as, or are derived from, those of the three ternary systems Al-Cu-Mg, Al-Cu-Zn, and Al-Mg-Zn. No new quaternary phase has been found. The *S* phase of the system Al-Cu-Mg dissolves little or no zinc. The T_{AlMgZn} and T_{AlCuMg} phases are isomorphous and give rise to quaternary $T_{AlCuMgZn}$ solid solutions. The *M* ($MgZn_2$) phase of the binary system Mg-Zn is isomorphous with the AlCuMg phase of the ternary system Al-Cu-Mg, and quaternary $M_{AlCuMgZn}$ solid solutions are formed, which may exist in aluminium-rich alloys if the zinc content be sufficiently great. The *Z* phases of the Mg-Zn and Al-Cu-Mg systems are isomorphous and give rise to quaternary $Z_{AlCuMgZn}$ solid solutions. The equilibria in the quaternary alloys are exceedingly complicated, and with some compositions long periods of annealing are required in order to obtain true equilibrium.

I.—INTRODUCTION.

PREVIOUS papers ^{1, 2, 3, 4, 5} have described the equilibrium diagrams of the system Al-Mg-Mn-Zn.|| The addition of copper to these alloys produces an extremely complicated quinary system which can be understood only when the various quaternary systems have been established securely. The present paper describes an investigation of the quaternary system Al-Cu-Mg-Zn at 460° C.; as previously explained,⁵ this temperature was chosen as a standard temperature for the first survey of the equilibrium diagrams, and is one sometimes used for the heat-treatment of alloys of the Al-Mg-Mn-Zn type.

The understanding of the quaternary equilibria involves that of

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|| For abbreviation, the authors have ventured to use chemical symbols in this paper. If words are used, the constituents of a quaternary alloy are frequently spread over two lines of print, and it is suggested that the subject matter is grasped more clearly by the use of symbols.

MAGNESIUM, ATOMIC PER CENT.

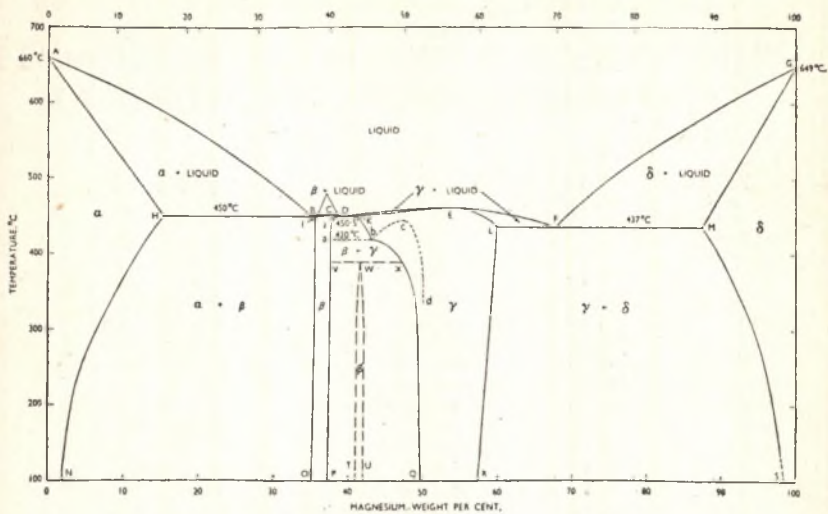


FIG. 1.—The Equilibrium Diagram of the System Aluminium—Magnesium.

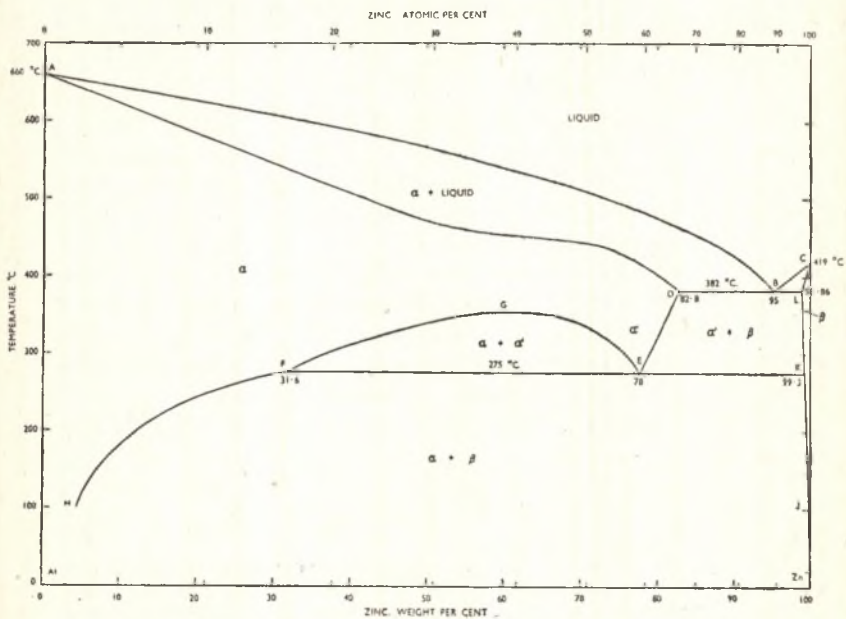


FIG. 2.—The Equilibrium Diagram of the System Aluminium-Zinc.

the various binary and ternary systems involved. For the binary systems Al-Mg, Al-Zn, and Al-Cu, the annotated equilibrium diagrams prepared by G. V. Raynor may be accepted, and are reproduced in Figs. 1, 2, and 3.

In the system Al-Mg at 460° C., the α solid solution in aluminium

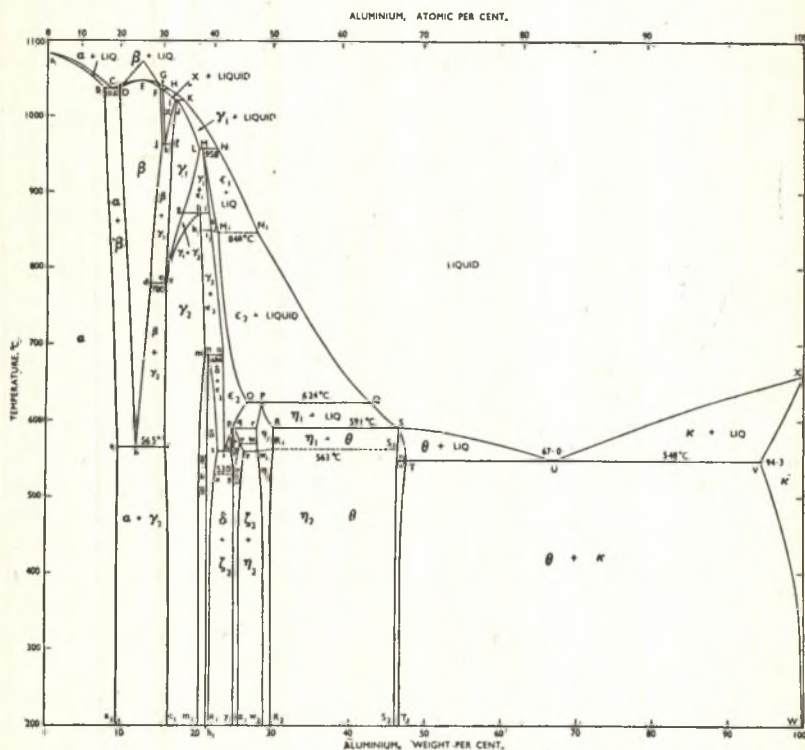


FIG. 3.—The Equilibrium Diagram of the System Aluminium-Copper.

is in equilibrium with the liquid phase. In the system Al-Cu at 460° C., the α solid solution is in equilibrium with the phase usually called " CuAl_2 ", although the composition corresponding exactly to this formula lies just outside the limits of homogeneity of the phase. Many investigators have used the symbol θ for this phase, and this policy has been adopted in the diagrams in the present paper. It is also necessary to consider the equilibrium diagram of the system Mg-Zn, and this is shown in Fig. 4, from which it will be seen that there are three intermediate phases in this system. Of these, the zinc-rich phase

is called MgZn_5 or $\text{Mg}_2\text{Zn}_{11}$ by different authors, and, as in the previous paper,⁵ the present authors have used the symbol Z for this phase, and M for the next phase,* MgZn_2 .

II.—THE TERNARY SYSTEM ALUMINIUM-COPPER-ZINC.

For the quaternary system Al-Cu-Mg-Zn , it has been found most convenient to draw the diagrams in terms of rectangular co-ordinates, and with two exceptions (Figs. 8 and 9) the same policy is adopted for

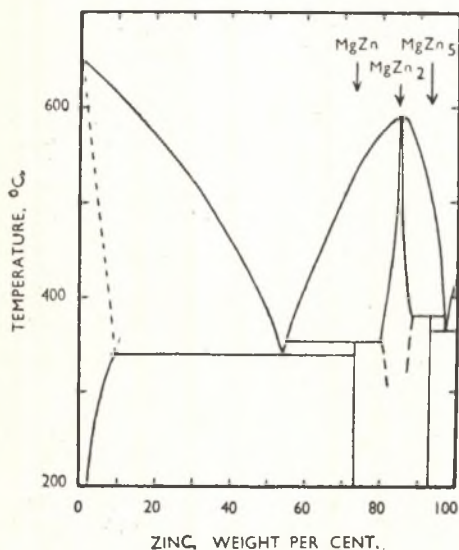


FIG. 4.—The Equilibrium Diagram of the System Magnesium-Zinc.

the ternary systems. As the work proceeded, it became clear that the solubility of copper in aluminium is increased by the presence of zinc, and this point was examined in detail. The results for the aluminium-rich alloys are shown in Fig. 5. In this and all later diagrams, the alloys whose compositions were determined by actual analysis of the specimens after annealing are shown by full points, while the open points refer to nominal compositions estimated from the weights of metals melted together. As will be appreciated from Section XI, the intended and analysed compositions were in very good agreement. The results show clearly that the solubility of copper increases steadily with increasing zinc content. It was necessary also to determine the order of the phases in the region of the θ (CuAl_2) phase, and for this purpose the alloys shown in Fig. 6 (and several not shown, of composition very near to " CuAl_2 "), were prepared and examined. Fig. 6 shows that the effect of zinc in increasing the solubility of copper continues at least as far as 24% zinc. The experiments also show that the CuAl_2 phase is able to take up from 1 to 1.5% of zinc into solid solution. The system Al-Cu-Zn contains a ternary phase which previous

* These symbols were chosen because MgZn_2 is the middle phase and MgZn_5 the phase containing most zinc.

investigators⁶ have called T , but as this symbol has already been used for the ternary phase in the system Al-Mg-Zn, the symbol T_{Cu} has been used here in order to avoid confusion. Fig. 6 shows that the phase fields lie in regular order, $\alpha + \theta$, $\alpha + \theta + \text{liquid}$, $\theta + \text{liquid}$, $\theta + \text{liquid} + T_{Cu}$, and $\theta + T_{Cu}$.

III.—THE TERNARY SYSTEM ALUMINIUM—MAGNESIUM— ZINC.

The equilibrium diagram of this system has already⁴ been determined at 500° and 400° C. The present authors have investigated the isothermal section at 460° C., and the results are shown in Fig. 7. This diagram has the general form to be expected from the earlier work. In the alloys of low zinc content, the α solubility curve represents equilibrium between the α solid solution and the liquid phase. With increasing zinc content, the α solid solution comes into equilibrium with the T phase, which is usually described as $Al_2Mg_3Zn_3$, but which is actually of widely varying composition, the characteristic of the structure being a ratio of 12 large magnesium atoms to 20 smaller zinc

or aluminium atoms. The α corner of the three-phase ($\alpha + T + \text{liquid}$) triangle lies at 8.85% magnesium and 3.8% zinc. The boundaries of the $\alpha + T + \text{liquid}$ field lie in the general direction suggested by ternary sections and liquidus diagrams of other workers,^{7, 9, 10} but extrapolation from the present results suggests that the liquid corner of the field lies at about 5% more magnesium and less zinc than proposed

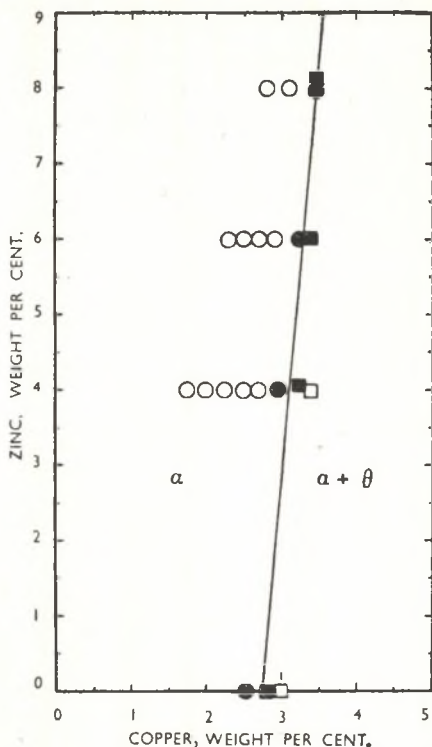


FIG. 5.—The Aluminium Corner of the System—Aluminium-Copper-Zinc at 460° C. The solubility of copper in aluminium is increased by the presence of zinc.

KEY, FIGS. 5-19.

- ● = Homogeneous alloys.
- ■ = 2-phase alloys.
- △ ▲ = 3-phase alloys.
- ⊖ ⊕ = 4-phase alloys.

by Köster, and 2% less zinc than indicated by Mikheeva. The diagram is in good agreement with that obtained by extrapolation to 460° C. of the results of Fink and Willey⁸ at 350°, 400°, and 440° C., except

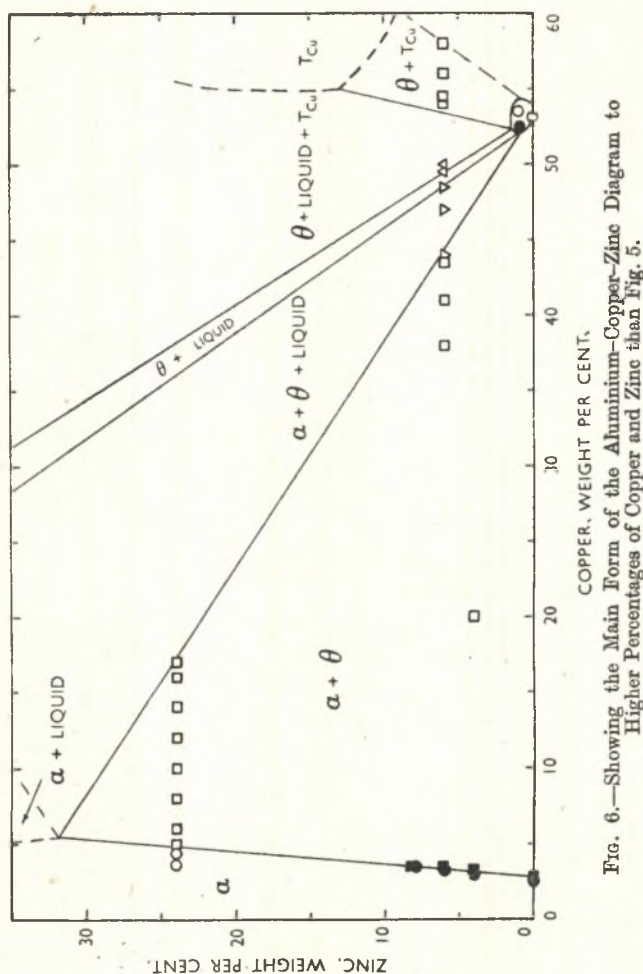


FIG. 6.—Showing the Main Form of the Aluminum-Copper-Zinc Diagram to Higher Percentages of Copper and Zinc than Fig. 5.

that the α corner of the three-phase ($\alpha + T + \text{MgZn}_2$) triangle* must lie at at least 1% more zinc and 0.5% less magnesium than would be expected by extrapolation from their diagrams. The dotted lines in

* In Fig. 7, the symbol η is used for the MgZn_2 phase.

Fig. 7 show the probable positions of the boundaries in this part of the diagram.

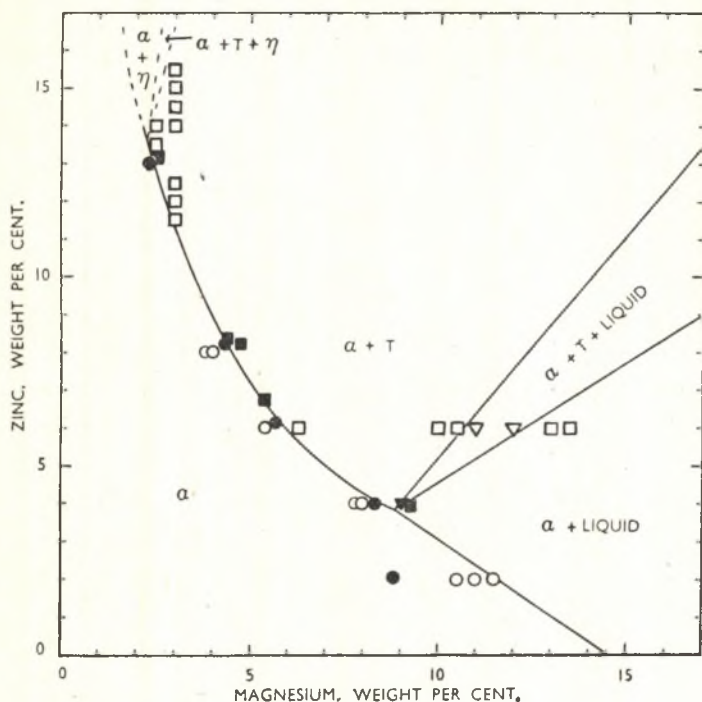


FIG. 7.—The 460° C. Isothermal Section Across the Equilibrium Diagram of the System Aluminium-Magnesium-Zinc.

IV.—THE TERNARY SYSTEM ALUMINIUM-COPPER-MAGNESIUM.

The equilibrium diagram of this system at 460° C. was investigated by Little, Hume-Rothery, and Raynor,⁵ whose diagram is reproduced in Fig. 8. The focal point in this diagram is that of the S phase, whose composition corresponds almost exactly to the formula Al_2CuMg (magnesium 17.1 and copper 44.8 wt.-%). The Z phase, $\text{Mg}_3\text{Cu}_7\text{Al}_{10}$, is isomorphous with the Z phase ($\text{Mg}_2\text{Zn}_{11}$) of the binary system Mg-Zn, the common characteristic being 6 large magnesium atoms to about 33 or 34 smaller atoms of copper, aluminium, or zinc. In the system Al-Cu-Mg, the Z phase at 460° C. is never in equilibrium with the α solid solution, but in the quaternary system Al-Cu-Mg-Zn, alloys are obtained (see p. 202) in which α is in equilibrium with Z . The T phase

in the Al-Cu-Mg system is usually called Al_6CuMg_4 , and is isomorphous with the T phase, $\text{Al}_2\text{Mg}_3\text{Zn}_3$, of the Al-Mg-Zn system, the common

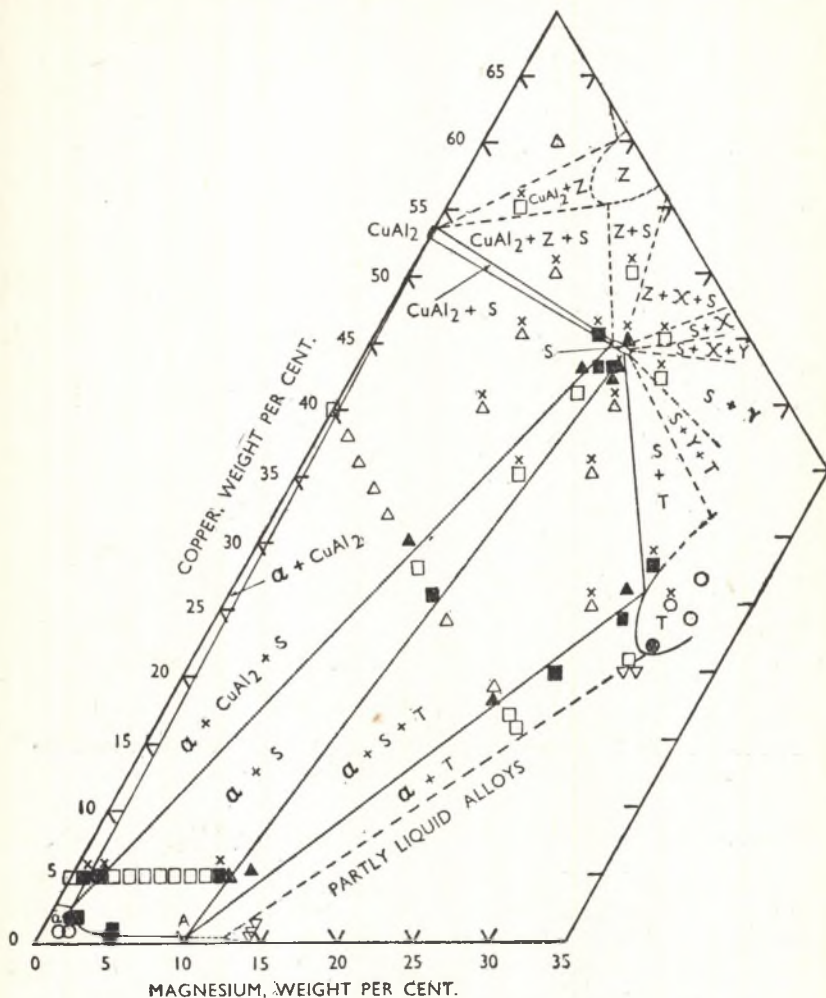


FIG. 8.—The 460° C. Isothermal Section Across the Equilibrium Diagram of the System Aluminium-Copper-Magnesium (according to Little, Hume-Rothery, and Raynor).

characteristic being a ratio of 12 large magnesium atoms to 20–21 smaller atoms of aluminium, copper, or zinc.

In the previous paper,⁵ the phase fields surrounding S were examined

in detail only so far as was necessary for the understanding of the aluminium-rich alloys, and the order of the remaining phase fields was sketched in tentatively. In the present work, it has been necessary to examine this question in greater detail, and the results obtained are shown in Fig. 9. *This diagram is drawn in triangular co-ordinates so*

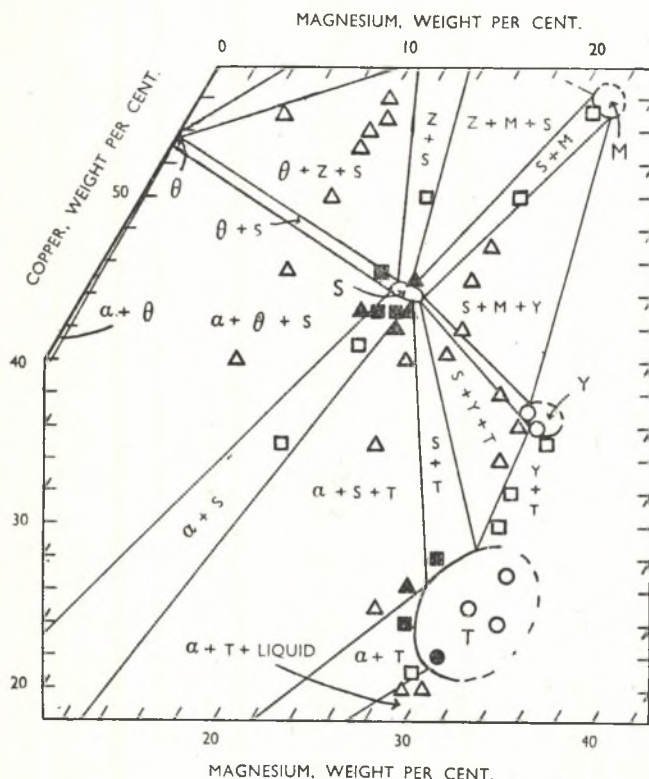


FIG. 9.—The 460° C. Isothermal Section Across the Equilibrium Diagram of the System Aluminium-Copper-Magnesium in the Region of the *S* Phase.

that direct comparison can be made with Fig. 8. Fig. 9 includes points for many of the alloys in Fig. 8 (some of which have been re-examined microscopically), together with new alloys prepared for the present work. Comparison of these two Figures leads to the following conclusions :

The $(\alpha + \theta + S)$, $(\theta + S)$, $(\theta + Z + S)$, and $(Z + S)$ fields are confirmed as occurring in this order, but the $(Z + S)$ field is narrower

than was suggested before, because the boundary between the $(\theta + Z + S)$ and $(Z + S)$ fields is displaced to the right.

The alloy (copper 55, magnesium 5%) which was previously described as $(\theta + Z)$ was re-examined and found to contain particles of S as well as of θ and Z . This means that the boundary between the $(\theta + Z + S)$ and $(\theta + Z)$ fields slopes upwards more steeply than is shown in Fig. 8, and the Z phase must contain somewhat more copper than is indicated by the formula $Mg_3Cu_7Al_{10}$ given by Laves and Witte,¹¹ although the ratio of large to small atoms need not be affected by the change. It may be that the electron concentration of the Z phase (isomorphous with $MgZn_5$) is much nearer to 2 than previously indicated.*

In the previous work,⁵ it was suggested that the phase denoted X might be $AlCuMg$, although the direction of the boundaries of the $(S + X)$ fields would confirm this suggestion only if the phase were of widely varying composition. The present work has shown that X is almost certainly based on $AlCuMg$, and X-ray methods have shown that its crystal structure is the same as that of the M ($MgZn_2$) phase in the binary Mg - Zn system, and the symbol M has therefore been substituted for X in the present paper. An alloy of composition $AlCuMg$ (copper 55.3, magnesium 21.2%) was prepared and annealed for 8 days, and was found to consist almost entirely of M with only small amounts of S ; the point for this alloy is shown in Fig. 9 as lying just outside the region of the homogeneous M phase. The alloy previously described (Fig. 8), consisting of $(S + X)$, must have been accidentally etched so that X (i.e. M) and Y were not distinguished.

With diminishing copper content, the phase fields in the region of S lie in the order $(S + M)$, $(S + M + Y)$, $(S + Y)$, $(S + Y + T)$, and $(S + T)$. The composition of the Y phase is in the region of copper 37, magnesium 28%; the nearest simple whole-number ratio of atoms is $Al_7Cu_3Mg_6$ (copper 36.3, magnesium 27.8%), in which the ratio of large to small atoms is 3 : 5. This is interesting, in that the ratio (3 : 5) is one of the factors considered to account for the isomorphism of T_{AlCuMg} and T_{AlMgZn} . Moreover, the electron concentrations of Y and T_{AlCuMg} both lie within the limits of that of the elongated T_{AlMgZn} phase.

It was also found desirable to re-determine the aluminium corner of the Al - Cu - Mg diagram, and the results are shown in Fig. 10, which is drawn in rectangular co-ordinates for comparison with later diagrams. In Fig. 10, the results of the present investigation are shown in the form of large circles and squares, while the small points refer to the earlier

* The 1 large : 5 small atoms line intersects the electron concentration = 2 line at about 65.6% copper and 8.6% magnesium.

work. The effect of the new experiments is to raise the α solubility curve by about 0.1% copper.

V.—THE QUATERNARY SYSTEM ALUMINIUM-COPPER-MAGNESIUM-ZINC : INTRODUCTION.

In the quaternary alloys which the authors have studied, only phases which are the same as, or derived from, those of the three ternary systems have been found; and no new quaternary phase has been

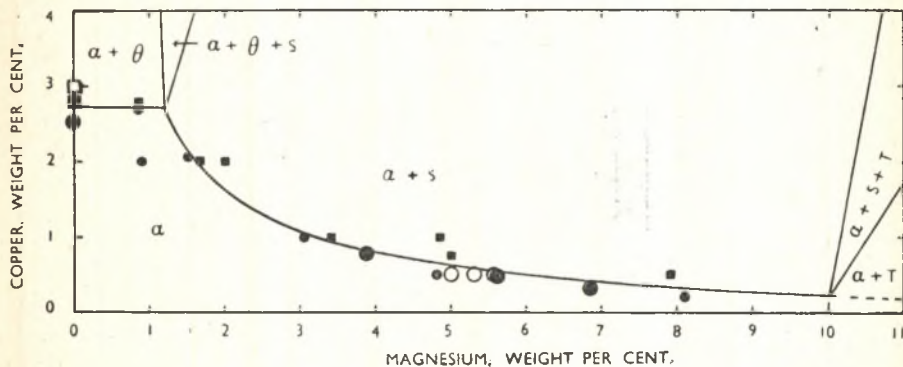


FIG. 10.—The 460° C. Isothermal Section Across the Equilibrium Diagram of the System Aluminium-Copper-Magnesium. Aluminium-rich alloys.

encountered. The following points should be appreciated in order to understand the very complicated equilibrium diagrams :

(1) The $CuAl_2$ or θ phase is found in quaternary alloys containing only a small percentage of magnesium and is able to take up from 1-2% of zinc into solid solution.

(2) The S phase of the system Al-Cu-Mg is formed in a wide range of quaternary alloys and dissolves little or no zinc. This point is of importance, because it means that in quaternary alloys of the $(\alpha + S)$ type, the whole of the zinc is contained in the α solid solution. In the region of the S phase, seven alloys containing 1% zinc, and 5 containing 4% zinc, were examined. No homogeneous S alloys were found, and the occurrence of α in equilibrium with M confirmed the absence of a homogeneous S region in each of these planes (see Table I).

(3) The T_{AlMgZn} and T_{AlCuMg} phases are isomorphous and give rise to quaternary $T_{AlCuMgZn}$ solid solutions.

(4) The M ($MgZn_2$) phase of the binary system Mg-Zn is isomorphous with the $AlCuMg$ phase of the ternary system Al-Cu-Mg;

quaternary M_{AlCuMgZn} solid solutions are found, and may exist in aluminium-rich alloys if the zinc content is sufficiently great.

(5) *The Z phases* of the systems Mg-Zn and Al-Cu-Mg are isomorphous and give rise to quaternary Z_{AlCuMgZn} solid solutions.

TABLE I.—*The Effect of Zinc on the S Phase.*

| Alloy No. | Composition, wt.-% (none analysed). | | | Annealing Time, days. | Constitution.* |
|-----------|--|-------|-----|--------------------------|--------------------------|
| | Cu. | Mg. | Zn. | | |
| F7 | 45 | 16 | 1 | 8 | $S + Z + M$ vsa |
| F8 | 45 | 17 | 1 | 8 | $S + M + Z$ vsa |
| F10 | 45 | 18 | 1 | 8 | $S + M + Y$ sa |
| F11 R | 44.5 | 16.7 | 1 | 49 | $S + M + Z$ vsa |
| F12 R | 44.2 | 17 | 1 | 49 | $S + M + \alpha$ mt |
| F13 | 44 | 18 | 1 | 8 | $S + M + Y$ and/or T † |
| R38 | 44.5 | 17 | 1 | 8 | $S + M$ |
| R57 R | 43.7 | 15.23 | 4 | 49 | $S + Z + \alpha + M$ sa |
| R58 R | 42.3 | 16.93 | 4 | 49 | $S + M + \alpha$ vsa |
| R60 | 45.5 | 15 | 4 | 8 | $S + Z + M$ sa |
| R61 | 44 | 16.5 | 4 | 8 | $S + M + Z$ mt |
| R62 | 42.5 | 19 | 4 | 8 | $S + M + Y$ and/or T † |

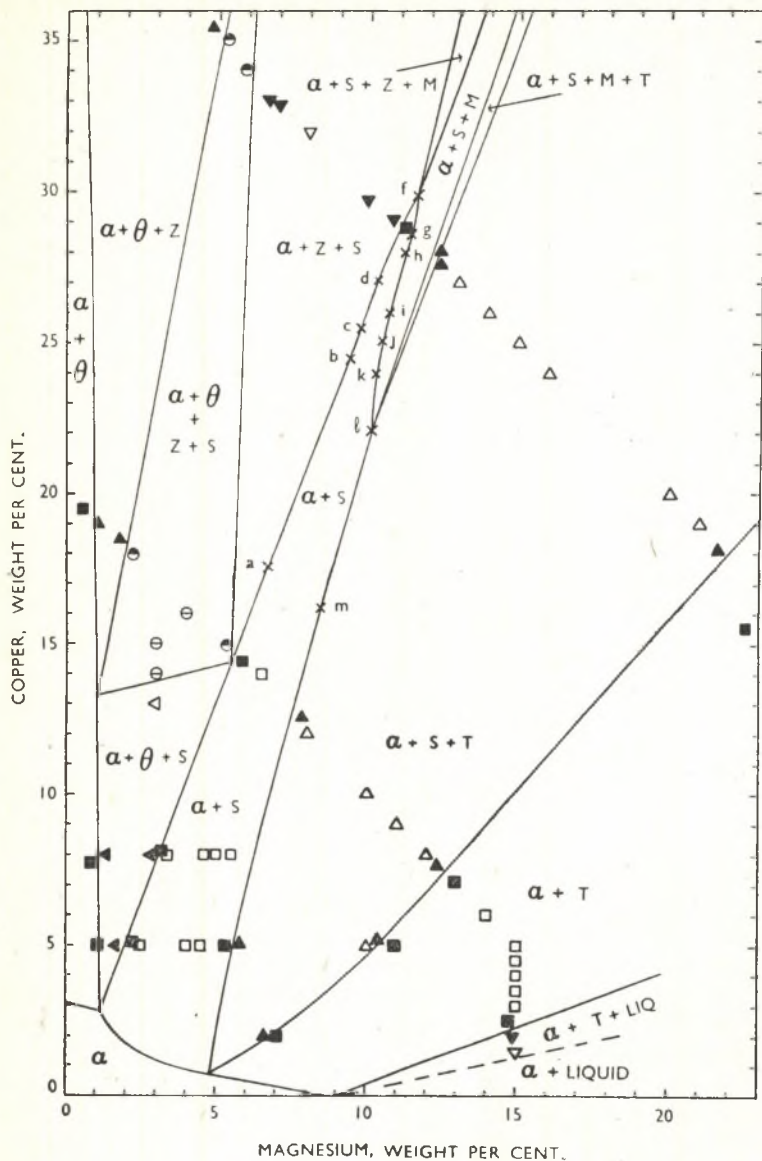
* vsa = very small amounts; sa = small amounts; mt = minute trace.

† As only 3 quaternary alloys possibly containing Y and/or T were examined, it was impossible to distinguish Y and T with certainty here.

VI.—THE QUATERNARY SYSTEM ALUMINIUM-COPPER-MAGNESIUM-ZINC: ALLOYS WITH 4% ZINC.

It was found convenient first to investigate the quaternary system by examining sections across the quaternary model at constant percentages of zinc. The resulting structures may then be compared with those of the ternary system Al-Cu-Mg, the diagram of which may be regarded as lying in the basal plane of a 3-dimensional quaternary model. If this procedure is adopted, the region of the S phase lies in the basal plane, because this phase takes little or no zinc into solid solution.

Fig. 11 shows the results obtained for alloys containing 4% zinc, while Fig. 12 shows the aluminium-rich corner on a larger scale. From Fig. 12, it will be seen that so far as the aluminium-rich alloys are concerned, the effect of 4% zinc is to change the predominantly $(\alpha + S)$ type of diagram of the system Al-Cu-Mg (Fig. 10) into a diagram with $(\alpha + S)$, $(\alpha + S + T)$, and $(\alpha + T)$ fields. This general tendency has been predicted previously,⁵ and the present work establishes the diagram accurately in this region. With higher percentages of copper, the effect of 4% zinc is to introduce alloys containing the Z phase, and, as will be seen from Fig. 11, the phase fields occur in the order $(\alpha + \theta)$,



($\alpha + \theta + Z$), ($\alpha + \theta + Z + S$), ($\alpha + Z + S$), and ($\alpha + S$). The occurrence of the Z phase is the result of the fact that the θ (CuAl_2) phase can dissolve only small quantities of zinc, while the solubility of zinc in the S phase is very small. This means that the two-phase ($\theta + S$) field in the ternary Al-Cu-Mg system (Figs. 8 and 9) can project only a small way into the quaternary model, and cannot cut the section at 4% zinc. The fact that the θ (CuAl_2) and S phases contain little or no zinc implies that alloys in the ($\alpha + \theta + S$) and ($\alpha + S$)

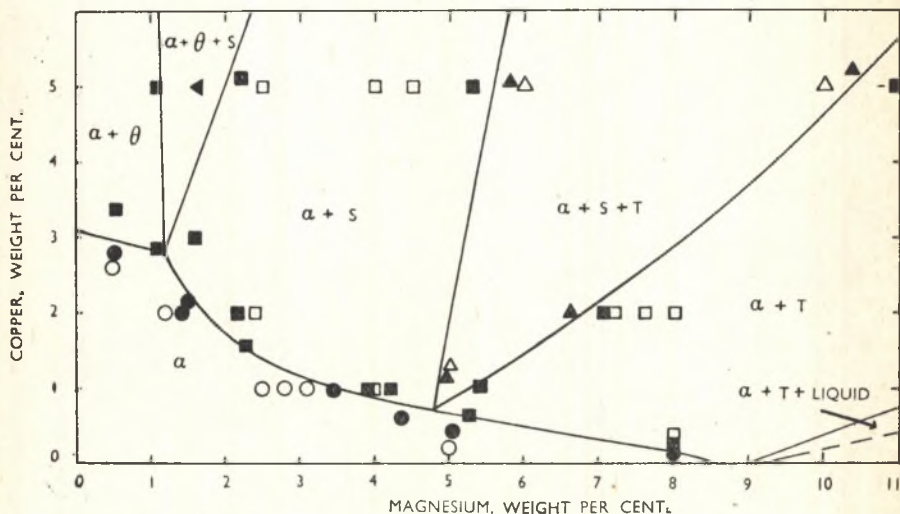


FIG. 12.—The Quaternary System Aluminium-Copper-Magnesium-Zinc at 460° C. Aluminium-rich alloys containing 4% zinc.

fields of Figs. 11 and 12 will contain nearly all of their zinc in the α phase, which will therefore contain more than 4% zinc.

The experiments suggested that after 8 days annealing the majority of the alloys in Fig. 11 were in a state of equilibrium, or very nearly so. There was, however, evidence that alloys in or near the region of the 4-phase ($\alpha + \theta + Z + S$) field were not always in equilibrium after this treatment, and for these alloys the annealing treatments were extended up to five weeks.

In a quaternary system a 4-phase field is bounded by the plane faces of a tetrahedron,* and consequently the boundaries of the ($\alpha + \theta + Z + S$), ($\alpha + S + Z + M$), and ($\alpha + S + M + T$) fields in Fig. 11

* This applies whether the quaternary diagram is drawn with the percentages of copper, magnesium, and zinc on three mutually perpendicular axes, or if the model of a regular tetrahedron is used.

must be straight lines. The boundaries between the 2-phase and 3-phase fields need not be straight lines, and the results indicate a definite curvature of the line between the $(\alpha + S + T)$ and $(\alpha + T)$ fields, and suggest a slight curvature in the lines separating the $(\alpha + S)$ field from the $(\alpha + S + T)$ and $(\alpha + S + M)$ fields.

Fig. 11 shows that in the region concerned, the M -phase fields enter the 4%-zinc section in the form of thin wedges including $(\alpha + S + Z + M)$, $(\alpha + S + M)$, and $(\alpha + S + M + T)$ fields. The alloys prepared did not contain the M phase, and these boundaries have been inserted as the result of calculations based on other sections through the quaternary model. These calculations are discussed in Section X, and the crosses on the $(\alpha + S)$ boundaries marked *a, b, c, d, f, g, h, i, j, k, l*, and *m* were calculated in this way.

VII.—THE QUATERNARY SYSTEM ALUMINIUM-COPPER-MAGNESIUM-ZINC: ALLOYS CONTAINING 6% ZINC.

The results for the section through the quaternary model at 6% zinc are complicated, and the work was made more difficult by the long periods required for the attainment of equilibrium in some regions. It has been necessary to examine alloys whose compositions differed only very slightly, and for this reason several illustrations are required in order to show how the diagram was established.

Fig. 13 shows the equilibrium diagram for the aluminium-rich alloys as indicated by annealing periods of several weeks. When Fig. 13 is compared with Fig. 11, it will be seen that on increasing the zinc content from 4 to 6%, the $(\alpha + T)$ field has increased at the expense of the $(\alpha + S)$ field, in agreement with the prediction that increasing zinc content would change the diagram from the $(\alpha + S)$ to the $(\alpha + T)$ type. At the same time, the fields involving the Z phase, which in the 4%-zinc alloys had entered from the top of the diagram (Fig. 11), have at 6% zinc penetrated so far that they reach the α solid-solubility curve. The α solid-solubility curve at the aluminium-rich corner is divided into the four sections representing equilibrium between α and θ , Z , S , and T , respectively, and after prolonged annealing the various 2-phase and 3-phase fields were convincingly established. It will be seen that the $(\alpha + Z)$ field is very narrow, and this characteristic is discussed later (see p. 214). A group of 18 alloys in the region where the $(\alpha + Z)$ and α fields meet was examined. Of these, the 14 most critical alloys were analysed, and it will be seen that in spite of the very small composition differences involved, the microscopic and analytical results are in excellent agreement.

Fig. 13 refers to alloys annealed to what appears to be nearly true

equilibrium, but with alloys annealed for only 8 days the structures obtained were as shown in Fig. 14. The characteristic of Fig. 14 is that 4-phase alloys of the $(\alpha + \theta + Z + S)$ type are found and change only very slowly to the equilibrium state.

Fig. 15 shows the general form of the section at 6% zinc; and Fig. 16 shows the lower portion of Fig. 15 in the region where the scale of the latter is too small to show the composition of the alloys examined.*

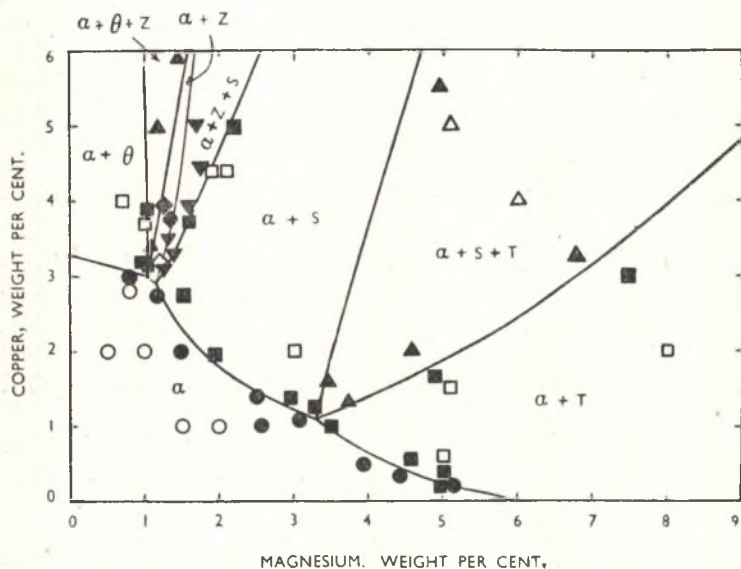


FIG. 13.—The Quaternary System Aluminium-Copper-Magnesium-Zinc at 460° C. Aluminium-rich alloys containing 6% zinc.

Reference to Fig. 15 shows that in the alloys of low magnesium content a very narrow $(\alpha + Z)$ field exists over almost the whole length of the diagram. This was shown by the existence of the three $(\alpha + Z)$ alloys shown in Fig. 13, and the one alloy at 12.2% copper in Figs. 15 and 16. It was further confirmed by the fact that in some other alloys where slight transverse segregation was shown, the portions of the alloy consisting of $(\alpha + \theta + Z)$ and $(\alpha + Z + S)$ did not merge into one another (see p. 219), but were separated by a region consisting of $(\alpha + Z)$.

In the region of high magnesium content, the phase fields fall in the order $(\alpha + \text{liquid})$, $(\alpha + T + \text{liquid})$, and $(\alpha + T)$, and it will be seen that two alloys containing 6% zinc were found to consist of

* Fig. 13 contains many points which have had to be omitted from Fig. 16, and Fig. 16 contains points too close together to be shown in Fig. 15.

homogeneous *T*. This confirms that the *T* phase of the Al-Cu-Mg system can take up zinc into solid solution, and it is probable that this quaternary *T* phase extends across the diagram to the *T*-phase region of the Al-Mg-Zn system.

At higher percentages of copper, a homogeneous *M* alloy was obtained whose composition was magnesium 21.6, copper 52.4, zinc 6, and aluminium 20%. The atomic composition may be written $\text{MgCu}_{0.928}\text{Zn}_{0.103}\text{Al}_{0.8351}$; the corresponding electron concentration is 1.96, while the ratio of small atoms:large atoms is 1.87. If the *M* phase in the Al-Cu-Mg system is AlCuMg , it will be seen that zinc is taken up in such a way that the electron concentration, rather than the ratio of small and large atoms, remains approximately constant.

From Fig. 15 it will be seen that a 4-phase ($\alpha + Z + S + M$) field exists over a considerable range, and a number of 4-phase alloys were obtained in the region of 42% copper and 14% magnesium. The form of the lower portion of this 4-phase field was established by the calculations described in Section X. The crosses marked *b, c, d, f, g, h, i, j, k*, and *l* in Fig. 16, and those marked *f, n, p*, and *l* in Fig. 15 are from these calculations.

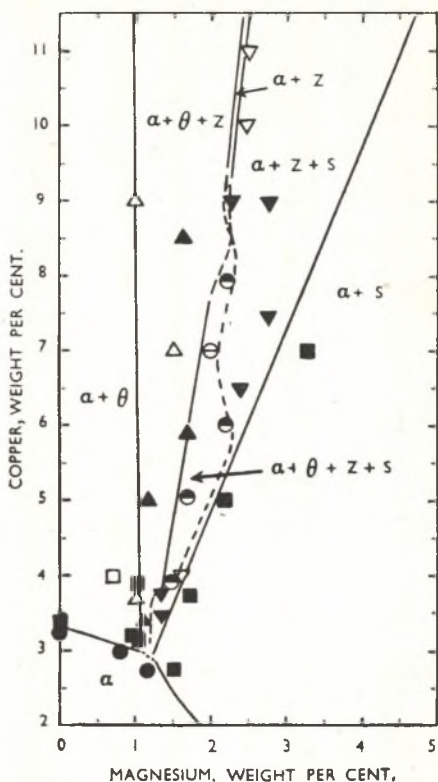


FIG. 14.—The Quaternary System Aluminium-Copper-Magnesium-Zinc at 460° C. The constitution of aluminium-rich alloys containing 6% zinc after annealing for 8 days.

VIII.—THE QUATERNARY SYSTEM ALUMINIUM-COPPER-MAGNESIUM ZINC: ALLOYS CONTAINING 8% ZINC.

The constitution of the section across the quaternary model at 8% zinc is shown in Fig. 17, while Fig. 18 shows the structures of the

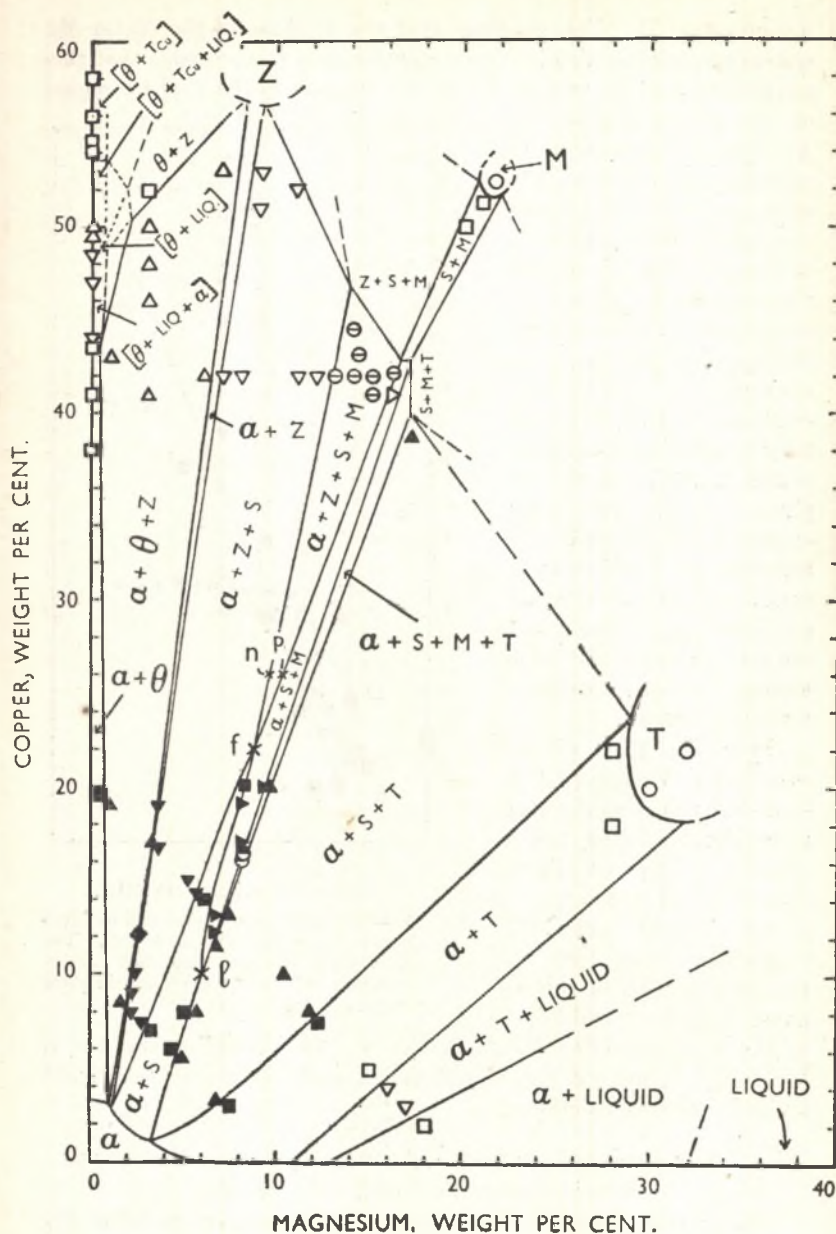


FIG. 15.—The Quaternary System Aluminium-Copper-Magnesium-Zinc at 460° C.
Alloys containing 6% zinc.

aluminium-rich alloys. The increase in zinc content from 6 to 8% has produced the expected broadening of the ($\alpha + T$) area and narrowing

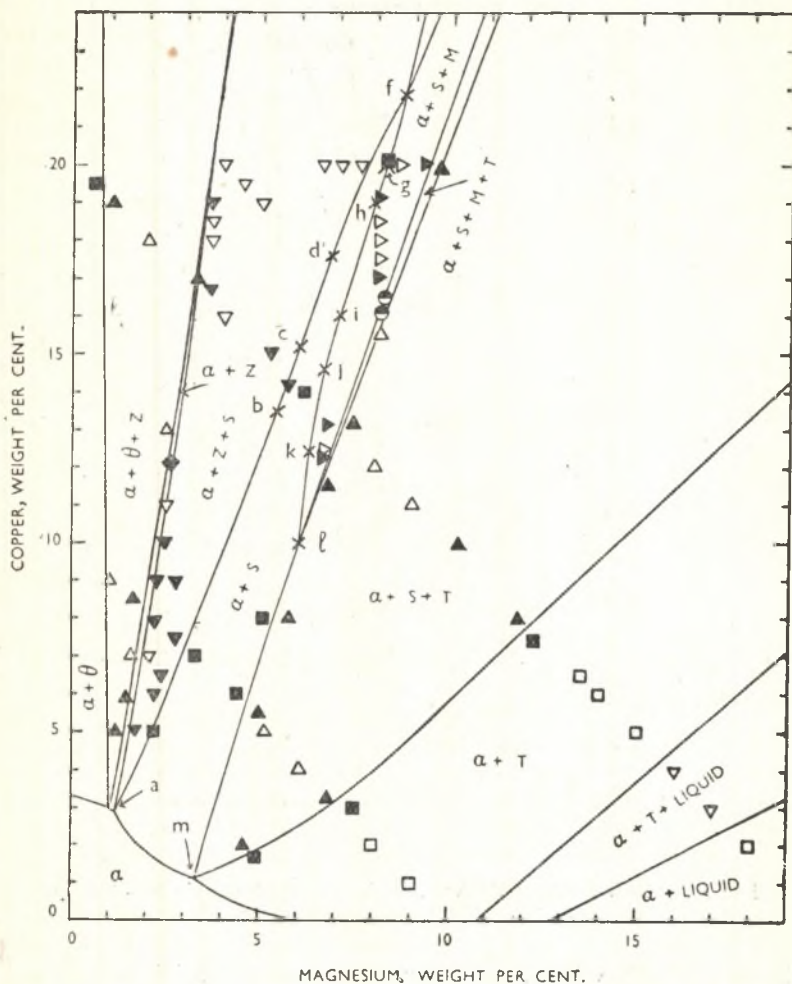


FIG. 16.—The Quaternary System Aluminium-Copper-Magnesium-Zinc at 460° C. Alloys containing 6% zinc.

of the ($\alpha + S$) field. At the same time, the ($\alpha + Z$) field has widened, and the fields involving M have extended so far that they reach the α -boundary. The diagram is thus very complicated, and the α solid-

VOL. LXXIV. Q 2

solubility curve in Fig. 18 is divided into five sections, representing equilibrium with the θ , Z , S , M , and T phases, respectively. As will

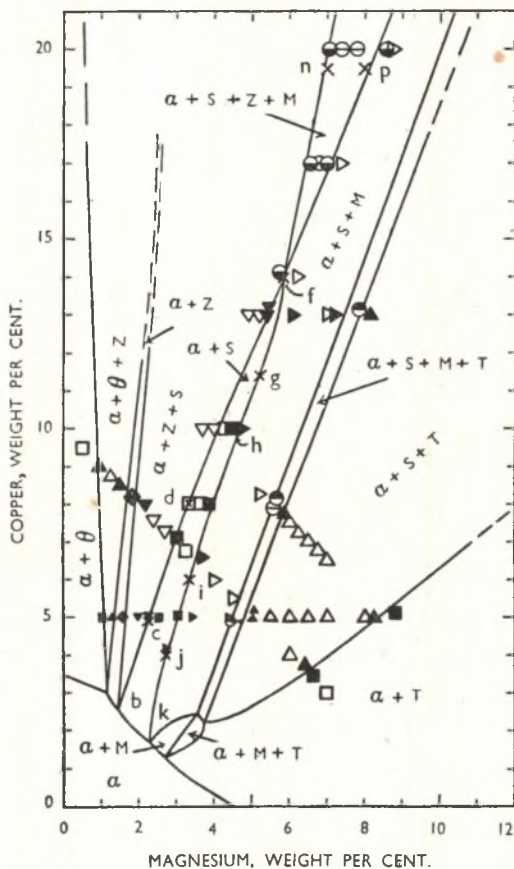


FIG. 17.—The Quaternary System Aluminium-Copper-Magnesium-Zinc at 460° C. Alloys containing 8% zinc.

be seen from Fig. 18, the microstructures are very satisfactorily consistent with the results of the chemical analyses.

Fig. 17 shows all the results obtained for the alloys containing 8% zinc, and is almost self-explanatory. As in the previous diagrams, the lettered crosses refer to the calculations in Section X.

IX.—THE QUATERNARY SYSTEM ALUMINIUM-COPPER-MAGNESIUM-ZINC: ALLOYS CONTAINING 6.5% COPPER.

As will be appreciated from Section X, the boundaries of some of the phase fields are very nearly parallel to the Al-Cu-Mg basal plane of the quaternary model, and are thus very sensitive to slight changes in the zinc content. As it was not practicable to have all the alloys analysed for several metals, it was desirable to check the results described in Sections VI, VII, and VIII by a section at a constant percentage of

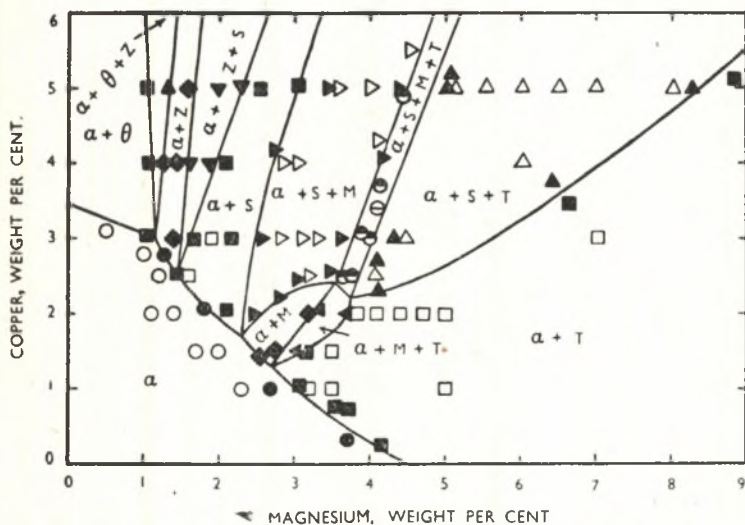


FIG. 18.—The Quaternary System Aluminium-Copper-Magnesium-Zinc at 460° C. Aluminium-rich alloys containing 8% zinc.

copper, to ensure that slight errors in the zinc content had not involved an erroneous placing of the boundaries in the preceding diagram. A series of alloys containing 6.5% copper was therefore prepared and examined after annealing for six weeks, and the critical alloys were analysed. The results are shown in Fig. 19, where the crosses mark the positions of the boundaries in the 4%- and 6%-zinc diagrams. As a further precaution, the alloys under which arrows are placed were annealed for an additional 4 weeks, making a total of 10 weeks in all. This treatment might be expected to result in a very slight loss (of the order 0.1-0.2%) of magnesium, and hence to change the composition in the direction shown by the arrows. After this treatment, the alloy marked *m* showed slight traces of Z which had not been present in the

specimen annealed for 6 weeks; this change was in the direction to be expected from a slight loss in magnesium. The alloy marked *n* showed less of θ after 10 weeks annealing than after 6 weeks; this change is in the opposite direction from that to be expected from a loss of magnesium, and is presumably the result of a closer approach to equilibrium. This one alloy was analysed after the 10-weeks anneal; the analytical result and the intended composition are both indicated, with the arrow representing loss of magnesium joining the symbols. In all other cases,

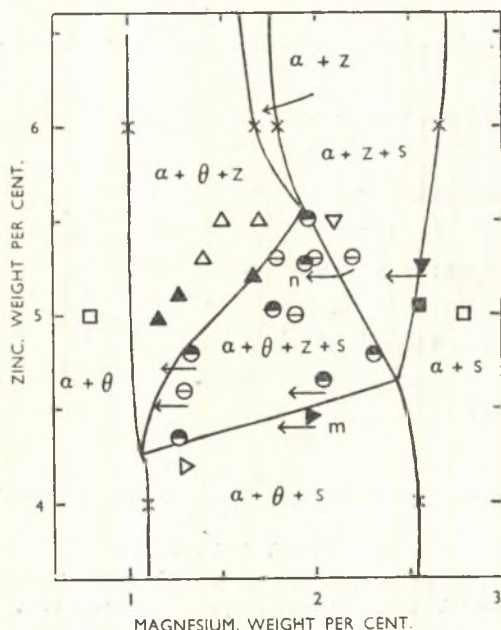


FIG. 19.—The Quaternary System Aluminium-Copper-Magnesium-Zinc at 460° C. The constitution of alloys containing 6.5% copper after annealing for 10 weeks.

the analyses in Fig. 19 refer to the specimen after the 6-weeks anneal. The structures of the remaining alloys were unchanged by the additional 4-weeks anneal. If true equilibrium were established, the 4-phase ($\alpha + \theta + Z + S$) area in Fig. 19 should be a triangle bounded by straight lines, but actually one boundary has to be drawn slightly curved if all the structures are to be included. This suggests that even after 10 weeks annealing, equilibrium has not yet been completely established,* and this conclusion is also suggested by the

* So far as Fig. 19 is concerned, all of the 4-phase ($\alpha + \theta + Z + S$) alloys would be included in a triangle if the composition of one alloy were shifted by

calculations of Section X. It was not, however, possible to continue the annealing for longer periods, and Fig. 19 should thus be regarded as a constitutional diagram based on annealing treatments of 10 weeks.

X.—DISCUSSION OF RESULTS.

The previous Sections have described the results obtained for the 460° C. isothermal sections across the quaternary Al-Cu-Mg-Zn model at 4, 6, and 8% zinc, and at 6.5% copper. So far as the authors can judge, the results refer to alloys which are very nearly in equilibrium, except for the small region of the 4-phase ($\alpha + \theta + Z + S$) field where

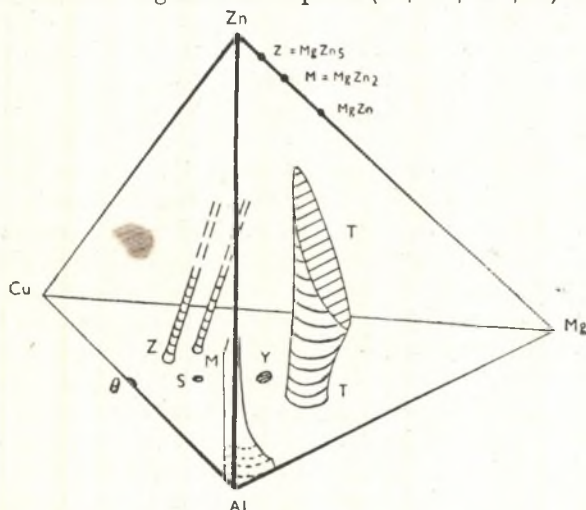


FIG. 20.—Perspective Sketch Showing the Disposition of Single-Phase Regions in the Quaternary Model.

a slight uncertainty exists. The general accuracy of the work may be checked in several ways, of which the most simple is the examination of the various 4-phase regions. For this purpose, a 3-dimensional model may be imagined in which the Al-Cu-Mg system of Figs. 8 and 10 occupies the basal plane, and the axes are arranged as shown in Fig. 20, so that the right-hand face represents the Al-Mg-Zn system at 460° C. (Fig. 7), while the left-hand face represents the system Al-Cu-Zn (Fig. 6). For abbreviation, expressions such as “*X* lies close to *Y*” are used instead of the more correct “the point indicating the composition of *X* . . .”

0.1% magnesium. This difference is of the same order as the experimental error, but, as will be appreciated from what follows, there are other indications that true equilibrium was not reached.

On the base of the model there are the phases α , θ , S , Z , M , Y , and T (cf. Figs. 8, 9, and 10). The θ (CuAl_2) phase dissolves from 1.5 to 2.0% zinc, and little or no magnesium; and its extent is represented by a small area on the left-hand (Al-Cu-Zn) side of the diagram. The S phase dissolves little or no zinc, and is represented by a small area on the basal plane (Fig. 20). The Z_{AlCuMg} phase gives rise to a quaternary Z_{AlCuMgZn} solid solution extending in the direction of the composition corresponding to MgZn_5 in the binary Mg-Zn system; but there cannot be a solid solution extending the whole way from Z_{AlCuMg} to MgZn_5 because the latter melts below 460°C . The M_{AlCuMg} phase forms a quaternary solid solution stretching as a thin column in the direction MgZn_2 . The T_{AlCuMg} phase extends from an area 4 or 5% in dia. on the base of the model, widening out to the elongated T_{AlMgZn} region on the front face of the model. The Y_{AlCuMg} phase lies on the base of the model on the side of T remote from the α boundary, and the fact that the T_{AlCuMgZn} region extends upwards through the model suggests that Y does not come into equilibrium with α . Fig. 20 shows clearly how the $(\theta + S)$ field cannot rise above 1.5% zinc, and enables one to understand the extreme sensitivity of the aluminium-rich alloy structures to the exact zinc content. Fig. 20 also shows how the thin wedge-shaped areas arise in the sections at constant zinc content.

In a quaternary system, under conditions of true equilibrium at a given temperature, a 4-phase field is a tetrahedron whose corners give the compositions of the single phases which exist in equilibrium with one another throughout the tetrahedron. We may consider a hypothetical $(A + B + C + D)$ 4-phase tetrahedron, whose corners A , B , C , and D give the compositions of the four phases in equilibrium. The three edges AB , AC , and AD are straight lines which converge on A . If, therefore, there are two plane sections through the quaternary model which cut the lines AB , AC , and AD , the equations of these lines can be calculated, and if equilibrium has been established they should meet at a point which will be the point A . If true equilibrium has not been established, the lines will in general not converge to a point. If more than two plane sections through the model are available, we can test whether the different points which should lie on AB do actually lie on a straight line; while if independent evidence indicates the composition of the point A , further checks can be obtained as to whether the different sectional diagrams satisfy the conditions for true equilibrium.

The reasoning above may now be applied to the present system, and for simplicity in representation we may imagine the three straight lines AB , AC , and AD to be projected on the Al-Mg-Zn and Al-Cu-Zn

faces of the 3-dimensional model of Fig. 20. The projections of these straight lines should then be straight lines meeting the projections of the point *A* on the two faces, and the conditions for equilibrium can be tested.

1. *The ($\alpha + \theta + Z + S$) Tetrahedron.*

The θ corner of this tetrahedron must lie within 1.5% zinc of the binary (Al-Cu) θ phase, while the *S* corner must lie within 1% zinc of the *S* phase. In the 4%-zinc diagram of Fig. 11, the ($\alpha + \theta + Z + S$) field is a triangle, while in the 6%-zinc diagram of Fig. 15, there is a 2-phase ($\alpha + Z$) field. It follows that the αZ edge of the $\alpha\theta ZS$ tetrahedron runs from a point on *Z* below 4% zinc to a point on α between 4 and 6% zinc. By a similar examination of the diagrams for 0 and 4% zinc, and 6.5% copper, the following indications are obtained of some points on the $\alpha\theta$, αS , and αZ edges of the $\alpha\theta ZS$ tetrahedron :

| Edge. | End Phase. | 4% Zinc. | 6.5% Copper. |
|----------------|----------------|---------------|---------------|
| $\alpha\theta$ | 53% Cu | 12-13.5% Cu | 6.5% Cu |
| | <1.5% Zn | 4% Zn | 4.3-4.5% Zn |
| | No Mg | \cong 1% Mg | \cong 1% Mg |
| αS | 44-45% Cu | 14-15% Cu | 6.5% Cu |
| | <1% Zn | 4% Zn | 4.3-4.7% Zn |
| | 16-17% Mg | 5.4-5.7% Mg | 2.4-2.5% Mg |
| αZ | \cong 58% Cu | 38.5-44% Cu | 6.5% Cu |
| | < 4% Zn | 4% Zn | 5.4-5.6% Zn |
| | \cong 10% Mg | 6-7% Mg | 1.7-2.0% Mg |

The projections of these points on the AlMgZn and AlCuZn sides of the model are shown in Fig. 21 (*a*) and (*b*). The lines should meet at the α corner, and from the α -boundary diagrams it is clear that the α corner must be very near to 2.8% copper and 1.2% magnesium. In Fig. 21 (*a*), it will be seen that the $\alpha CuAl_2$ and αS lines intersect at 1.2% magnesium, in agreement with the α solid-solubility curve, but the αZ line lies distinctly higher. In Fig. 21 (*b*), the $\alpha\theta$ and αS lines can again be drawn so as to intersect at the correct point on the α -boundary, but the angle between them is so small that this is not a critical test; the αZ line is again slightly too high. From this, it is concluded that even after annealing treatments of 10 weeks, the alloys have not yet reached complete equilibrium, although the discrepancy is not very great. In the course of the work, a series of alloys in this region, containing 5% zinc, was prepared and gave erratic results even after annealing treatments of 7 weeks. The above considerations make it clear that this was due partly to lack of complete equilibrium, and partly because the αZ edge of the 4-phase field lay roughly at 5% zinc in the region investigated, with the result that the structures were extremely sensitive to slight variations in the zinc content.

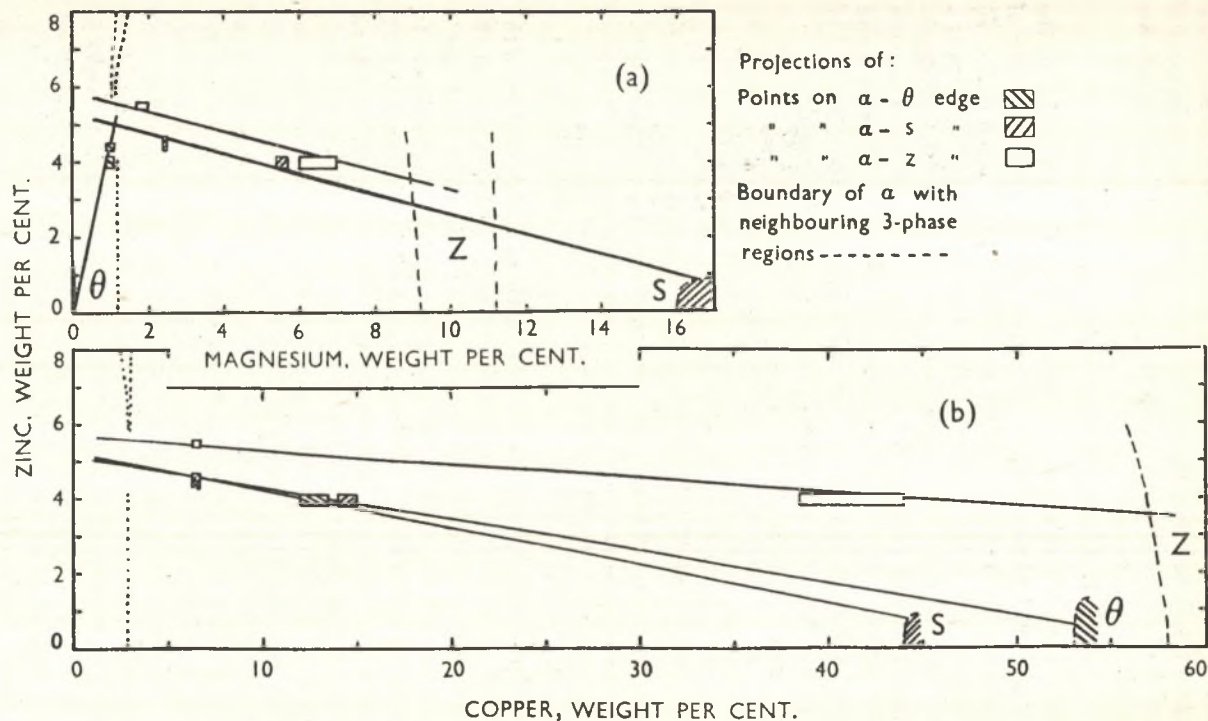


FIG. 21.—Projections of Three Edges of the $\alpha + \theta + Z + S$ Region on Two Faces of the Quaternary Isothermal.
(a) Projection on the AlMgZn face. (b) Projection on the AlCuZn face.

2. The ($\alpha + S + Z + M$) Tetrahedron.

Methods analogous to those described above have shown that this 4-phase field is an elongated tetrahedron rising from S (at copper 44, magnesium 16.6, and zinc 0.5%) to α (at copper 3 ± 0.5 , magnesium 1.95 ± 0.2 , and zinc $10.8 \pm 0.2\%$), with the Z corner of the region at zinc 14 ± 2 , copper 50, and magnesium 11%, while the M corner probably lies at a much higher percentage of zinc. The results suggest that equilibrium has been reached in the aluminium-rich alloys.

3. The ($\alpha + S + M + T$) Tetrahedron.

Similar methods show that in this 4-phase field the S edge rises from S to α (at copper 1.2, magnesium 3, and zinc 7.45%), the α corner being established with some precision. The M corner involves a long extrapolation, but the results are consistent, and indicate a composition of copper 39, magnesium 20, and zinc $25 \pm 2\%$. The T corner can only be estimated as lying at approximately copper 10-25, magnesium 30, and zinc $20 \pm 5\%$. The results suggest that equilibrium has been reached in the aluminium-rich alloys.

4. Equilibrium with the S Phase.

In the ternary system Al-Cu-Mg, the S phase exists as a small elongated area, from which the various phase fields radiate as shown in Fig. 9. The S phase dissolves only small percentages of zinc, and the results suggest that the phase may be regarded as rising very slightly above the base of the quaternary model, and as possessing ridges dividing the areas in equilibrium with the different phases as shown in Fig. 22. The intersections of these ridges at the points q , f , and l represent the S -corners of the 4-phase ($\alpha + \theta + S + Z$), ($\alpha + S + Z + M$), and ($\alpha + S + M + T$) tetrahedra. The ridges represent the compositions of S in the various 3-phase regions, while the different slopes of the " S hill" include the compositions of S concerned in the 2-phase alloys. The present work has established the boundaries of ($\alpha + S$) over a considerable range, and a series of points can be taken on the ($\alpha + S$) slope of Fig. 22, and on the α -phase boundary, and by trial and error pairs of points can be selected whose tie lines intersect

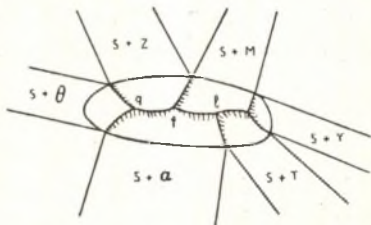


FIG. 22.—Sketch Showing the Form of the S -Phase Region in the Quaternary Isothermal.

the different sectional diagrams in best agreement with the facts. A general examination of these will decide whether the results are consistent. It can readily be shown that S and α are so far from one another that the exact zinc content of S is unimportant.

In Fig. 22, f is the S corner of the $(\alpha + S + Z + M)$ tetrahedron, whose α corner was described above (see p. 217). When these points are joined by a straight line, this line intersects the 8%-zinc section of Fig. 17 at the point marked f , and is in good agreement with the observed microstructures. The intersection of the same straight line with the 6%-zinc section of Fig. 15 is again marked f , and agrees with observation, although there is no very close bracket. The intersection of the same straight line with the 4%-zinc section is shown in Fig. 11 by the point f , and as explained previously (see p. 205), it was in this way that the corner of the 4-phase triangle was placed in Fig. 11. The remaining lettered crosses in these Figures were obtained in the same way for other tie lines; a given letter refers to the intersection of a particular straight line with the different plane sections through the quaternary model. Several calculations have been made to check the equilibrium of the quaternary model, using the ruled surfaces of 3-phase fields, and the plane sides of the 4-phase tetrahedra. The general conclusion reached from these calculations is that, with the exception of the exact boundaries of the $(\alpha + \theta + S + Z)$ region, the results are consistent with the conditions for true equilibrium. This is, of course, not a proof that equilibrium was established, but it would be a remarkable coincidence if the different plane sections fitted together so well for alloys which were not reasonably near to equilibrium.

XI.—EXPERIMENTAL DETAILS.

1. *Materials Used.*

The aluminium used in the present work was super-purity aluminium supplied by the British Aluminium Company, Ltd., while the zinc was of 99.99% purity, obtained from the National Smelting Corporation. The copper was from a batch of specially pure metal kindly presented to the authors some years ago by the British Non-Ferrous Metals Research Association. The magnesium metal was either of 99.95% purity, supplied by the Magnesium Metals and Alloys Company, Ltd., or of 99.979% purity, from a Canadian source.

2. *Preparation of Alloys.*

The alloys were prepared by melting under flux in crucibles lined with alumina-fluorspar mixture. They were cast into heavy copper

moulds which gave cylindrical ingots of $\frac{1}{4}$ or $\frac{5}{16}$ in. dia. The methods of annealing in sealed evacuated glass tubes, quenching, grinding, and polishing were in general the same as those described in previous papers.^{1,3,5} In the course of the work, it was found that polishing could be carried out more quickly by using a "Brasso" type of polish on a rotating wheel, followed by a short light hand-polish with "Brasso" on chamois leather, and then with white spirit on chamois leather. Specimens were usually washed in a bath of alcohol and dried by wiping on a clean cotton rag. When a particularly good finish was required, the surface was washed with a jet of benzene, and then with a jet of alcohol, and finally gently wiped on soft chamois leather; this gave better results than drying in a current of warm air.

3. *Microscopic Examination.*

The constitutional diagrams presented are based almost entirely on the results of microscopic examination. In all cases it was found desirable to examine the specimen thoroughly in the unetched state, since much information could be gained from variations in the colour, shade, smoothness, hardness, and relief of the different phases. Systematic examination gave no evidence of longitudinal segregation in the annealed ingots, but slight transverse segregation was noted in some alloys, and could often be used to give valuable information. For this purpose, a pantographic attachment was devised which was screwed to the travelling stage of the microscope, and indicated the relative movement of the specimen and objective on a magnification of 4 dia. A pencil was fixed to the long arm of the pantograph, so that when the surface of the specimen was scanned, a pencil mark could be made on a piece of paper to indicate the position at which a particle of a particular phase was noted. In this way, a general survey of the surface of a specimen could be drawn at a magnification of 4 dia., and this was often of great assistance to the work. If, for example, the outside of the specimen consisted of $(A + B + C)$, while the inside was $(A + B)$, it was possible to turn off the outside or to drill out the inside, after which analysis of both samples would give a close composition bracket of the line separating the 2-phase and 3-phase fields.* The systematic examination by means of the pantograph device also showed that in some alloys where the outside consisted of $(\alpha + Z + S)$, and the inside of $(\alpha + Z + \theta)$, there was a narrow 2-phase $(\alpha + Z)$ zone between the two 3-phase regions, and this clearly suggested the existence of a 2-phase $(\alpha + Z)$ field in the part of the diagram con-

* This method assumes that the annealing treatment was sufficient to produce local equilibrium at any one region in the alloy.

cerned. In contrast with this, other alloys were found in which $(\alpha + Z + S)$ and $(\alpha + Z + \theta)$ regions overlapped and this clearly suggested the existence of a 4-phase $(\alpha + Z + S + \theta)$ field.

4. *Chemical Analysis.*

The analyses of the specimens were carried out by Messrs. Johnson, Matthey and Company, Ltd., and the authors must express their indebtedness to Mr. A. R. Powell for his continual help and supervision. Specimens sent for analysis were always examined at both ends in order to ensure that longitudinal segregation was absent. It was not possible to have all specimens analysed for magnesium, zinc, and copper, and the policy adopted was to have magnesium determined in all cases, since this constituent might be lost, both during prolonged annealing treatments at $460^{\circ}\text{C}.$, and also as the result of accidental overheating during the melting process. The results showed that losses of the order of 0.1 or 0.2% magnesium might occur during a 4-weeks annealing treatment, but otherwise no loss in magnesium occurred, and the magnesium contents of the alloys as determined by analysis were usually about 0.1% higher than had been intended. The results suggested that in general the magnesium content was satisfactorily controlled by using a strictly standardized melting technique in which overheating was prevented. The zinc contents of a number of alloys were determined, and the results suggested that in general the intended and actual zinc contents would not differ by more than 0.2%, and would usually agree within 0.1%. The copper contents of a number of alloys were also checked, and a good agreement was again found between the intended and actual percentages.

It will be appreciated that in alloys where slight segregation was noted, the procedure of determining magnesium alone was often not sufficiently precise, since if the segregation affected the magnesium content of the inside and outside of the alloy, it might also affect the percentages of zinc and copper. From the earlier Sections, it will be seen that in most parts of the diagrams with which the present paper is concerned, an error in the zinc content of an alloy has much more serious results than a corresponding error in the copper content. For this reason, nearly all of the alloys whose centres were drilled out were analysed for zinc as well as for magnesium, while the copper contents were determined in a number of cases.

5. *Etching Technique.*

The great majority of specimens were etched by simple immersion in the reagent concerned, the specimen being held in a glass spoon.

In some cases, good results were obtained by etching in nitric acid vapour, and for this purpose the specimen was placed in a glass spoon whose handle was bent at right angles and suspended from a cork which closed a jar containing a little of the concentrated acid.

The most useful etching reagents were 1-2% aqueous hydrofluoric acid, Keller's reagent, concentrated nitric acid, 10% aqueous caustic soda, and a reagent which was called ψ -molybdate. This consisted of an aqueous solution of 1.44 g. ammonium nitrate, 9.4 c.c. concentrated nitric acid per 100 c.c. of water, shaken up with excess of molybdic acid (MoO_3), and left for one or two days with occasional shaking; the solution was used diluted with an equal volume of water. This reagent was adopted because experience showed that the ordinary "ammonium molybdate" solutions used in analytical chemistry often gave inconsistent results which appeared to depend on the age of the solution.

With many alloys, the first etch of a polished surface tended to give spurious results, and it appears desirable always to repeat the polishing and etching processes until it is certain that the true structure is being observed. The etching characteristics of the different phases are summarized in Table II. The exact behaviour of the phase is not always the same in alloys of high aluminium content as in alloys with high percentages of copper. Dealing first with the aluminium-rich alloys, the following points may be noted.

The CuAl_2 or θ -phase is characterized by being unetched, or very lightly outlined, by normal times of etching in the acid reagents, but is turned brown with a black outline by immersion in 10% aqueous sodium hydroxide for 30-60 sec. When CuAl_2 is present in small amounts in aluminium-rich alloys of the $(\alpha + \theta)$ type, it may also be etched to a very faint brown colour by the above treatment, and the α solid solution often becomes tarnished if the etching time is prolonged sufficiently to turn the CuAl_2 phase a dark brown. In the aluminium-rich alloys, the S and Z phases come into equilibrium with CuAl_2 . Both these phases are outlined in black by aqueous sodium hydroxide; it is perhaps more correct to say that the α solid solution is outlined when in contact with S or Z , because no outline is seen where crystals of S and Z touch one another. Aqueous sodium hydroxide turns the S phase bright mauve-white, and the Z phase bright bluish-white, so that they are readily distinguished from the CuAl_2 phase, although not from one another.

The S and Z phases are distinguished by immersion for 10-20 sec. in Keller's reagent, or for 1-2 min. in ψ -molybdate. The S phase is outlined and turned smooth black, while small crystals may be dissolved out, particularly if the zinc content is high (8%). The Z phase is out-

TABLE II.—*Etching Characteristics of the Phases θ , Z, S, M, and T.*

The general characteristics most useful for distinguishing between the phases are shown in black type.

| | CuAl_2 ($\equiv \theta$). | Z. | S. | M. | T. |
|----------------------------------|---|---|--|--|--|
| Unetched. | Pale lilac grey, scratched. | Smooth lavender-grey. Bright and in relief in dilute alloys, becoming dim with more copper. | Mauvish-grey, scratched. | Pale lilac-grey, slightly scratched. Dim in copper-rich alloys. | Faint lilac-grey, scratched. |
| 10% NaOH, 30 sec. | Outlined Brown. Sometimes only faint brown especially in dilute alloys.* | Black Outline ; Bright Bluish-White. (Only interfaces with α are outlined). | Black Outline ; Bright Mauvish-White. (Only interfaces with α are outlined). | Outlined ; bluish-white. | Outlined ; bluish-white. |
| Keller's etch, 10-20 sec. | Very Thinly Outlined. | Black Outline ; Bright Grey to Salmon-Brown Tarnish ; usually incomplete.† | Outlined ; Smooth Black. Tendency to dissolve in 8%-zinc alloys. | Heavily outlined or dissolved. | Black. |
| ψ -Molybdate, 1-2 min. | Unetched. Sometimes slightly outlined. | Brown. Liable to vary from pitted pale-brown to dirty black in 8%-zinc alloys.† | Black. Sometimes very dark brown. | Black. Usually with a chocolate tint. | Black ; sometimes dissolved. |
| 10-30 sec. | Unetched. | Unetched. | Brown-Pitted Grey to Dirty Light-Brown. | Black Outlined ; Smooth "Pale Black". | Black Outlined ; Smooth "Pale Black". |
| Dilute HF (1-2%), 10-30 sec. | Unetched. | Unetched. Appears brightened in copper-rich alloys. | Usually Light-Brown Scratchy Tarnish. Not Outlined. Local pitting or darkening. | Thinly Outlined ; Pale Grey. (Slightly pitted in copper-rich alloys.) | Black. Usually smooth with various tints.‡ |
| Conc. HNO_3 , 6-10 sec. | Slightly outlined, otherwise unetched. | Slightly outlined, otherwise unetched. | Unetched. Perhaps paler. | Dissolved (or pitted black). | Black Outlined ; Pale Light-Brown. Fainter with increasing zinc.§ |
| 3-5 sec. | Unetched. | Unetched. | Unetched. | Heavily Outlined ; or Partly Dissolved. | Unetched, or Thinly Outlined. § |

* In dilute ($\alpha + \theta$) alloys, the θ is sometimes not browned at all.

† Frequently not browned in very dilute alloys.

‡ Often various local colours, especially the larger crystals, which are heavily outlined brown.

§ Pits, and dissolves in 8%-zinc, magnesium-rich alloys.

lined in black and turned bright grey, which tends to become tarnished brown with increasing copper content.

In quaternary alloys, the *M* phase is blackened by immersion for 1-2 min. in ψ -molybdate. With a shorter period of immersion (10-30 sec.), the *M* phase is outlined and turned a smooth grey-black colour; under the same conditions, *Z* is unattacked, and *S* is turned a brown-pitted grey or dirty light-brown.

The *T* phase is attacked by all the acid reagents. Immersion for 15 sec. in ψ -molybdate makes *T* almost indistinguishable from *M*. Immersion for 10-30 sec. in 1-2% aqueous hydrofluoric acid turns *T* black; its appearance is usually smooth, while sometimes various tints of red, blue, or green are obtained, although these are not reproducible. The same reagent does not blacken *M*, but lightly outlines the *M* crystals, which become pale grey and sometimes slightly pitted. With the 4-phase ($\alpha + S + T + M$) alloys, it was found satisfactory to etch first in dilute hydrofluoric acid and to examine for *T* and *M*, and then, without repolishing, to etch in ψ -molybdate for 15 sec., when *T* and *M* are smooth and outlined with olive-green or chocolate tints, while the *S* is tarnished pale brown, but not outlined.

The *S* and *T* phases are distinguished by immersion for 6-10 sec. in concentrated nitric acid, in which *S* is unattacked, while *T* is outlined and turned pale light-brown which becomes fainter with increasing zinc content. In the alloys containing zinc 8, copper *ca.* 1, and magnesium 3%, the *T* phase tends to be dissolved. The *M* phase is always heavily pitted or dissolved by the above treatment in concentrated nitric acid. Except in the 8%-zinc, 3%-magnesium region of composition, the *M* and *T* phases may be distinguished by a shorter etch in concentrated nitric acid, which heavily outlines and partly dissolves the *M* phase, but leaves *T* unattacked except occasionally for a thin outline. This etching treatment can be followed by an immersion in dilute hydrofluoric acid, which blackens the *T* and tarnishes the *S*, while leaving *M* grey with a heavy outline. This method enables small amounts of *M* to be detected among *S* and *T*. Nitric acid vapour was used to distinguish liquid in ($\alpha + \text{liquid}$) and ($\alpha + T + \text{liquid}$) alloys. With about 1-2 min. etching, the fine-structure chilled liquid showed up pale-straw coloured, while the *T*, when present in more than small amounts, was heavily pitted in rather remarkable black spots, which, with the straggling lace-like structure of *T* near the solidus, caused some confusion at first between *T* and liquid. The effect was similar to, though rather less marked than, the behaviour of the *Y* phase in hydrochloric acid (see p. 224).

6. *Etching Characteristics of Aluminium-Copper-Zinc Alloys of High Copper Content.*

In alloys of composition in the region of that of CuAl_2 , the phases T_{AlCuZn} , η_{AlCu} ("CuAl"), and liquid were found. Liquid was clearly etched by 15-sec. immersion in concentrated nitric acid to a bright mottled brown; the η phase was darker unetched than θ , and the ternary phase was darker grey.

7. *Etching Characteristics in the Region of the S Phase.*

The etching characteristics of the different phases in the alloys of high copper content were in general similar to those described above; but the effects of the reagents differed greatly in degree, and where the phases were of widely varying composition, regular changes in the etching characteristics could often be traced.

The *S* phase is darkened by the action of dilute hydrofluoric acid, often with the production of local spots of brown tarnish. Immersion for 1-2 min. in ψ -molybdate turns the *S* crystals brown; the different grains usually show up in slightly different shades, but are never so dark as in the aluminium-rich alloys.

In alloys of low zinc content, the *Z* phase was unattacked after a 1-2 min. immersion in ψ -molybdate; but with increasing zinc content, this phase was outlined and was sometimes partly turned brown or grey.

The behaviour of the *M* phase on etching with ψ -molybdate shows a regular change with increasing zinc content. In the ternary Al-Cu-Mg alloys, the *M* phase etches to a thinly outlined pale-straw colour. In the 1%-zinc alloys, the *M* phase is outlined and appears light brown to dark olive-brown. On increasing the zinc content of the alloys to 4 and 6%, the crystals of *M* become more darkly outlined, and the colour changes from dark olive-brown to olive-black and dark black.

The *T* phase is blackened by 30-sec. immersion in ψ -molybdate, and is outlined by dilute hydrofluoric acid, which colours the crystals blue to brown; the intensity of etching varies greatly with the composition. The *Y* phase of the system Al-Cu-Mg behaves very similarly to the *T* phase, and a distinction between the two is often difficult. On etching with dilute hydrofluoric acid, the tints of the brown obtained on *T* and *Y* vary greatly, but in general *Y* is etched to a darker shade. A point which should be noted is that in some of the (*Y* + *T*) and (*Y* + *T* + *S*) alloys, spurious effects are obtained by etching *Y* in dilute alcoholic hydrochloric acid. In this reagent, the *S* was either unattacked or slightly browned, while the *Y* became covered with

large black spots which were quite different from the usual pitting effects, and which readily gave the impression that the crystals of Y consisted of two phases. Careful examination of specimens etched for increasing times of immersion showed this effect to be spurious, although the etching is so clean that a misleading conclusion is easily drawn.

ACKNOWLEDGEMENTS.

The authors must express their gratitude to Professor C. N. Hinshelwood, F.R.S., for laboratory accommodation and many other facilities which have greatly encouraged the present research.

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METALLURGICAL ABSTRACTS

| | PAGE |
|--|------|
| I. Properties of Metals | 137 |
| II. Properties of Alloys | 147 |
| III. Structure (Metallography ; Macrography ; Crystal Structure). | 149 |
| IV. Dental Metallurgy | — |
| V. Powder Metallurgy | 151 |
| VI. Corrosion and Related Phenomena | 152 |
| VII. Protection (Other than by Electrodeposition) | 154 |
| VIII. Electrodeposition | 157 |
| IX. Electrometallurgy and Electrochemistry (Other than Electro- deposition) | 157 |
| X. Refining | 157 |
| XI. Analysis | 157 |
| XII. Laboratory Apparatus, Instruments, &c. | 159 |
| XIII. Physical and Mechanical Testing, Inspection, and Radiology. | 160 |
| XIV. Temperature Measurement and Control | 161 |
| XV. Foundry Practice and Appliances | 162 |
| XVI. Secondary Metals : Scrap, Residues, &c. | 164 |
| XVII. Furnaces, Fuels, and Refractory Materials | 164 |
| XVIII. Heat-Treatment | 164 |
| XIX. Working | 165 |
| XX. Cleaning and Finishing | 166 |
| XXI. Joining | 166 |
| XXII. Industrial Uses and Applications | — |
| XXIII. Miscellaneous | — |
| XXIV. Bibliography | 168 |
| XXV. Book Reviews | 172 |

AUTHOR INDEX TO ABSTRACTS

- ADAMS, R. C., 159.
Aitchison, L., 164.
Albano, V. J., 155.
Almen, J. O., 173.
Armstrong, W. M., 162.

Baeyerztz, M., 169.
Barnett, S. J., 148.
Barr, E. E., 159.
Barrett, C. S., 174.
Bartoli, I., 174.
Bass, N. W., 137.
Batty, H. B., 159.
Beaumont, R. A., 169.
Beeby, W. L., 163.
Benedict, O. J., Jr., 169.
Bennett, F. C., Jr., 158.
Berry, N. E., 154.
Bialosky, J. M., 152, 154.
Billings, R. H., 159.
Birch, F., 142.
Bloodgood, H., 153.
Blythe, N. C., 163.
Boas, W., 139, 140.
de Boer, J., 149.
Bogroff, S., 172.
Bonner, W. F., 156.
Boucher, J., 163.
Bowen, I. G., 148.
Bozorth, R. M., 149.
Brady, G. S., 169.
Brugg, (Sir) L., 150.
Bristow, J. R., 144.
Brown, R. H., 152, 155, 156, 162.
Bulow, C. L., 152.
Burton, L. W., 156.

Cabrera, N., 137.
Calingaert, G., 148.
Carne, J. B., 164.
Cass, W. G., 155.
Castro, R., 158.
Chalmers, B., 143.
Charrin, V., 170.
Chase, H., 162.
Christen, H., 170.
Clark, H. T., 174.
Clark, K. L., 162.
Clarke, F. E., 159.
Cole, J. H., 138.
Cook, P., 161.
Corney, G. M., 161.
Cozzo, G., 170.
Cramer, E. M., 163.
Cross, R. J., 166.
Crowe, J. J., 166.
Cummings, J. M., 162.
Curry, T. W., 162.
Cusset, F., 176.
Custers, J. F. H., 150.

Darrin, M., 154.
Daut, J. G., 146.
Davies, O. L., 170.
Davis, R. T., Jr., 139.
Dean, R. S., 145.
Deniges, G., 158.
Denison, I. A., 157.
Dews, J. W., 162.
Dietze, I. C., 156.
Dively, R. W., 161.

Dixon, E. O., 174.
Du Mond, J. W. M., 159.
Du Mont, C. S., 170.
Dunbeck, N. J., 163.
Dunkley, G. T., 171.
Dunn, E. J., Jr., 156.
Durand, S. R., 164.

Eeles, C. C., 165.
Elliott, H. E., 162.
Elliott, M. A., 160.
v. Engel, A., 145.

Featherly, R. L., 156.
Fergus, D. J., 153.
Findley, W. N., 160.
Fitzgerald, J. W., 138.
Fitzgerald-Lee, G., 155.
Folgnier, H. A., 166.
Forrester, P. G., 143.
Fox, F. A., 168.
Freudenthal, A. M., 143.
Frye, R. A., 154.

Gardner, C. R., 163.
Garrido, C., 171.
Gibb, (Sir) C. D., 164.
Gibbs, L. E., 175.
Gibney, R. B., 147.
Girschig, R., 160.
Goldkamp, C., 154.
Gordy, W., 145.
Gosnell, E. C., 154.
Gourley, V. C., 175.
Gow, J. T., 153.
Graves, H. B., Jr., 171.
Greenwood, H. W., 151, 152.
Greenwood, J. N., 138.
Griffiths, E., 171.
Gwatkin, J. G., 165.
Gwyther, R. E., 166.

Hamann, C. E., 156.
Hamburg, H. F., 174.
Hamon, J., 137.
Harkins, W. D., 144.
Harper, W. E., 155.
Heywood, R. B., 143.
Hill, R., 140.
Hiskey, D. R., 156.
Holler, H. D., 154.
Honeycombe, R. W. K., 139, 140, 171.
Hoover, C. P., 154.
Horger, O. J., 173.
Hothersall, A. W., 157.
Howson, H. O., 163.
Hoxeng, R. B., 156.
Huang, K., 149.
Hudson, D. R., 151.
Hudson, F., 162.
Hunter, E., 162.
Hurle, B. G., 138.
Hyde, W. L., 159.

Imbembo, E. A., 160.
Ingall, D. H., 164.

Janco, N., 162.
Jaycox, E. K., 158.
Jelatus, D. G., 159.
Jenkins, I., 165.

Johnson, V. A., 147.
Johnson, C. G., 171.
Jimeno, E., 171.
Kahn, N. A., 160.
Kê, T.-S., 137.
Kemball, C., 138, 139.
Kemsley, D. S., 171.
Kessler, K. G., 159.
King, C. V., 153.
Kirk, R. E., 171.
Kittel, C., 145.
Kleinschmidt, B., 171.
Klug, H. P., 138.
Kochanovska, A., 149.
Kosting, P. R., 173.
Krohn, I. T., 148.

Lark-Horowitz, K., 147.
Laurent, P., 172.
Lawrie, R. D., 164.
Lee, E. H., 140.
Lichy, C. M., 174.
Longmuir, J. B., 164.
Lype, E. F., 149.

McAfee, E. J., 163.
McKeehan, L. W., 145.
McRaven, C. H., 157.
Maréchal, J. R., 172.
Masi, F., 174.
Mason, C. W., 172.
Mason, E. W., 165.
Mears, R. B., 155.
Mendelssohn, K., 146.
Mersereau, S. F., 172.
Meyer, E. G., 160.
Mezoff, F. G., 162.
Miller, J. L., 176.
Miller, M. C., 154.
Mills, B. D., Jr., 161.
Milner, G. W. C., 158.
Mitchell, N. W., 152.
Moore, H. F., 173.
Morrigh, H., 148.
Morton, B. B., 153.
Morton, C. A., 165.
Morucci, R., 172.
Murray, W. M., 173.

Naylor, B. F., 149.
Nye, J. F., 150.

Ogg, R. A., Jr., 146.
Orland, J., 171.
Orth, R. L., 163.
Othmer, D. F., 171.
Owen, E. A., 138.

Parkes, A. R., 162.
Pearson, G. L., 147.
Pereny, L., 154.
PHELPS, E. R., 143.
Pitaval, R., 174.
Plantenberg, G., 138.
Poncelet, E. F., 142.
Pope, J. A., 141.
Pope, R., 155.
Ponvreaux, J. M., 158.
Pullin, V. E., 161.

Quadt, H. A., 164.

Raynor, G. V., 147.
Reynolds, I. W. G., 166.
Rideal, E. K., 138.

Ringo, G. R., 138.
Robinson, H. A., 156.
Robrnan, F. A., 154.
Roush, W. L., 166.

Saacke, F. C., 166.
Saibel, E., 142.
Sâlcăanu, C., 141, 142.
Sanderson, L., 158.
Saunderson, J. L., 174.
Sawyer, D. W., 152.
Schotfeld, M., 157.
Schroeder, A. J., 155.
Schulman, J. H., 159.
Segsworth, R. S., 174.
Shaler, A. J., 151.
Shapiro, H., 148.
Shaw, C., 163.
Shestopal, V. M., 162.
Shriner, M. E., 165.
Simmons, C. R., 163.
Simoni, G., 174.
Singer, F., 151.
Sladden, J. W., 165.
Sondheimer, E. H., 146.
Squires, A. T. B. P., 168.
Stout, A. D., Jr., 155.
Sweet, M. H., 161.
Symes, W., 163.

Tama, M., 164.
Tate, L. C., 161.
Telford, A. C., 175.
Terrier, J., 137.
Thurnauer, H., 151.
Tupper, S. J., 140.

Uhlig, H. H., 153, 155.

Valeur, J., 172.
Vennerholm, G., 161.
Verink, E. D., 156.

Wakeman, D. W., 147.
Walker, H. S., 165.
Webber, D. S., 148.
Weber, A. H., 138.
Weisberg, L., 157.
Welter, G., 160.
Wilkinson, E. R., 154.
Williams, N. T., 167.
Williams, R. W., 138.
Williams, S. V., 165.
Williams, W. J., 148.
van der Willigen, P. C., 167.
Willis, M. S., 145.
Wilson, A. H., 146.
Wilson, S. P., 156.
Wintner, A., 150.
Wishinsky, H., 153.
Wolfe, R. A., 159.
Wood, D. H., 164.
Wood, E. I., 156.
Wright, D. A., 157.
Wulff, J., 151.
Wyer, R. F., 167.
Wyllie, M. R. J., 150.

Yager, W. A., 149.

Zener, C., 148.
Ziegfeld, R. L., 153.
Zuidema, H. H., 152.

METALLURGICAL ABSTRACTS

(GENERAL AND NON-FERROUS)

Volume 15

DECEMBER 1947

Part 4

I.—PROPERTIES OF METALS

***Stress Relaxation Across Grain Boundaries in Metals [Internal Friction in Aluminium].** T'ing-Sui Kê (*Phys. Rev.*, 1947, [ii], 72, (1), 41–46).—Kê's view (*ibid.*, 1947, 71, 533; *Met. Abs.*, 1947, 14, 305), that grain boundaries in metals behave in a viscous manner, is tested by experiments on the temp. dependence of the internal friction and rigidity modulus of 99.991% aluminium at different frequencies of torsional vibration, using specimens with different grain-sizes. For the same specimen an increase in the frequency of vibration shifts the internal-friction curve and rigidity-relaxation curve to higher temp. At const. frequency, an increased grain-size shifts the two curves to higher temp. The observed phenomena agree with the hypothesis of stress relaxation across grain boundaries, arising from the viscous behaviour of the grain-boundary material. The observations lead to a heat of activation $H = 32,000$ cal./mol. associated with the stress relaxation.—W. H.-R.

***On the Oxidation of Aluminium in a Dry Atmosphere.** Nicolas Cabrera, Jean Terrien, and Jean Hamon (*Compt. rend.*, 1947, 224, (22), 1558–1560).—The authors describe the oxidation of aluminium and comment on the various mechanisms suggested by N. F. Mott (*Trans. Faraday Soc.*, 1940, 36, 472; *Met. Abs.*, 1940, 7, 297): (a) the passage of ions is easier than that of electrons, (b) the passage of electrons is easier than that of ions (Mott leans towards hypothesis (a)). They obtained transparent films of aluminium by evaporation *in vacuo* and traced the variation of factors of transmission and reflection as a function of the time. The results indicated that aluminium corresponds more to hypothesis (b). W. Welkenhorst (*Z. techn. Physik*, 1941, 22, 14) attributes the acceleration of oxidation in the presence of ultra-violet light to the formation of ozone. Experiments show, however, that even in the presence of ozone, the oxidation is controlled by the diffusion of the Al^{+++} ions and is independent of the ozone or oxygen pressure.—J. H. W.

***On the Oxidation of Aluminium at High Temperature.** Nicolas Cabrera and Jean Hamon (*Compt. rend.*, 1947, 224, (24), 1713–1715).—The authors discuss a new theory of oxidation by Mott (in the press), which supposes that the electrons pass easily through the oxide film and thus produce in the film an electric field, which favours the diffusion of the Al^{+++} ions. This theory would lead one to expect a very rapid increase in the rate of oxidation at 200° C. Experiments on aluminium films, prepared as previously described (see previous abstract), show that the rate of oxidation does, in fact, increase at 200° C., becoming very rapid at 400° C. Above 200° C., aluminium films of this thickness (approx. 200 m μ) are not continuous, but have a granular structure. C. and H. discuss G. Haas's experiments (*Optik*, 1946, 1, 134) on the variation of the oxide film at high temp. and deduce equations for the electron energy.—J. H. W.

Beryllium as an Alloying Compound. N. W. Bass (*Indust. Plastics*, 1946, 1, (11), 16–18, 36; *C. Abs.*, 1946, 40, (11), 3088).—The production of beryllium-copper master alloy and the physical properties of beryllium are discussed.

* Denotes a paper describing the results of original research.

† Denotes a first-class critical review.

***Rapid and Direct Measurement of Vapour Pressure of Liquid Metals [Vapour Pressure of Bismuth at 969.6° K.].** A. H. Weber and Gonzaga Plantenberg (*Phys. Rev.*, 1946, [ii], 69, (11/12), 649-651).—A rapid direct method for measuring the vapour pressure of liquid metals is described in which a stream of vapour from the surface of the metal is allowed to impinge on the bottom of a glass bucket suspended from a helical quartz spiral, the resulting upthrust being measured. The theory of the method is described, and the vapour pressure of bismuth at 969.6° K. is determined as 0.0166 ± 0.0017 mm. mercury. The errors of the method are discussed.—W. H.-R.

***The Effect of Temperature on the Intensity of X-Ray Reflection [of Gold, Copper, and Aluminium].** E. A. Owen and R. W. Williams (*Proc. Roy. Soc.*, 1947, [A], 188, (1015), 509-521).—The effect of temp. on the intensity of X-ray reflection by pure gold, copper, and aluminium was studied by making microphotometric measurements on lines in X-ray spectra obtained with powder specimens in a Debye-Scherrer camera. The cylindrical powder specimens, 0.8 mm. dia. and of uniform particle size, were held together without adhesive and were free from a core of foreign material. They were maintained *in vacuo* at temp. up to $\sim 900^\circ$ K., the temp. being estimated from lattice-parameter measurements. The primary beam was standardized using a flat-plate X-ray camera furnished with a plate of pure gold, which provided a spectrum whose lines could be accurately measured. The observed fall of intensity of X-ray reflection by gold and copper as the temp. is raised up to $\sim 900^\circ$ K. was found to be in accordance with the equation, $\Theta_T = \Theta_1[1 - \alpha\gamma(T - T_1)]$, where Θ_T and Θ_1 are the characteristic temp. at temp. T and T_1 , α is the cubical coeff. of thermal expansion, and γ is the Grüneisen constant. The equation was found to hold also for aluminium up to $\sim 600^\circ$ K., but beyond this the fall in intensity exceeds that to be expected, and this may be due to the removal of energy from the primary beam to form extra reflections. The characteristic temp. at room temp. (293° K.) were found to be: gold 175° K., copper 314° K., and aluminium 395° K. These values show good agreement with those obtained by specific-heat and electrical-conductivity measurements.—E. N.

***A Re-Determination of the Lattice Constant of Lead.** Harold P. Klug (*J. Amer. Chem. Soc.*, 1946, 68, (8), 1493-1494).—Lead of 99.999+ % purity was examined by K-X-radiation. The lattice constant at $25 \pm 0.1^\circ$ C. is 4.9408 ± 0.0001 kX. units.—J. B. C.

***Creep Rate of Various Industrial Leads.** J. Neill Greenwood and J. H. Cole (*Metallurgia*, 1947, 36, (215), 233-235).—Creep tests were carried out on several brands of industrial lead to determine whether results were in accordance with those obtained previously with synthetic laboratory products. No unexpected results were obtained. The behaviour of the metal under prolonged stress depended more on the nature of impurities present than on their total content. A 100-days test at 500 lb./in.², supplemented by a test for embrittlement, is suggested as a means of classifying industrial lead alloys.

—M. A. V.

***Propagation of U.H.F. Sound in Mercury.** G. R. Ringo, J. W. Fitzgerald, and B. G. Hurdle (*Phys. Rev.*, 1947, [ii], 72, (1), 87-88).—A note describing measurements of the velocity and attenuation of sound in mercury in the frequency range 100 to 1000 Mc./s. The results for the velocity varied from 1.44×10^5 to 1.47×10^5 cm./sec. at temp. between 24° and 28° C., and did not show any definite dependence on the frequency. The values for the frequency-free pressure absorption coeff. varied from 4.7 to 6.0 ± 1.0 .

—W. H.-R.

***The Adsorption of Vapours on Mercury. I.—Non-Polar Substances [Benzene, Toluene, and *n*-Heptane].** C. Kamball and E. K. Rideal (*Proc. Roy. Soc.*, 1946, [A], 187, (1008), 53-73).—Reversible results for the adsorp-

tion of pure benzene, toluene, and *n*-heptane vapours on mercury were obtained using the method of sessile drops. Isotherms were normally obtained at 25° and 50° C., but in the case of benzene vapours some measurements were made at 75° C. The films were found to be gaseous and obeyed the Volmer equation $F(A - b) = kT$, where F = spreading pressure, A = area per molecule, and b = co-area. The possibility that the films might be immobile was considered, and the Langmuir equation was applied but was found to be unsatisfactory. A standard state for the surface phase is defined which is independent of temp. in the same manner as the standard pressure of one atmosphere is independent of temp. Values for the free energy, total energy, and entropy of adsorption of the various substances at the various temp. are evaluated. It is shown that the heat of adsorption increases with the amount on the surface. After the completion of monolayer adsorption, which is stable up to high values of p/p_0 , p being the vapour pressure and p_0 the saturation vapour pressure, a number of phase changes occur, the most striking being interpreted as the change from "flat" to "vertical" adsorption of the toluene molecule. Others are thought to be either two-dimensional condensation or adsorption of a second layer.—E. N.

***The Adsorption of Vapours on Mercury. II.—The Entropy and Heat of Adsorption of Non-Polar Substances.** C. Kamball (*Proc. Roy. Soc.*, 1946, [A], 187, (1008), 73–87).—Equations are derived which enable the entropy of adsorption on mercury of benzene, toluene, and *n*-heptane and the heat of adsorption of benzene to be calculated. The values obtained were of the same magnitude as the experimental values (see preceding abstract) and indicate with fair accuracy the amount of translational and rotational freedom possessed by the substances on the surface of the mercury. Benzene appears to rotate only in the plane of the ring and has no third degree of translational freedom, the surface mobility of toluene is considerably hindered, and the molecules of *n*-heptane are partially rolled up.—E. N.

***The Adsorption of Vapours on Mercury. III.—Polar Substances [Water, Acetone, Alcohols].** C. Kamball (*Proc. Roy. Soc.*, 1947, [A], 190, (1020), 117–137).—Cf. preceding abstract. Using methods previously described, determinations were made of the adsorption of water, acetone, and normal alcohols from methyl to hexyl on mercury at 25° and 50° C. All substances gave reversible adsorption, and, with the exception of water, as had been found with non-polar substances, the first region of the adsorption isotherm was always a gaseous monolayer obeying the Volmer type of equation. Methyl and ethyl alcohol both formed second layers, the double layer having half the co-area of the original monolayer, while the higher alcohols from *n*-butyl upwards formed condensed films. Acetone gave rise to a double and finally a triple layer. Contrary to the results of previous workers, water vapour was found to be adsorbed on mercury, although not strongly at 50° C. It showed no inclination to form a second layer, only a monolayer being formed at high ratios of p/p_0 . The large entropy (35.9 ± 1.1 cal./deg. mol.) and heat of adsorption of water are evidence for the association of the adsorbed water molecules on the surface of the mercury, and this probably occurs to some extent with methyl alcohol as well.—E. N.

***The Activated Adsorption of Nitrogen on a Finely Divided Tungsten Powder.** Raymond T. Davis, Jr. (*J. Amer. Chem. Soc.*, 1946, 68, (8), 1395–1402).—The adsorption of nitrogen on tungsten powder was studied in a pressure range of 10^{-6} to 35 mm. and a temp. range of 400°–750°. At saturation there was one molecule of nitrogen for every four surface atoms of tungsten. The thermodynamics of the tungsten–nitrogen system are discussed.—J. B. C.

***The Plastic Deformation of Non-Cubic Metals by Heating and Cooling.** W. Boas and R. W. K. Honeycombe (*Proc. Roy. Soc.*, 1946, [A], 188, (1004), 57–71).—A comparative study of the properties of tin-base and lead-base

bearing alloys revealed that after alternate heating and cooling, surface roughening and cracking occurred on the formerly smooth surface of the tin-base bearing, which increased with the number of treatments, whereas the surface of the lead-base bearing remained quite smooth. The phenomenon was found to be due to an inherent property of the alloy or its constituents. In order to make a fundamental study of the phenomenon, specimens of pure metals, relieved of residual stresses set up by previous cold work, were subjected to cyclic thermal treatment between 30° and 150° C. The non-cubic metals, zinc, cadmium, and tin showed signs of plastic deformation—slip lines, some evidence of twinning, roughness of the surface, and intensification of grain boundaries—after a small number of cycles, the effect becoming more pronounced the greater the number of cycles. The phenomenon was not observed in lead, which has a cubic crystal structure. It is shown that: (1) factors which influence the distortion are, duration and number of cycles, temp., and orientation of the crystals, (2) the deformation is independent of grain-size, (3) lattice distortions produced by the plastic deformation of the specimen are not removed by the cyclic treatment but remain in the specimen and, therefore, become more extensive as the number of cycles increases, (4) grain-boundary migration occurs with tin and cadmium but not with zinc; it is dependent on the duration of the cycle and occurs to a much greater extent during the cooling phase of the cycle, (5) slip lines continue through the crystals to the grain boundaries, where they are emphasized. It is concluded that the cause of the deformation is the anisotropy of thermal expansion in hexagonal and tetragonal crystal systems, and an estimation was made of the order of magnitude of the stresses set up, based on considerations of the linear boundary element between two crystals. Mention is made of some of the theoretical and practical applications of the phenomenon: the difficulty of obtaining completely strain-free zinc and cadmium at room temp., the failure of certain bearing alloys, and the effect of such stresses superimposed on externally applied stresses, e.g. fatigue and creep conditions.—E. N.

***The Anisotropy of Thermal Expansion as a Cause of Deformation in Metals and Alloys.** W. Boas and R. W. K. Honeycombe (*Proc. Roy. Soc.*, 1947, [A], 188, (1015), 427-439).—The work described in an earlier paper (see preceding abstract) has been extended to the temp. range - 190° to 250° C. As the temp. range is increased, the extent of deformation increases. Cyclic treatment of tin, cadmium, and zinc between room temp. and that of liquid air results in complex slipping and twinning, but grain-boundary migration is practically absent. Cooling from the liquid state, which represents half a thermal cycle, sets up stresses in metals possessing anisotropy of thermal expansion, e.g. zinc, cadmium, and tin, and leads to plastic deformation. In cadmium subsequent annealing results in marked grain growth. Duplex alloys of tin-rich tin-antimony, consisting of a tin-rich matrix in which particles of a hard second phase of cubic crystal structure are embedded, show considerably smaller deformation in the region of the boundaries between crystals of the two phases than that in the region of the crystal boundaries of the anisotropic matrix. Similar results are obtained with tin-base bearing alloys.—E. N.

***The Theory of Wedge Indentation of Ductile Materials.** R. Hill, E. H. Lee, and S. J. Tupper (*Proc. Roy. Soc.*, 1947, [A], 188, (1013), 273-288).—As a first step towards the correlation of hardness-test results with the deformation properties of a material under conditions of stress, e.g. the tensile test, a theoretical solution is given for the deformation produced by a rigid, frictionless wedge penetrating a plastic material. The solution determines the form of the lip and the deformation of the material squeezed out towards the surface. The variation with wedge angle of the force required for penetration

is determined in terms of the yield stress in the tensile test, and the average strain due to wedge indentation corresponds to an equivalent reduction of area in a tensile test, which increases with increasing wedge angle. The theory is compared with experiments in which lead blocks were indented by steel wedges coated with vaseline, and satisfactorily predicts the deformation of a grid of squares ruled on a cross-section of the block.—E. N.

***Deformation of Metals During Single and Repeated Tensile Impact.** J. A. Pope (*J. Iron Steel Inst.*, 1947, 157, (1), 31–54).—P. treats mathematically the case of a bar, one end of which is struck by a hammer, the other end being rigid. From consideration of the stress-wave reflections and deformations taking place at the ends of the bar, generalized curves are derived for the variations with time of the rates of deformation and energies absorbed at the two ends of the bar. A system of dimensionless units is employed in plotting these curves. In developing the theory a number of assumptions were made: (1) that the load on the bar remains const. after the metal has yielded (equal to the dynamic yield stress), (2) that the stress waves are reflected perfectly, (3) that the weight of the specimen is small compared with that of the hammer, and (4) that the kinetic and elastic energies of the bar are negligible in comparison with the plastic energy absorbed. P. describes the results of tests carried out on mild steel (carbon 0.22, manganese 0.49%) and Lowmoor iron (0.085% carbon), using a falling-tup impact machine. Stops were fitted to the machine so as to limit the amount of extension on the gauge length, the remaining energy in the tup, which greatly exceeded that required to deform the specimen, being absorbed by that part of the specimen outside the gauge length. It was thus possible (a) to split a single impact into stages by subjecting a number of specimens to different extensions, and (b) to carry out repeated-impact tests at approx. const. velocity. After impact, hardness explorations and microscopical examinations were performed on the specimens. The spread of deformation during impact was shown to be fundamentally different from that in a static test. The increase in hardness at the centre of the impacted specimens was greater than that at the edge by a larger amount than was the case with static specimens. Statically tested Lowmoor iron specimens show more slip bands than those tested in impact. In specimens of mild steel, under both single and repeated impact, necking at both ends occurs initially. After a small extension the necks disappear and the specimen again becomes parallel; eventually a single neck occurs near the centre of the specimen and leads to fracture. Specimens in Lowmoor iron also show double necking, but deformation does not spread to the centre until considerable extension has occurred, and the specimen generally breaks at one of the original necks. The ratio $\frac{\text{impact elongation, \%}}{\text{static elongation, \%}}$ is a function of gauge length and is not a fundamental property of the material. P. concludes that, in general, the experimental results are in accord with the mathematical theory; such discrepancies as exist are attributed to the inaccuracy of assumption (1), which precludes deformation other than at the specimen ends.—R. W. R.

***Experiments on the Elastic Properties of Metals by Means of Two Oberbeck Resonance Pendulums.** Constantin Sălceanu (*Compt. rend.*, 1947, 224, (25), 1756–1758).—The elastic properties of iron, aluminium, silver, copper, and brass, were studied by means of the resonance exhibited by two pendulums of the same length connected by a wire of the metal being studied. One pendulum is made to oscillate and is followed by the other. The time between two minima of oscillation of one pendulum is measured and plotted against the tension. In all cases, time-saturation was obtained. The order of the metals given by this method does not correspond to any of the known elastic properties of the metals, and S. suggests that his results are indicative of a

property analogous to that of viscosity in liquids. Another set of experiments on the same metals, involving torsion under const. tension, gives an order inverse to that given by the first set.—J. H. W.

***The Application of the Method of the Resonant Pendulum to the Measurement of the Coefficient of Rigidity of Metals.** Constantin Sălceanu (*Compt. rend.*, 1947, 224, (26), 1810–1811).—The resonance of equal pendulums connected by a wire of the metal to be studied (see previous abstract) was used to measure the coeff. of rigidity of nickel, iron, steel, nickel-chrome, copper, silver, aluminium, and brass. The static method, involving torsion under const. tension (see above), showed that if C is the constant of torsion (given

by $gd = C \frac{0r^4}{l}$, where g is the tension, r the dia. of the wire, l the length, and θ the torsion) and T the time, then $C + T$ is a constant within the limits of experimental error. The effect of heating the specimens is described for each metal.—J. H. W.

***Finite Elastic Strain of Cubic Crystals.** Francis Birch (*Phys. Rev.*, 1947, [ii], 71, (11), 809–824).—Murnaghan's (*Amer. J. Math.*, 1937, 49, 235; *Met. Abs.*, 1938, 5, 468) theory of finite strain is developed for a medium of cubic symmetry subjected to finite hydrostatic compression plus an arbitrary homogeneous infinitesimal strain. The free energy is developed for cubic symmetry to include terms of the third order in the strain components. The effect of pressure upon the second-order elastic constants is found and compared with experiment, with particular reference to the compressibility. The compressibility data for numerous metals are tabulated and discussed. In general, the data confirm the theory, but there is an indication that Bridgman's results at pressures above 50,000 kg./cm.² are not directly comparable with those at lower pressures. The results are also compared with some of the calculations based on Born's lattice theory, and some developments of the latter by other workers are criticized.—W. H.-R.

A Thermodynamic Criterion for the Fracture of Metals. Edward Saibel (*Phys. Rev.*, 1946, [ii], 69, (11/12), 667).—A note. The difficulties in accounting for the difference between the calculated and observed strengths of metals are outlined. A new theory by S. is based on the following assumptions: (1) All of the strain energy is available for the abolition of cohesive strength. (2) The heat of fusion is uniformly partitioned throughout the vol. of the substance. (3) The quantity of energy required for the abolition of cohesive strength is that fractional part of the energy of fusion which is associated with the change in vol. on passing from the solid to the liquid state. These assumptions enable the criterion for fracture to be expressed in the form $U = JQ\Delta V/V$, where U is the strain energy per unit vol., Q is the latent heat of fusion in kg.-cal./mole, V is the vol. occupied by a mole of the substance, ΔV is the change in vol. per mole on passing from solid to liquid, and J is the mechanical equivalent of heat. Good agreement is shown for some substances which fail by brittle fracture, and reasonable agreement where plastic flow precedes fracture.—W. H.-R.

Nature of Strength and Failure in Brittle Solids. Eugene F. Poncelet (*Colloid Chem.*, 1946, 6, 77–88; *C. Abs.*, 1946, 40, (9), 2375).—An ideal brittle solid can be visualized as a collection of identical particles held at definite spacings by electrostatic bonds. The Morse curve is the graph representing the resultant of the simultaneously existing and changing attractions and repulsions. A broken bond arises when a critical distance between particles is exceeded. The following factors are considered: the physical nature of failure; failure under tension; fracture under compression; mixed stresses; the physical nature of strength in solids; and the fundamental difference between viscous and plastic flow. The "flaws" assumed by Griffith, Smekal, Orowan, and others are not essential to fracture. Compressive

strength exceeds tensile strength eight times or more (in glass between nine and fifty times).

***The Statistical Aspect of Fatigue of Metals.** A. M. Freudenthal (*Proc. Roy. Soc.*, 1946, [A], 187, (1011), 416–429).—Fatigue of metals, or the more adequate term “progressive failure” is the expression on a macroscopic scale of the progressive destruction of the cohesive bonds as a result of the repetitive action of an external load. As such it has the typical features of a mass phenomenon, for both the cohesive bonds and the load repetitions are collectives in the statistical sense. By applying the fundamental rules of the theory of probability, many of the established relations between the principal variables, e.g. amplitude, frequency and number of load cycles sustained, notch effect, &c., are theoretically deduced from the purely formal assumption of the separation-strength of cohesive bonds. The principal practical application is the evaluation of the damaging effect of repeated load cycles of varying amplitude and of the effect of overstress, which are the main problems in the design of structures.—E. N.

***The Relationship Between Fatigue and Stress Concentration.** R. B. Heywood (*Aircraft Eng.*, 1947, 19, (217), 81–84).—H. discusses the effect of stress concentration at notches on the elastic stress and fatigue properties. He

deduces, from observed values, that the expression: $\frac{K}{K_f} - 1 = \frac{0.065}{\sqrt{r}}$ (where

K is the elastic-stress-concentration factor, i.e. the max. stress in the notch divided by the nominal stress; K_f is the fatigue-stress-concentration factor, i.e. the endurance limit of un-notched specimens divided by that of notched specimens; and r is the radius of the stress raiser) gives fair agreement for carbon steels. For other classes of material, other values of the constant, which H. refers to as the “augmented constant”, are used.—H. S.

A Summary of Published Literature on Internal Stresses in Metals. — (B.S.A. Group Research Centre, Sheffield, Publ., 1947, (GRC/S. 29), 45 pp.).—185 abstracts are given of articles dealing with the occurrence, effects, measurement, and control of internal stresses, covering the period 1938–1946.—J. L. T.

***Kinetic Friction in or Near the Boundary Region. I.—Apparatus and Experimental Methods.** B. Chalmers, P. G. Forrester, and E. R. Phelps (*Proc. Roy. Soc.*, 1946, [A], 187, (1011), 430–439).—An apparatus is described and illustrated for obtaining relatively pure boundary friction, which is done by controlling the conditions of load, speed, and contact area, so that little or no opportunity is given for fluid-film formation. One specimen (the plate) is driven at a fixed velocity and a second specimen (the slider) is applied to it by a dead load. The force required to restrain the second specimen is measured by balancing against a variable dead load, instability being suppressed by fluid damping. A direct reading of the coeff. of friction is thus obtained by a null method. Reproducibility of determinations is generally within 10%, the limiting factor being the accuracy with which exactly similar surfaces can be reproduced. The method of preparing the specimens is described; the tests can be conducted at temp. up to 150° C. within an accuracy of $\pm 1^\circ$ C. of that required.—E. N.

***Kinetic Friction in or Near the Boundary Region. II.—The Influence of Sliding Velocity and Other Variables on Kinetic Friction in or Near the Boundary Region.** P. G. Forrester (*Proc. Roy. Soc.*, 1946, [A], 187, (1011), 439–463).—Using the apparatus described (see preceding abstract), a study was made of the causes underlying the change of friction with sliding velocity. Measurements were made of the friction of several different combinations of materials, mainly tin-base Babbitt (with 7% antimony and 3½% copper) running on steel and with hard steel on phosphor bronze, at velocities between 0.01–2.25 cm./sec. and under three different conditions: dry, with thin films of various lubricants applied by two different methods, and with excess of

lubricants. The lubricants used were oleic acid, medicinal paraffin, and I.C.E. (crank-case) oil. The experiments show that changes in friction with velocity may be derived from at least three different sources: (1) From the properties of clean metal surfaces. Certain combinations show, when unlubricated, a decrease in friction with increasing velocity. This is most marked when one component is a soft metal of low m.p., which suggests that it may be associated with reduction in shear strength of the metal with increasing temp. (2) From the partial destruction of the film under boundary conditions. This leads to an increase of friction with increasing velocity, as the rate of destruction rises with increasing sliding speed. (3) From the transition from boundary to fluid-film conditions. This tendency is also most marked when one component is a soft metal, in which case the real area of contact is greater and the local pressures lower than for two hard metals. It results in a decrease of friction with increasing velocity. "Running-in" brings about changes in the physical conditions and geometry of the metal surfaces and also in the state of the lubricant film; it may influence the friction either way, but its influence is always much greater with rough plates than with smooth. The influence of surface finish is wholly through its effect on the lubricant film; it accelerates the onset of fluid lubrication and has more influence on the combination Babbitt/steel than in the combination steel/bronze. The practical implications of the results are discussed.—E. N.

***Kinetic Boundary Friction.** J. R. Bristow (*Proc. Roy. Soc.*, 1947, [A], 189, (1016), 88–102).—Using an apparatus which is described, curves of boundary friction against velocity (0–0.5 cm./sec.) for various sliding surfaces (steel on steel and phosphor bronze, brass or tin on hard steel) were determined for a number of lubricants. The results show that smooth sliding and relaxation oscillations, or "stick-slips", under boundary-lubrication conditions, when frictional forces are measured by the deflection of an elastic system, are due to the dependence of kinetic friction on velocity. In cases giving smooth sliding, kinetic friction decreases as velocity decreases, at very low speeds; in cases giving relaxation oscillations, kinetic friction increases as velocity decreases. Thus, sliding under boundary conditions is not inherently discontinuous; any discontinuous motion is due to the dynamics of the measuring instrument as a result of the kinetic friction increasing as the velocity decreases. Generally the friction falls continuously with increasing molecular weight for a series of esters of fatty acids, and is dependent on the percentage of fatty oil in a compounded lubricant such as oleic acid in mineral oil, and on temp. for a pure substance such as ethyl palmitate, and a mineral oil. The temp. at which relaxation oscillations first occur depends on the speed of sliding, and it appears, therefore, that measurements of the temp. at which relaxation oscillations start at a const. sliding speed are not a measure of the temp. at which there is a discontinuity in the properties of the boundary layer.—E. N.

The Surface of Solids and Liquids and the Films that Form on Them. II.—Solids and Adsorption at the Surface of Solids or Liquids. W. D. Harkins (*Colloid Chem.*, 1946, 6, 1–76; *C. Abs.*, 1946, 40, (9), 2371).—A review of fifteen years' work which deals with: classes of solids; effect of sub-phase on metallic films; calculation and determination of surface-energy values illustrated by diamond and ionic crystals; adsorption at interfaces in solid, liquid, and gaseous systems; water/oil; the application of the Gibbs equation to solid surfaces; experimental procedures; areas of solids from adsorption isotherms; extension of the attractive energy of a solid into a liquid and the thickness of adsorbed films; theories of adsorption; desorptions; multi-molecular films and other types; experimental methods for determination of energy of adhesion, adsorption, heat of immersion, &c.; contact angle,

theory, data, and experimental methods for determining it; graphite as a hydrophobic solid; topochemistry; chemical changes at crystal corners, edges, and interfaces. Besides 68 numbered references, there are given 113 references to papers by Harkins and his school, classified chronologically.

Colloidal Behaviour in Metals and Alloys. Reginald S. Dean (*Colloid Chem.*, 1946, **6**, 561–578; *C. Abs.*, 1946, **40**, (9), 2427).—A discussion of: (1) Gases in metals: physicochemical nature of metallic interfaces; gas-metal systems as colloids; degasification of metals; grain-size control; hydrogen embrittlement. (2) Slag-metal systems: the Aston wrought-iron process; steelmaking reactions; powder metallurgy; magnetic, electric, and mechanical properties of metal compacts. (3) Dispersions of metals in metals: solid metals in solid metals; ordering in alloys; dispersion-hardening; internal friction or vibration-damping capacity of metals. 78 references are given.

***A New Method of Determining Electro-Negativity from Other Atomic Properties.** Walter Gordy (*Phys. Rev.*, 1946, [ii], **69**, (11/12), 604–607).—

The empirical relation $\alpha = 0.31 \left(\frac{n+1}{r} \right) + 0.50$ has been found to connect the electro-negativity, α , of an element according to Pauling's revised scale, with n the number of electrons in its incompletely filled (valence) shells, and r its single-bond co-valent radius measured in Å. This relation does not hold for copper, silver, or gold, but is in good agreement with results for many elements, and is used to construct a table of electro-negativities for 52 elements. The theoretical justification is discussed.—W. H.-R.

Magnetic Dipole Fields in Unstrained Cubic Crystals. L. W. McKeehan (*Phys. Rev.*, 1947, [ii], **72**, (1), 78).—Numerical errors and misprints in an earlier paper (McKeehan, *Phys. Rev.*, 1933, [ii], **43**, 913; *J. Inst. Metals (Met. Abs.)*, 1933, **53**, 441) are corrected. These mistakes involve the paper by Luttinger and Tisza (*Phys. Rev.*, 1946, **70**, 954).—W. H.-R.

***Theory of Long-Period Magnetic Relaxation.** Charles Kittel (*Phys. Rev.*, 1946, [ii], **69**, (11/12), 640–644).—Long-period changes in the magnetization of a mild-steel specimen are discussed. If a specimen in a const. field of the order of 0.5 gauss is submitted to alternating stresses for a period of the order of 5 years, it approximates to a state of infinite effective permeability. If the applied field is changed suddenly, a considerable fraction of the magnetization changes almost instantaneously; this fraction is determined by the ordinary permeability, and by the demagnetization coeff. Following this sudden change, a further slow change in magnetization occurs with a time constant of the order of 3 months, while the remainder of the magnetization changes with a period of the order of 5 years. A formal treatment of the phenomena is given following the lines of the time-dependent barrier potential used by Snoek (*Physica*, 1938, **5**, 663; *Met. Abs.*, 1938, **5**, 656).—W. H.-R.

***Transverse Magnetization in Ferromagnetic Crystals in Relation to Domain Structure.** A. von Engel and M. S. Wills (*Proc. Roy. Soc.*, 1947, [A], **188**, (1015), 464–484).—Although the formal theory of ferromagnetic anisotropy is in good agreement with experimental results as regards the components of magnetization parallel to the field, similar results are not obtained with the transverse component for the planes (100), (110), and (111), where experimental results for single crystals show that it diminishes to zero in very weak fields, instead of increasing according to theory. However, if the directions of magnetization of domains (small regions spontaneously magnetized to saturation) are treated as being distributed continuously in angle rather than as restricted to a limited number of particular directions, and, assuming that the proportions of the volumes of domain magnetized in any direction are larger the lower the energy of magnetization in that direction, then reasonable agreement between theory and experimental results is obtained.—E. N.

***The Theory of the Magneto-Resistance Effects in Metals.** E. H. Sondheimer and A. H. Wilson (*Proc. Roy. Soc.*, 1947, [A], 190, (1023), 435-455).—General formulæ are obtained for the effect of a magnetic field on the electrical and thermal conductivities of a metal in which there are two overlapping partially filled electron bands of normal form, the *s*- and *d*-bands, in each of which the energy is proportional to the square of the wave number. It is assumed that *s-d* transitions are negligible, as is the quantization of the electron orbits due to the magnetic field. The formulæ, though not strictly valid for all temp. and fields, are further developed for the limiting cases of very high and very low temp. and for very strong magnetic fields; at very low temp. they are in fair quantitative agreement with experimental results on cadmium. The behaviour of the electrical resistance at low temp. is discussed, and it is shown that: (1) the formulæ explain the fact that in certain cases the resistance may pass through a minimum as the temp. is increased, provided that the magnetic field is large enough, e.g. cadmium at liquid-helium temp.; and (2) Matthiessen's empirical rule, that electrical resistivity consists of two parts, cannot be expected to be valid except more or less by accident. Considering the electronic thermal conductivity, in general the Lorenz number is increased by the presence of a magnetic field, which is in agreement with the experimental facts, whereas the thermal conductivity of the lattice is unaffected by a magnetic field.—E. N.

***An Experiment on the Mechanism of Supraconductivity.** J. G. Daunt and K. Mendelssohn (*Proc. Roy. Soc.*, 1946, [A], 185, (1001), 225-239).—Using an apparatus which is described, the Thompson coeff. of supraconductive lead was determined and found to be zero ($<4 \times 10^{-9}$ V./deg.). This leads to the conclusion that the electrons engaged in the supraconductive current remain energetically at absolute zero, and sustains the authors' previous assumption that the apparent electronic specific heat, C_s , of a supraconductor is due to an excitation of electrons from the lowest state. It is shown that

$C_s = \frac{3\gamma}{T_c^2} T^3$, where γ is the coeff. of the Sommerfeld electronic specific heat and T_c is the transition temp., a result borne out by Keesom and van Laer's calorimetric experiments on tin. Thus, the whole mechanism of supraconductivity seems to imply the existence of a small gap ($\sim 10^{-4}$ eV.) in the energy distribution between the lowest state occupied by the supraconductive electrons and the higher states to which they can be thermally excited. The frictionless transport of electrons is due to metastable states within the gap in which energy cannot be dissipated. Calculated results show that (1) the number of electrons which are capable of such frictionless transport is only about 10^{-3} of the number of atoms, and (2) the depth λ to which a magnetic field can penetrate into a supraconductor is about 10^{-4} cm. for lead. It is concluded that the remarkable similarity between the frictionless transport in supraconductors and that in liquid helium II is due to the fact that they are caused by very similar mechanisms—an aggregation of freely mobile particles of zero thermal energy, irrespective of whether the particles in question are electrons or atoms.—E. N.

Physical Interaction of Electrons with Liquid Dielectric Media. The Properties of Metal-Ammonia Solutions. Richard A. Ogg, Jr. (*Phys. Rev.*, 1946, [ii], 69, (11/12), 668-669).—A note describing theoretical considerations which preceded recent work (R. A. Ogg, Jr., *J. Amer. Chem. Soc.*, 1946, 68, 155; *J. Chem. Phys.*, 1946, 14, 114, 295; *Phys. Rev.*, 1946, [ii], 69, 243) on the properties of metal-ammonia solutions. The basis of the treatment is the model of Kraus ("The Properties of Electrically Conducting Systems", Chemical Catalogue Co.: 1922) of an electrolyte-like character for the solute metal in ammonia solutions, the negative ion constituent being the "solvated" electron. At low concentrations, individual electrons are "self-trapped" in

physical cavities in the solvent, and the treatment shows that the lowest energy is given if the electrons are trapped in pairs, two electrons in each cavity. At higher concentrations, unpairing of the electrons occurs.—W. H.-R.

***The Magnetic Susceptibility of Sodium in Liquid Ammonia Solutions at Low Temperatures.** R. B. Gibney and G. L. Pearson (*Phys. Rev.*, 1947, [ii], 72, (1), 76–77).—A note. The claims made by Ogg (*ibid.*, 1946, 69, 243; 70, 93) regarding the supposed supraconductivity of frozen solutions of sodium in liquid ammonia at 180° K. were based on the detection of persistent currents. This method is regarded as unsatisfactory because the results may be affected by cracking of the sample. Measurements of magnetic susceptibility are not affected by small cracks, and give a sensitive test for the existence of supraconductivity. Experiments made with solutions of different concentrations indicated that if any supraconducting material was present, its amount was not greater than 1 part in 10,000 by vol. Other methods also gave negative results for the existence of supraconductivity.—W. H.-R.

Erratum : Transition from Classical to Quantum Statistics in Germanium Semiconductors at Low Temperature. Vivian A. Johnson and K. Lark-Horovitz (*Phys. Rev.*, 1947, [ii], 71, (12), 909).—Corrections to an earlier paper (*Phys. Rev.*, 1947, [ii], 71, 374; *Met. Abs.*, 1947, 14, 306).—W. H.-R.

II.—PROPERTIES OF ALLOYS

***The Intermetallic-Compound Phases of the System Aluminium-Manganese-Zinc.** G. V. Raynor and D. W. Wakeman (*Proc. Roy. Soc.*, 1947, [A], 190, (1020), 82–101).—The aluminium-manganese-zinc system was examined in the range 0–95% zinc and 0–3% manganese. The alloys were prepared from pure aluminium, zinc, and aluminium-manganese master alloys, which were melted in an electric furnace, using a crucible lined with alumina-fluorspar mixture, and then slowly cooled in the furnace at 1–2° C./min. All alloys were examined micrographically, after which primary and secondary crystals were extracted by an electrolytic method and then subjected to micrographic, X-ray, and analytical examination. According to the composition, the succession of phases deposited on passing along the eutectic valley towards the ternary eutectic is: $\text{MnAl}_6 \rightarrow T_1 \rightarrow \text{MnAl}_4 \rightarrow T_2 \rightarrow T_3 \rightarrow \text{MnAl}_3$. Up to a zinc content of ~35% at 2% manganese or 43% at 3% manganese, the primary phase is MnAl_6 , which can take up small quantities (~0.8%) of zinc. In a region from 35 to ~69% zinc, for manganese contents between 1 and 3%, the ternary compound T_1 crystallizes as the primary constituent; it is characterized by a ratio of four aluminium atoms to one of combined solutes, and an electron:atom ratio of 1.85, calculated on the basis of the Pauling theory of transitional metals. According to this theory, transitional metal atoms have vacancies for electrons in their atomic orbitals, and the present experiments, in conjunction with earlier work, suggest that these may be filled up as a consequence of alloy formation. The compound T_1 is analogous to the ternary compounds observed in the aluminium-manganese-nickel and aluminium-manganese-copper systems. The primary MnAl_4 field extends, at low manganese contents, only from ~69–76% zinc and will dissolve zinc up to a limit of ~5.2%. The ternary phases T_2 and T_3 may be represented respectively by the formulæ Mg_2ZnAl_9 and $(\text{Mn.Zn})_5\text{Al}_{11}$ or $\text{Mn}_{2.8}\text{Zn}_{2.2}\text{Al}_{11}$. MnAl_3 , which can dissolve small quantities of zinc, enters into equilibrium at a ternary eutectic (Zn 95, Mn 0.05%; at 378° C.) with the primary solid solutions in zinc and aluminium respectively. Specimen photomicrographs are reproduced, together with diagrams showing the form of the surfaces of primary separation.—E. N.

***The Compressive Strength of Short Circular Tubes [Aluminium Alloys].** I. G. Bowen (*Aircraft Eng.*, 1947, 19, (218), 128-129).—A brief digest of M.A.P. Scientific and Technical Memoranda 17/44. Reliable estimates of the strength of axially loaded tubes in compression, with friction opposing displacement of the ends, can be gained by the use of Donnell's equation where thin-walled tubes are concerned, and in the case of medium and thick tubes by the use of equations deduced by B. for steels and aluminium alloys.—H. S.

Beryllium as an Alloying Compound. (Bass). See p. 137.

Contributions to the Theory of Beta-Phase Alloys [Brass]. Clarence Zener (*Phys. Rev.*, 1947, [ii], 71, (12), 846-851).—(1) The theory of the α/β brass equilibrium is discussed and extended. The original theory of H. Jones (*Proc. Phys. Soc.*, 1937, 49, 243, 250; *Met. Abs.*, 1937, 4, 237) is correct in predicting the approx. position of the $\alpha/\alpha + \beta$ and $\alpha + \beta/\beta$ phase boundaries in alloys of the copper-zinc type. It does not, however, predict the correct variation with temp., and Z. regards J.'s work as involving an error in computation. (2) The high elastic anisotropy of single crystals of β -brass is discussed. The anomalously low value of the $(C_{11}-C_{12})/2$ shear coeff. of β -brass results from the combination of a body-centred cubic lattice with ions containing only closed shells. It is to be expected that all β -type alloys with closed inner shells will have a similarly low value of this shear constant. The susceptibility of a body-centred cubic structure to mechanical instability with respect to a (100)[110] type shear explains the limitation of body-centred cubic lattices to elements in certain places in the Periodic Table. The same line of argument explains the positive value of the temp. coeff. of E_{100} in β -brass.—W. H.-R.

Copper-Manganese-Aluminium Alloys. — (*Engineer*, 1947, 183, (4766), 470).—A short review of some recent publications dealing with alloys containing copper 60, manganese 5-25%, and zinc remainder, and with the solid-solution area of the copper-manganese-aluminium system.—R. GR.

***Note on a Variation with Frequency of the Torsional Modulus of German-Silver Wire and Its Relation to Gyromagnetic Measurements.** S. J. Barnett and D. S. Webber (*Phys. Rev.*, 1947, [ii], 71, (12), 896-902).—The dynamic torsional modulus, M_d , of German-silver wire was measured at frequencies ranging approx. from 17 to 50 c./s., and at much lower frequencies, the periods of which ranged from 4 to 28 sec. No change in modulus could be detected in either the high-frequency or the low-frequency range, but the modulus in the high-frequency range was about 1% smaller than that for oscillations of period 5 sec. This variation is in the right direction to account for part of the difference between results for the gyromagnetic ratios obtained by S. J. Barnett (*Proc. Amer. Acad. Arts Sci.*, 1940, 73, 401; 1944, 75, 109; *Met. Abs.*, 1945, 12, 107; 1946, 13, 204) and by Bates and by Sucksmith (*Proc. Roy. Soc.*, 1923, [A], 104, 499; 1925, [A], 108, 638; *J. Inst. Metals*, 1925, 34, 347), because the latter work involved the assumption that the torsional modulus of a rapidly vibrating German-silver wire was the same as the static value. The greater part of the discrepancy must, however, be due to some other cause.—W. H.-R.

***The Intermetallic Compound $Mg_4Na_4Pb_3$.** George Calingaert, Hymin Shapiro, and Ivar T. Krohn (*J. Amer. Chem. Soc.*, 1946, 68, (3), 520-521).—A note giving details of experimental melts, testing, and microscopical analysis of the compound. Some of its properties are mentioned.—J. B. C.

Joint Discussion on the Papers: "Graphite Formation in Cast Iron and in Nickel-Carbon and Cobalt-Carbon Alloys", by H. Morrogh and W. J. Williams, and "A Note on the Occurrence of Tellurium in Cast Iron", by H. Morrogh. — (*J. Iron Steel Inst.*, 1947, 156, (4), 491-496; 157, (2), 193-197).—Cf. *J. Iron Steel Inst.*, 1947, 155, (3), 321-371; see *Met. Abs.*, this vol., p. 35.—J. L. T.

***Ferromagnetic Resonance at Micro-Wave Frequencies** [Supermalloy]. W. A. Yager and R. M. Bozorth (*Phys. Rev.*, 1947, [ii], **72**, (1), 80–81).—A note. The resonance phenomenon discovered by Griffiths (*Nature*, 1946, **158**, 670; *Met. Abs.*, 1947, **14**, 4) for ferromagnetic materials was interpreted theoretically by Kittel (*Phys. Rev.*, 1947, [ii], **71**, 270; *Met. Abs.*, 1947, **14**, 310). Experiments have been made on Supermalloy in order to test Kittel's theory and to evaluate the gyromagnetic ratio. The results indicated a Landé splitting factor, g , greater than 2, and as this is not to be expected, a refinement of Kittel's theory will be necessary. Some results were in better agreement with Frenkel's (*J. Physics (U.S.S.R.)*, 1945, **9**, 299) form of damping term than with that of Kittel.—W. H.-R.

***High-Temperature Heat Contents of Titanium Carbide and Titanium Nitride.** B. F. Naylor (*J. Amer. Chem. Soc.*, 1946, **68**, (3), 370–371).—High-temp. heat contents above 298° K. of these compounds were measured from about 360° to 1735° K. Specific-heat equations, heat contents, and entropies are given for each substance.—J. B. C.

Order-Disorder Phenomena in Ferromagnetics and Binary Alloys. J. de Boer (*Ned. Tijdschr. Natuurkunde*, 1947, **13**, (3), 29–49; (4), 57–74).—[In Dutch]. A critical consideration of modern theoretical treatments of these phenomena. The exactness with which various parameters, calculated from the viewpoint of different theories, approach practical conditions is discussed. Among these parameters are: specific heat, spontaneous magnetization, and transition temp. Considerable space is devoted to a discussion of the mathematical problems involved. It is shown that Onsager's rigorous treatment of the phenomenon (*Phys. Rev.*, 1944, [ii], **65**, 117; *Met. Abs.*, 1944, **11**, 253) as an "eigenvalue" problem approaches reality most closely, and that there are serious errors if one of the numerous approx. treatments is used. This is particularly true as regards the representation of discontinuous parameters in the region of their discontinuity (transition point).—S. M.

Thermodynamic Equilibria of Higher Order. E. F. Lyte (*Phys. Rev.*, 1946, [ii], **69**, (11/12), 652–665).—Theoretical.—W. H.-R.

***X-Ray Reflections from Dilute Solid Solutions.** K. Huang (*Proc. Roy. Soc.*, 1947, [A], **190**, (1020), 102–117).—A theoretical study was made of the effects on the X-ray reflection of deviations of the atoms from the ideal lattice sites, caused by the presence of randomly-distributed foreign atoms in a dilute solid solution. It is shown that the reflections should be modified in a manner similar to that caused by thermal agitation, producing (1) a weakening of the ordinary interference maxima, and (2) the presence of "diffuse maxima". The results are discussed with regard to solid solutions of gold and copper (10 and 20%), which are of the cubic, face-centred lattice type, and it is concluded that although it should be possible to detect the first effect experimentally, the second effect may be masked by thermal diffuse maxima.—E. N.

Colloidal Behaviour in Metals and Alloys. (Dean). See p. 145.

III.—STRUCTURE

(Metallography; Macrography; Crystal Structure.)

[For all abstracts on the constitution of alloy systems, including X-ray studies, see II.—Properties of Alloys.]

***On the Determination of the Deformation of Single Crystals in Polycrystalline Metals by X-Ray Methods** [Aluminium]. Adéla Kochanovska (*Rev. Mét.*, 1947, **43**, (7/8), 192–196; discussion, 196–197).—K. describes the use of reflection photographs, taken at wave-lengths so chosen that reflections on $\theta = 90^\circ$ are obtained from three crystallographic directions, for the determin-

ation of the cell dimensions in cubic crystals. Internal standards (reflections from silver) were used on each plate in order to obtain the requisite high accuracy. The method was used for the study of the effect of deformation on the single crystals in polycrystalline steel and aluminium. In aluminium, the unit cells were compressed, but not deformed, i.e. they remained isotropic; in steel, on the other hand, they became anisotropic.—S. M.

***On the Relation Between Deformation and Recrystallization Texture of Nickel-Iron with Cubic Orientation.** J. F. H. Custers (*Physica*, 1947, 13, (1/3), 97–116; and *Lab. N. V. Philips' Gloeilampenfabrie. Eindhoven, Separaat*, 1947, 1727).—[In English]. Work was undertaken to find a satisfactory explanation for the fact that while nickel-iron (50:50) and aluminium, when rolled in the same direction, give rise to the same deformation structures, their structures become markedly different after subsequent recrystallization. The deformation structure of aluminium and nickel-iron, cold rolled in the [110] direction parallel to the (100) plane, is a combination of (110)[112] and (112)[111] orientations. While aluminium recrystallizes in this same orientation, nickel-iron orientates with a (100) plane parallel to the rolling plane and a [100] direction parallel to the rolling direction. It is thought that this recrystallization arises from fragments in this orientation situated on the slip planes acting as crystallization nuclei. No direct evidence for this could be found, however, so that the work in this sense must be called negative. It is held, however, that the quantitative data collected confirm Burgers's theory of recrystallization if allowance is made for some modifications due to Barrett.—S. M.

Grain Boundaries in Metals. — (*Engineer*, 1947, 184, (4779), 196–197).—A discussion of the work of Professor Zener and his co-workers at the University of Chicago on the viscous behaviour of grain boundaries.—R. GR.

***Stress Relaxation Across Grain Boundaries in Metals [Internal Friction in Aluminium].** (T'ing-Sui Kê). See p. 137.

***A Dynamical Model of a Crystal Structure.** (Sir) Lawrence Bragg and J. F. Nye (*Proc. Roy. Soc.*, 1947, [A], 190, (1023), 474–481).—The crystal structure of a metal can be represented by an assemblage of bubbles 2.0–0.1 mm. in dia. floating on the surface of a soap solution. The bubbles are blown from a fine pipette beneath the surface, with a const. air pressure and are remarkably uniform in size. These small bubbles are sufficiently persistent for experiments lasting an hour or more, they slide past each other without friction and they can be produced in large numbers. This model most nearly represents the behaviour of a metal structure, because the bubbles are of one type only and are held together by a general capillary attraction which represents the binding force of the free electrons in the metal. The assemblage shows structures which are supposed to exist in metals and simulate effects which have been observed. Photographs are given which show grain boundaries, dislocations and other types of fault, slip, recrystallization, annealing, and strain due to foreign bodies.—E. N.

***Finite Elastic Strain of Cubic Crystals.** (Birch). See p. 142.

***A Simple Technique for the X-Ray Determination of Fibre Axes in Electro-deposited Metals.** M. R. J. Wyllie (*Rev. Sci. Instruments*, 1947, 18, (6), 425–429).—The method described was specially developed so as to avoid stripping of the deposit. It therefore uses a glancing-beam method with a circular, fairly high camera in order to be able to record the largest possible number of lines. Methods of calculation for use in the interpretation of such photographs are given.—S. M.

Stability and Spectrum in the Wave Mechanics of Lattices. Aurel Wintner (*Phys. Rev.*, 1947, [ii], 72, (1), 81–82).—A theoretical note.—W. H.-R.

***Transverse Magnetization in Ferromagnetic Crystals in Relation to Domain Structure.** (von Engel and Wills). See p. 145.

V.—POWDER METALLURGY

Sinter-Alumina.—I. Felix Singer and Hans Thurnauer (*Metallurgia*, 1947, 36, (215), 237–242).—Previous work on the production of ceramics from pure oxides is briefly reviewed, and the mechanical properties of sintered alumina described.—M. A. V.

Carbide Cutting Tools. — (*Amer. Exporter (Indust.)*, 1946, 138, (6), s24).—Cemented carbides are produced by powder-metallurgy methods from the carbides of tungsten, titanium, and tantalum, together with a suitable binding material such as cobalt. The highly abrasive aluminium-silicon alloys now used for pistons are examples of the type of material now being easily machined by cemented-carbide-tipped tools.—H. PL.

***Rate of Sintering of Copper Powder.** A. J. Shaler and J. Wulff (*Phys. Rev.*, 1947, [ii], 72, (1), 79–80).—A note. Frenkel (*J. Physics (U.S.S.R.)*, 1945, 9, 392; *Met. Abs.*, 1946, 13, 249) has proposed that the sintering of metal powders is caused by the driving force of surface tension which accounts for a flow having the linear relation between strain rate and stress characteristic of viscous liquids. The phenomenon of self-diffusion entails the existence of such a viscous flow. By extending the analysis of Frenkel, expressions have been derived for the rate of shrinkage at various temp. of powder aggregates having pores of uniform size. Equations have also been obtained which include the presence of foreign gases inside the pores and outside the aggregate. Experimental results for the sintering of uniform spherical copper particles in argon and in a vacuum are in qualitative agreement with those ideas, but indicate a heat of activation of self-diffusion of copper of over 85,000 cal. instead of the 57,000–61,000 cal. reported by Barrer ("Diffusion in and through Solids"). The effects when both large and small pores are present are discussed.—W. H.-R.

Metallic Hydrides [Production and Uses of Titanium]. — (*Amer. Exporter (Indust.)*, 1946, 139, (3), s30).—Pure titanium metal is being made by Metal Hydrides, Inc., from the powdered hydrides pressed into briquettes and heated *in vacuo* to between 400° and 500° C. Sintered titanium has an electrical resistivity about 100 times that of copper so that it can be used in special conditions for electrical resistors for temp. much higher than those permissible for Nichrome and the other high-resistivity alloys. Titanium may prove a valuable substitute for tin in the production of special bronzes. At 900° C., it spreads like oil in a thin layer over a copper surface, and on cooling presents a coating much harder than pure copper. A layer of copper in which titanium is diffused by heat-treatment adheres very firmly to thin plates of iron and provides a protective coating on the inner surfaces of condenser tubes, &c. Zirconium, thorium, tantalum, chromium, and columbium of 99% purity are also produced by the hydride process.—H. PL.

Packing of Material in Bulk. Douglas Rennie Hudson (*Machinery (Lond.)*, 1947, 70, (1807), 617–622; (1809), 681–683).—Investigations on the packing densities of spheres, polyhedral materials, and irregular materials are reviewed. With actual spheres the packing is not nearly as close as in such metallic lattices as gold, silver, copper, aluminium (cubic), magnesium, β -calcium, and β -chromium (hexagonal); the voidage in the former case is approx. 37%, in metallic lattices it is approx. 26%.—J. L. T.

Modern Powder Metallurgy. H. W. Greenwood (*Engineering*, 1947, 163, (4246), 492).—G. reviews the general progress made in powder metallurgy up to the present and particularly during the war years in Germany, America, and Britain. He states that the progress made during the empirical era has been steady if not spectacular. Future fundamental investigations should provide valuable knowledge for wider fields of application. The possibilities

of powder metallurgy are beyond the range of conditions governed by the crucible and furnace, which means that the limitations of the phase rule, as indicated in the equilibrium diagram, do not hold.—R. GR.

Powder Metallurgy : Some Queries. H. W. Greenwood (*Engineer*, 1947, **183**, (4766), 471).—G. discusses the average figures for the mechanical properties of powder products, limitations of form and dimensions of components, cost and life of dies, and the advantages of powder methods.—R. GR.

Powder Metallurgy [the Key to High-Temperature Power Applications]. — (*Amer. Exporter (Indust.)*, 1946, **139**, (1), s26.—See *Met. Abs.*, this vol., p. 106.—H. PL.

VI.—CORROSION AND RELATED PHENOMENA

Resistance of Aluminium Alloys to Fresh Water. D. W. Sawyer and R. H. Brown (*Corrosion*, 1947, **3**, (9), 443–457).—A review of recent experience and published data.—M. A. V.

Bearing Corrosion. H. H. Zuidema (*Oil Gas J.*, 1946, **44**, (41), 100–108); (42), 151–158; (43), 66–72; *Machines et Métaux*, 1947, **31**, (343), 104–106; *C. Abs.*, 1946, **40**, (10), 2775).—A general discussion and literature review. A description is given of the ten groups of bearing metals, classified according to composition: tin-base Babbitt, lead-base Babbitt, alkali-hardened lead, cadmium alloy, copper-lead, bronze, silver, aluminium alloy, zinc alloy, and sintered powdered metals. Z. discusses also test methods, the mechanism of corrosion, factors influencing corrosion, and control of corrosion. Compounds for which inhibition of bearing corrosion is claimed in 163 representative U.S. patents are listed, together with the concentration required. 42 references are given.

***Anodic Corrosion of Brass.** J. M. Bialosky (*Corrosion and Material Protection*, 1947, **4**, (1), 15–16).—A series of experiments have been performed using Muntz metal, naval brass, arsenical Muntz, and arsenical naval brass with applied anodic current in various aqueous solutions at room temp. to determine the dezincification characteristics of these alloys. The results indicate that arsenical Muntz and arsenical naval brass resist this type of attack, and that naval brass is more resistant than Muntz metal under the conditions explored. The initial dezincification occurs in the β -phase and attack of the α -phase follows. The dezincification reaction which was produced in these tests must have been due to selective attack of the zinc, rather than to redeposition of copper, which could not plate out on the anode of the cells.—AUTHOR.

***A Study of the Corrosion of Copper Alloy Condenser Tubes.** N. W. Mitchell (*Corrosion*, 1947, **3**, (5), 243–251).—The electrochemical and chemical corrosion, stress-corrosion, corrosion-fatigue, and impact erosion of copper alloys used in condenser tubes in petroleum refineries are described and illustrated by photomicrographs. A table is given showing the loss in tensile strength, due to sulphur corrosion of antimonial Admiralty brass (72% copper), Admiralty brass (71% copper), red brass, 20% cupro-nickel, 30% cupro-nickel, aluminium brass, and Muntz metal, after various periods of exposure in different parts of the plants. Data are also given of corrosion by water, and certain chemicals.—M. A. V.

***Copper-Base Alloy Tubes in Power Plants.** C. L. Bulow (*Southern Power and Ind.*, 1946, **64**, (5), 54–59, 76, 98; *C. Abs.*, 1946, **40**, (13), 3713).—Recently, some replacement tubes in condensers and heat exchangers have failed much more rapidly than the original tubes of the same alloy. Among the causes of this are the longer hours of operation, higher water velocities, and chlorination. The average life of condenser tubes in sea water of pH

7-8 is normally shorter than in fresh water of the same pH. Admiralty tubes are satisfactory with pH ranging up to 10; copper-nickel is satisfactory in alkaline waters of pH 7-14. Acid gases and ammonia have an adverse effect. Organic and suspended matter and their decomposition products may increase corrosion. Increased localized corrosion may be due to uneven deposition of corrosion products; an endeavour should be made to secure the formation and maintenance of a thin, continuous, uniform film on the surface of the proper alloy. Impingement corrosion is reduced by the use of aluminium brass, 70:30 copper-nickel containing about 0.5% iron, "Duronze IV", and special inserts. Corrosion may be due to stresses: where these cannot be controlled, copper, 70:30 copper-nickel, or duplex tubes should be used. Cyclic stresses due to vibration must be eliminated. Corrosion in heat exchangers can be minimized by keeping tubes clean and operating at the minimum temp. The elimination of carbon dioxide, ammonia, and hydrogen sulphide may also be necessary.

A Survey of High-Temperature, Gas-Atmosphere Corrosion of Iron-Nickel-Chromium Alloys.—I. —II. James T. Gow (*Corrosion*, 1947, 3, (7), 311-324; (8), 383-403; discussion, 403-405).—(I.—) The available literature on the structure, properties, and corrosion-resistance of iron-nickel-chromium alloys of various compositions is reviewed. Corrosion by hot oxygen, steam, carbon dioxide, sulphur dioxide, carbon monoxide, hydrocarbons, and hydrogen sulphide is considered. (II.—) Recent work by Brasunas, Gow, and Harder on the effect of nickel content on hot-air corrosion of alloys of various fixed chromium contents is discussed. Results of Hatfield's and Avery's researches on furnace-atmosphere corrosion are summarized, and the work of various investigators on scaling, sub-surface corrosion, and the nature of the oxide layer discussed. In conclusion, the complex nature of gas-atmosphere corrosion, and the present lack of understanding of its fundamentals, are emphasized.—M. A. V.

Chemical Corrosion-Resistance of Lead. — (*Corrosion*, 1946, 2, (6), 330-333).—A list of chemical corroding agents, and their effects upon lead. —M. A. V.

Discussion of Paper on Chemical Corrosion-Resistance of Lead. H. H. Uhlig (*Corrosion*, 1947, 3, (3), 149-150).—Cf. preceding abstract. A note on the toxic effect of corrosion of lead piping.—M. A. V.

Further Discussion of Paper [on] Chemical Corrosion-Resistance of Lead. Robert L. Ziegfeld (*Corrosion*, 1947, 3, (7), 347-348).—Cf. preceding abstract. Z. discounts Uhlig's warning as to the toxic effect of corrosion of lead piping. —M. A. V.

***The Rate of Dissolution of Magnesium and Zinc in Acids.** Cecil V. King, Henry Wishinsky, and Harry Bloodgood (*J. Amer. Chem. Soc.*, 1946, 68, (2), 238-239).—The rates of solution of magnesium and zinc chips in acids are independent of the stirring speed. These rates are compared with those obtained with sheets of metals suspended in similar acid solutions.—J. B. C.

Resistance of Some Nickel-Containing Alloys to West Texas Crudes. B. B. Morton (*Corrosion*, 1947, 3, (1), 23-36).—The corrosion-resistances of metals and alloys used in W. Texas oil-producing equipment are reviewed. These include nickel-plated sucker rods, Monel metal polished rods, chromium-plated nickel-copper alloys for pumps, K-Monel metal wire and gas-lift equipment, copper-nickel vessel linings, Inconel and 70:30 copper-nickel condenser tubes, and Ni-Resist, S-Monel, and K-Monel pump parts.—M. A. V.

Corrosion—The Great Destroyer [Galvanized Tanks].—D. J. Fergus (*Corrosion*, 1947, 3, (2), 55-66).—The problem of corrosion of galvanized steel hot-water tanks is discussed. It is concluded that the best counter-measure is cathodic protection by magnesium, which, in addition to its galvanic action, generates protective films on the tank walls.—M. A. V.

Failures of [Galvanized] Domestic Hot-Water Storage Tanks. Charles P. Hoover (*Corrosion*, 1947, 3, (4), 185-191).—See *Met. Abs.*, 1946, 13, 390.

—M. A. V.

Corrosion of Galvanized Hot-Water Storage Tanks. J. M. Bialosky (*Corrosion*, 1947, 3, (4), 192-197).—See *Met. Abs.*, this vol., p. 39.—M. A. V.

Corrosion of Hot-Water-Storage Heaters. Chris Goldkamp (*Gas*, 1946, 22, (2), 33-35; *C. Abs.*, 1946, 40, (8), 2098).—An important cause of corrosion is galvanic couples, caused by the use of galvanized tanks with water pipes and intake pipes of copper. Local corrosion can be caused by defects in the galvanizing and by lead in the coating. Corrosion occurs rapidly if the salt concentration of the water is high, and increases rapidly with temp., the rate of corrosion being twice as great at 180° F. (82° C.) as at 140° F. (60° C.). Other minor causes are listed. The use of non-ferrous metals throughout the tanks and piping would solve the problem; vitreous enamel and plastic coatings might be effective.—J. L. T.

Corrosion-Resistant Processing Equipment of Clad Steels for Chemical and Allied Industries. Everett C. Gosnell (*Corrosion*, 1946, 2, (6), 287-306).—An account of the corrosion-resistant properties and applications of various clad steels. The cladding metals include nickel, Monel metal, Inconel, aluminium, and silver.—M. A. V.

Mechanical and Metallurgical Control of Sulphuric Acid Corrosion in Petroleum Processes. E. R. Wilkinson (*Corrosion*, 1947, 3, (5), 252-262).—The corrosion rates of steel, nickel-chromium alloys, copper alloys, and lead in sulphuric acid of varying concentrations at 100° F. (38° C.), and in 45% sulphuric acid at 50°-350° F. (10°-177° C.), are presented graphically, and the suitability of various materials for specific applications shown in tabular form. The selection of materials is discussed in the light of these data.—M. A. V.

The Electrical Engineer's Responsibility for Recognizing Corrosion as a Factor in the Design of Electrical Structures. M. C. Miller (*Corrosion*, 1947, 3, (7), 341-346).—M. A. V.

***Thermogalvanic Corrosion.** N. E. Berry (*Corrosion*, 1946, 2, (5), 261-267).—The question of electrochemical corrosion due to a temp. difference between two separated areas is considered thermodynamically, and tests with a copper/copper sulphate cell, in which dE/dT was measured, are reported. The observed values agreed well with theoretical calculations.—M. A. V.

Corrosion Ratings for Metals. H. D. Holler and R. A. Frye (*Corrosion*, 1947, 3, (1), 8-21; discussion, 22).—A number of common metals and alloys are listed in order in an electromotive series, and their corrosion ratings, against the attack of various corroding agents, are tabulated.—M. A. V.

Corrosion Criteria—Their Visual Evaluation. Marc Darrin (*Corrosion*, 1946, 2, (5), 268-272).—See *Met. Abs.*, 1946, 13, 297; 1947, 14, 261.—M. A. V.

Economic Aspects of Corrosion Problems. F. A. Rohrman (*Corrosion*, 1947, 3, (2), 67-72).—A general discourse.—M. A. V.

VII.—PROTECTION

(Other than by Electrodeposition.)

War-Time Aircraft Finishes Used by the Army Air Force [Protection of Aluminium Alloys]. Louis Pereny (*Nat. Paint, Varnish, Lacquer Assoc., Sci. Sect. Circ.*, 1946, (714), 8-25; *C. Abs.*, 1946, 40, (13), 3911).—A review of the performance of aircraft finishes, together with some comments on the military requirements and considerations involved and some very general references to the types of composition that were found most successful. General results

of paint tests are summarized. Included in the discussion are : effectiveness of paint coatings in retarding corrosion ; causes of corrosion in order of importance ; conclusions resulting from laboratory tests of surface pre-treatment of aluminium alloys ; problems in the measurement of specular gloss ; chalking ; and fading problems in low-gloss camouflage paints.

Continuous Galvanizing [of Pipes]. A. D. Stout, Jr. (*Iron Age*, 1947, 160, (9), 79–80).—S. describes a continuous pipe-galvanizing process capable of coating 600 tons of 2-in. pipe every 24 hr. It is said to produce greater smoothness, lustre, and uniformity than previous processes.—J. H. W.

Zinc-Plate Corrosion. New Phosphating Process. — (*Chem. Age*, 1946, 55, (1420), 325).—The Westinghouse Company has found that the use of a pre-dip of di-sodium phosphate containing traces of titanium gives greatly improved results.—M. A. V.

Rust-Proofing of Metals [“Banox” Process for Steel and Zinc]. — (*Amer. Exporter (Indust.)*, 1946, 139, (5), s32).—A brief description of the “Banox” process, a chemical method of producing a protective phosphate coating on steel, zinc, and other metals and alloys.—H. PL.

Phosphating Metallic Surfaces. I.—History and Pre-Treatments. W. G. Cass (*Chem. Age*, 1946, 55, (1410), 5–8).—A brief history of the process, with particular reference to patents.—M. A. V.

Phosphating Metallic Surfaces. II.—Baths and Compositions : Accelerating Methods. III.—Finishing Treatment. W. G. Cass (*Chem. Age*, 1946, 55, (1411), 35–38 ; (1412), 67–70).—Cf. preceding abstract. A review of patent literature.—M. A. V.

Phosphating Metallic Surfaces. IV.—Anti-Trust and Patent Litigation in the U.S. W. G. Cass (*Chem. Age*, 1946, 55, (1413), 101–104).—Cf. preceding abstract.—M. A. V.

The Prevention of Metallic Corrosion. G. Fitzgerald-Lee (*Aeroplane*, 1947, 73, (1890), 251–253).—Thirty methods of corrosion prevention are mentioned. Cadmium plating is the best process for the treatment of steel parts and is widely used for aero-engine cylinder barrels, valve springs, studs, nuts, &c. The Bengough-Stuart anodizing process is the best process for aluminium and its alloys. Anodizing is better for wrought than for cast alloys, because differences in grain-size of the castings cause variations in the thickness of the film. Chromate pickling is particularly used for magnesium alloy castings. Bengough has originated a bath containing selenium dioxide and sodium chloride for the treatment of magnesium alloys to specifications D.T.D. 59A, 88B, 136A, and 259.—H. PL.

Designing to Prevent Corrosion. R. B. Mears and R. H. Brown (*Corrosion*, 1947, 3, (3), 97–118 ; discussion, 119–120 ; (6), 299–300).—The prevention of corrosion by avoiding the setting up of galvanic couples or the contact of dissimilar metals, is discussed. Cathodic protection, protective coatings, and inhibitors receive attention.—M. A. V.

Fundamental Factors in Corrosion Control. Herbert H. Uhlig (*Corrosion*, 1947, 3, (4), 173–184).—See *Met. Abs.*, 1947, 14, 261.—M. A. V.

The Protection of Lighting Fittings Against Weathering and Corrosion. W. E. Harper and C. A. Morton (*G.E.C. J.*, 1946, 14, (2), 111–120).—H. and M. review the nature of atmospheric corrosion and discuss the standard methods of protection used for the various materials utilized in making lighting fittings. The importance of proper maintenance is stressed.

—J. B. C.

Protective Coatings on Bell-System Cables. V. J. Albano and Robert Pope (*Corrosion*, 1947, 3, (5), 221–226).—An account of the construction, efficacy, and application of various types of cable protection, including tape-armoured cable, gopher-protected thermoplastic covered cable, and copper-jacketed cable.—M. A. V.

Maintenance of Oil-Field Equipment. D. R. Hiskey (*Corrosion*, 1946, 2, (5), 235-247; discussion, 247-248).—Corrosion of oil-field equipment and its prevention are discussed generally. Non-ferrous metals are often used for instrument cases; these may well be protected by plastic-base coatings.—M. A. V.

Plastic Coatings to Control Metal Corrosion—A Review. S. P. Wilson (*Corrosion*, 1947, 3, (3), 141-148).—The characteristics and applications of numerous types of plastic coating are outlined.—M. A. V.

***Chemical Reaction in Metal Protective Paints.** E. J. Dunn, Jr. (*Corrosion*, 1947, 3, (8), 374-382).—Investigations are reported on the chemical changes in anti-corrosive paints during drying and weathering. The formation of lead soaps has a beneficial effect.—M. A. V.

Cathodic Protection of 138-kV. Lead-Sheathed Power Cables of the Los Angeles Department of Water and Power. Irwin C. Dietze (*Corrosion*, 1947, 3, (9), 432-442).—The main problems to be solved in designing cathodic protection for the system were the maintenance of the entire cable system at an adequate negative potential; providing a voltage step between cable sheaths and ground at each end of the line to pass fault currents but restrict drainage currents; and equalizing sheath potentials of other systems to prevent current at crossing points.—M. A. V.

***Galvanic Aluminium Anodes for Cathodic Protection.** R. B. Hoxeng, E. D. Verink, and R. H. Brown (*Corrosion*, 1947, 3, (6), 263-274).—Progress in the development of aluminium anodes for cathodic protection of underground steel structures is reviewed. Zinc, which is anodic to aluminium, has been found a useful alloying element. Results of laboratory and service tests are quoted, and it is concluded that, in the present stage of development, aluminium alloy anodes can be constructed to give 675 amp. hr./lb., a performance superior to magnesium or zinc.—M. A. V.

***Magnesium Anodes for the Cathodic Protection of Underground Structures.** H. A. Robinson (*Corrosion*, 1946, 2, (4), 199-218; and (abridged) *Metal Progress*, 1947, 51, (5), 814, 818).—The strongly anodic solution potential of magnesium and its low electrochemical equivalent suggest that it is well suited for the cathodic protection of most common structural metals. An extensive series of laboratory and field tests was undertaken to determine the performance of magnesium anodes. Laboratory tests showed that a good performance should be expected of magnesium-6% aluminium-3% zinc anodes; field tests, although not yet complete, generally support laboratory data.—M. A. V.

***A Magnesium-Anode Installation for Preventing the Corrosion of Lead Cable Sheath.** H. A. Robinson and R. L. Featherly (*Corrosion*, 1947, 3, (7), 349-357).—The Dow Chemical Company has developed and tested a galvanic magnesium anode for protecting underground lead cable. Results of tests are presented. The test installation showed no sign of deterioration after 21 months of service.—M. A. V.

Construction and Ratings of Copper Oxide Rectifiers for Cathodic Protection of Pipelines. L. W. Burton and C. E. Hamann (*Corrosion*, 1947, 3, (2), 75-95).—The construction, electrical characteristics (including ageing), and practical use of copper oxide rectifiers are described.—M. A. V.

Selenium Rectifiers for Cathodic Protection. W. F. Bonner (*Corrosion*, 1946, 2, (5), 249-260).—The construction, characteristics, and application of selenium rectifiers are described. Single-phase power is generally used for cathodic protection.—M. A. V.

Cathodic-Protection Rectifiers. W. L. Roush and E. I. Wood (*Corrosion*, 1947, 3, (4), 169-172).—Factors affecting the service life of self-cooled, fan-cooled, and oil-immersed rectifiers are considered. Experience shows the oil-immersed type to be the most adaptable for all atmospheric conditions.

—M. A. V.

Cathodic Protection. C. H. McRaven (*Corrosion*, 1946, 2, (6), 320–329).—A general discourse.—M. A. V.

Contributions of Sir Humphrey Davy to Cathodic Protection. I. A. Denison (*Corrosion*, 1947, 3, (6), 295–298).—An historical review.—M. A. V.

VIII.—ELECTRODEPOSITION

Colloid Factors in the Electrodeposition of Metals. Louis Weisberg (*Colloid Chem.*, 1946, 6, 579–586; *C. Abs.*, 1946, 40, (9), 2394).—W. discusses interference with crystal growth, colloid formation at the cathode, colloidal and surface-active addition agents, brighteners, stress and embrittlement, and anodic effects. 47 references are given.

Some Impressions of Electroplating in the U.S.A. A. W. Hotherhall (*Galvano*, 1947, 16, (128), 7–11).—See *Met. Abs.*, this vol., p. 47.

***A Simple Technique for the X-Ray Determination of Fibre Axes in Electrodeposited Metals.** (Wyllie). See p. 150.

IX.—ELECTROMETALLURGY AND ELECTROCHEMISTRY

(Other than Electrodeposition.)

***Oxide Coatings. The Effect of the Coating Core Interface on Conductivity and Emission [Coatings on Nickel].** D. A. Wright (*Proc. Roy. Soc.*, 1947, [A], 190, (1022), 394–417).—Measurements were made of the electrical conductivity and emission of typical barium/strontium oxide coatings on a base of nickel containing small amounts of magnesium or aluminium, under continuous current conditions at low c.d. It was found that a potential barrier occurs at the interface, leading to rectifier action, this barrier restricting the flow of current from metal to semi-conductor. The barrier layer, $< 10^{-4}$ cm. thick, is probably a semi-conducting layer, of nickel-containing magnesium oxide, with a higher resistance than that of the bulk coating. The rapid decay of emission immediately following the application of anode voltage is also to be associated with the barrier, and it is possible that an adsorbed film of barium is present on the nickel surface, in equilibrium, which reduces the work function of the nickel and consequently reduces the height of the barrier. The results are discussed and applied to the operation of cavity magnetrons.
—E. N.

X.—REFINING

The Story of Malleable Platinum. M. Schofield (*Endeavour*, 1947, 6, (23), 125–128).—To the early Spanish gold miners, platinum was merely an objectionable impurity. S. deals with the history of the attempts to fabricate platinum and their ultimate success. There is special reference to the work of W. H. Wollaston, who applied powder-metallurgical methods.—J. B. C.

XI.—ANALYSIS

Recent Developments in Analytical Chemistry.—XVII. [Detection and Determination of Copper]. — (*Chem. Age*, 1946, 55, (1415), 163–166).—Notes are given on recent methods of detecting and determining Cu, including spot-tests for Cu in steel, using α -benzoin oxime; the separation of Cu and

Cd by Evans, Garrett, and Quill's volumetric method, and Bishop's chromatographic method; the electrolytic estimation of Cu in bronzes, brasses, and Al alloys; the rapid volumetric determination of Cu in steel; and polarographic, colorimetric, and spectrophotometric methods. The Baker and Reedy test for Ag and the Evans and Higgs volumetric method are also described.—M. A. V.

Distinguishing the Be-Cu Alloys. Frank C. Bennett, Jr. (*Metal Progress*, 1947, 52, (2), 250).

***Two Very Sensitive Qualitative Tests for Metallic Mercury and Tin.** Georges Denigès (*Compt. rend.*, 1947, 224, (26), 1799-1801).—Three reagents are described. Reagent A: a 5% aqueous solution of $\text{Hg}(\text{CN})_2$; reagent B: an aqueous solution of mercury potassium iodide; reagent C: reagent B + an equal amount of 15% NaCl, which stabilizes the solution. D. gives details of the use of these reagents in the identification of metallic Hg and Sn, and its practical applications.—J. H. W.

***Applications of the Polarograph to Metallurgical Analysis. III.—Further Studies on a Polarographic Method for the Determination of Lead in Copper-Base Alloys.** G. W. C. Milner (*Metallurgia*, 1947, 36, (215), 287-289).—Cf. *Met. Abs.*, 1947, 14, 394. Polarographic methods of determining Pb in Cu-base alloys, previously described, are not completely satisfactory if Mn is present. A new method is described, in which the interfering Mn is converted by triethanolamine into a complex which is stable in the alkaline cyanide medium required for Pb determination.—M. A. V.

Polarography. The Electrochemical Analysis of Metals. L. Sanderson (*Chem. Age*, 1946, 55, (1419), 289-292).—The basic principles of the process are outlined.—M. A. V.

***A Study of the Effect of the Microstructure of the Electrodes on the Reproducibility of Spectrographic Analysis of Al-Cu-Mg-Si Alloys.** J. M. Pourvreau (*Rep. 7me. Congr. Groupement Avancement Méthodes Anal. Spectrograph. Produits Métallurg.* (Jan. 21-23), 1947, 61-63).—Al alloys containing 4% Cu, with Mg, Mn, Si, and Fe each <1%, were cast in 6-mm. rods in Cu chill moulds, and other samples were remelted and cast in slowly cooled graphite cylinders. 40 spark spectra were recorded from each sample, and the standard deviations of the concentration of the elements Mg, Mn, Si, and Fe were worked out from the microphotometric measurements of stepped spectra for each element. They ranged from 3.4 to 4.8% for the chill-cast samples and 8-11% for the remelted samples.—E. VAN S.

***The Spectrochemical Analysis of Nickel Alloys.** Edwin K. Jaycox (*J. Opt. Soc. Amer.*, 1947, 37, (3), 159-165).—To get over the difficulty of comparing various forms of wrought Ni and its alloys, they are treated by dissolving in HNO_3 and evaporating to give a mixture of nitrate and oxide, which is mixed with carbon dust so that it can be smoothly arc-ed in a graphite crater. Wave-lengths for the estimation of B, Cu, Mg, Mn, Fe, Si, Ti, Pb, and Zn are given with details and a few examples of analytical results. B can be estimated down to 0.0003% and the other elements down to 0.005%. —E. VAN S.

***Report on Tests of the Spark Generator for Spectrographic Analysis Made by M. R. Durr in the Spectral-Analysis Section of the Research Department of the Uginé Steelworks.** R. Castro (*Rep. 7me. Congr. Groupement Avancement Méthodes Anal. Spectrograph. Produits Métallurg.* (Jan. 21-23), 1947, 79-85).—A controlled-spark generator of the Feussner type, with a rotary interrupter in the discharge circuit, was compared with the Feussner generator by recording spectra from the two circuits on the same plate, using nominally the same values of capacitance and inductance in the discharge circuit. The differences observed appear to be due to different values of the indicated current in the H.F. circuit, and it is suggested that if this current, as well

as the capacitance and inductance, are specified, the spectrographic value of a spark can be completely described so that it can be reproduced by other workers. In reproducibility of spectra, the Durr source is similar to the Feussner one.—E. VAN S.

XII.—LABORATORY APPARATUS, INSTRUMENTS, &c.

(See also "Testing" and "Temperature Measurement and Control".)

***Measurement of Metal-Polish Performance.** Frank E. Clarke and Robert C. Adams (*Bull. Amer. Soc. Test. Mat.*, 1947, (147), 57–62).—A method of giving a standard degree of tarnish to a polished specimen, and then polishing away the tarnish under specific conditions, is described. The degree of tarnish and polish is measured by the reflectivity of the specimen. The efficiency of the metal polish is taken as the percentage restoration of reflectivity after standard polishing. Abrasion, caking, and other tests are also mentioned.—J. B. C.

Fisher Hi-Temp. Bath. — (*Laboratory*, 1947, 17, (2), 57).—The bath is cast in aluminium and has a built-in thermostat. It can be used for distilling, extracting, and melting.—J. L. T.

A New Polarograph. James H. Schulman, H. Bruce Batty, and Demetrius G. Jelatus (*Rev. Sci. Instruments*, 1947, 18, (4), 226–231).—Electrical and mechanical details of the construction of a polarograph are given. The essential feature is the use of a new type of D.C. amplifier, which permits instantaneous records to be obtained on a permanent ink-track recorder giving full deflection for 0.5 m.amp. The time lag in this current-recording system is of the order of 0.5 sec., so that accurate records can be obtained even at high rates of voltage change.—S. M.

***The Measurement of the Intensity Ratios of Spectral Lines with Electron-Multiplier Photo-Tubes.** K. G. Kessler and R. A. Wolfe (*J. Opt. Soc. Amer.*, 1947, 37, (3), 133–144).—A detailed description of the properties of some available photo-multiplier tubes and of a new circuit for measuring the ratio of the intensity of two spectrum lines. Each line illuminates one tube, and the photo-currents from the tubes are taken to calibrated potential dividers, followed by narrow band-pass filters tuned to twice the A.C. frequency. These raise the signal:noise ratio from the tubes. After one more stage of amplification each output is rectified, and they are fed in opposition to a valve voltmeter, used as a null instrument to balance the two circuits. The variable actually observed is the potential-divider reading in one of the circuits, and the precision of reading is about as good as photographic methods for Cr in Fe. One analysis takes about 2 min.—E. VAN S.

***Method of Correcting Low-Angle X-Ray Diffraction Curves for the Study of Small Particle Sizes.** Jesse W. M. Du Mond. (*Phys. Rev.*, 1947, [ii], 72, (1), 83–84).—A note. The reflection-type focusing, curved-crystal spectrometer of Guinier (*Ann. Physique*, 1939, [xi], 12, 161; *Met. Abs.*, 1940, 7, 66) is described, and also a new two-crystal spectrometer for the study of low-angle X-ray diffraction. The diffraction patterns obtained in both cases require a correction in order to obtain the true radial intensity distribution. A method for making this correction is described.—W. H.-R.

***An Investigation of the Properties of Evaporated [Nickel] Metal Bolometers.** R. H. Billings, W. L. Hyde, and E. E. Barr (*J. Opt. Soc. Amer.*, 1947, 37, (3), 123–132).—Strips of nickel less than 1 μ thick, deposited on a plastic base by evaporation, form one of the most sensitive methods of detecting

radiation, and a useful comparison with thermistor bolometers, dielectric bolometers, and thermocouples is given. A theoretical analysis of the performance of bolometers is complicated by the fact that both the coeff. of resistivity and the temp. coeff. of resistivity of evaporated nickel are functions of the film thickness in the range 100–500 Å. Useful details on the determination of electrical resistivity and film thicknesses are given: an interferometric estimate of thickness is recommended since the films are somewhat porous.—E. VAN S.

XIII.—PHYSICAL AND MECHANICAL TESTING, INSPECTION, AND RADIOLOGY

***Conducting-Paint Electrodes for Dielectric Measurements.** E. Gerald Meyer and Myron A. Elliott (*Bull. Amer. Soc. Test. Mat.*, 1947, (147), 63–64).—Various types of conducting materials, including tin-foil, zinc, and “conducting silver paint”, are compared as electrode materials for dielectric-constant and power-factor measurements on polystyrene. A convenient method of preparing and applying the paint as a quick-drying spray is described. There is no damaging of the surface of the specimen by this method.—J. B. C.

Non-Destructive Thickness Measurements. — (*Metal Finishing*, 1947, 45, (10), 87).—Engineering data sheet.—J. L. T.

***The Micro-Sclerometer: A New Micro-Hardness Tester.** R. Girschig (*Metallurgia*, 1947, 36, (215), 269–273).—An abridged translation of *Rev. Mét.*, 1946, 43, 95–112; see *Met. Abs.*, this vol., p. 25.—M. A. V.

***New Apparatus for Axial-Load Fatigue Testing.** William N. Findley (*Bull. Amer. Soc. Test. Mat.*, 1947, (147), 54–56).—A fatigue-testing machine is described which permits testing of specimens in axial tension or compression. The machine is designed so that strains, introduced into the specimen when clamped, may be detected and corrected. Hence, the stress in the specimen may be made more nearly uniform over the cross-section than is usually possible.—J. B. C.

***Reproducibility of the Single-Blow Charpy Notched-Bar Test.** N. A. Kahn and E. A. Imbembo (*Bull. Amer. Soc. Test. Mat.*, 1947, (146), 66–74).—Charpy test-specimen blanks, completely machined but not notched, were prepared from a uniformly stress-relieved mild steel. 24 blanks were sent to seven different laboratories. Each prepared 12 specimens with the key-hole notch and 12 with the V-notch. 6 of each type were tested at the laboratory and 6 by the authors. The temp.-impact relationship for both types of notch was determined. Evidence is presented which indicates definite superiority of the keyhole notch over the V-notch for the material tested, with respect to the reproducibility of the Charpy energy values and revelation of the transition zone in the temp.-impact relationship.—J. B. C.

The Notched-Bar Impact Test-Piece. — (*Engineer*, 1947, 184, (4779), 197).—Schnadt, as quoted by J. A. Haringx, proposes to remove the material in the region which would become the compression zone in an impact test-piece, by drilling a hole in the specimen and inserting a loose-fitting hardened steel pin. The pendulum strikes against the steel pin instead of the softer material of the test-piece. This proposal is discussed. The study made by Kahn and Imbembo on the reproducibility of results obtained in the single-blow Charpy test with two types of notch (see preceding abstract) is also summarized.—R. GR.

***The Effect of Notching on Materials of Construction Under Static and Dynamic Tension.** Georges Welter (*Metallurgia*, 1947, 36, (215), 283–286).—Static and dynamic tensile tests are reported on notched specimens, of various

sizes and shapes, of aluminium, aluminium alloy, copper, brass, AM57S magnesium alloy, zinc, Monel R.B, and steel. Loading speeds in the dynamic tests were 11.78, 16.68, and 29 ft./sec. Work of previous investigators (which is reviewed) showed the resistance to increase generally with testing speed.—M. A. V.

Engineering Significance of Metal Testing. Blake D. Mills, Jr. (*Iron Age*, 1947, 160, (6), 78–83).—M. discusses several types of physical-testing methods, including tension, compression, notched-bar, high-velocity, creep, and fatigue tests, with particular reference to their correlation with engineering practice, and describes the use of statistical methods of checking material quality.—J. H. W.

***Deformation of Metals During Single and Repeated Tensile Impact.** (Pope). See p. 141.

Inspection in a Mechanized Foundry. P. Cook (*Proc. Inst. Brit. Found.*, 1945–46, 39, B32–B45).—See *Met. Abs.*, 1946, 13, 307.—J. E. G.

RADIOLOGY

Radiography in the Die-Casting Industry. R. W. Dively (*Indust. Radiography Non-Destructive Test.*, 1947, 6, (1), 20–21, 39).—A 140-kV. X-ray unit is utilized to determine the presence of porosity, cold shuts, inclusions, and shrinks in aluminium and zinc die-castings up to 5 in. and $\frac{3}{8}$ in. in thickness, respectively, with a sensitivity of 0.5%. Inclusions of a precipitated sludge of Al–Si–Fe–Mn have been found in aluminium alloy die-castings.—L. M.

Sliding Scales to Increase the Usefulness of Radiographic Exposure Charts. G. M. Corney (*Indust. Radiography Non-Destructive Test.*, 1947, 6, (1), 44–46).—A standard radiographic-exposure chart for any given metal and X-ray equipment may be readily used for different films, other film densities, and increased or decreased focus–film distances, by substituting a sliding scale for the fixed scale on the exposure axis. A fixed mark on the sliding scale is moved to coincide with reference marks on the exposure axis, which are fixed from a knowledge of the changes of exposure resulting from use of a different film, density, or focus–film distance.—L. M.

A Densitometer of Unusually High Sensitivity. Monroe H. Sweet (*Indust. Radiography Non-Destructive Test.*, 1947, 6, (1), 47–48).—A brief description of a densitometer for measuring film densities, e.g. in X-ray sensitometry, up to 6.0.—L. M.

Engineering Radiography. V. E. Pullin (*Engineer*, 1947, 184, (4784), 319).—P. states that in future radon or radium emanation for radiography will become generally available. It has advantages over radium salt, which he enumerates.—R. GR.

High Speed X-Ray Photography. — (*Machinery Lloyd*, 1946, 18, (10), 87).—The Westinghouse Electric Corporation has perfected an X-ray tube capable of making exposures of a millionth of a second. In arc welding, it is possible to take X-ray photographs which are not in the least blurred by the light from the electric arc, and thus the transfer of metal during welding can be studied.—H. PL.

XIV.—TEMPERATURE MEASUREMENT AND CONTROL

Temperature Determination of Molten Metal. G. Vennerholm and L. C. Tate (*Amer. Foundryman*, 1947, 11, (5), 56–63).—Recent developments in the construction and application of radiation and immersion pyrometers, for measuring molten-metal temp. in the range 2200°–3200° F. (1204°–1760° C.), are discussed.—V. K.

Temperature Measurement by Means of an Immersion Pyrometer. E. Hunter, A. R. Parkes, and J. W. Dews (*Proc. Inst. Brit. Found.*, 1945-46, 39, B75-B81).—See *Met. Abs.*, 1946, 13, 133.—J. E. G.

An Air-Operated Automatic Controller. — (*Engineer*, 1947, 184, (4778), 171-173).—A description is given of a controller for temp., pressure, &c. It is designed to perform the following kinds of control: proportional, floating and proportional, proportional and first derivative, and floating plus proportional plus first derivative.—R. GR.

XV.—FOUNDRY PRACTICE AND APPLIANCES

Casting Magnesium in Metal Moulds. Herbert Chase (*Iron Age*, 1947, 160, (13), 73-76).—C. describes the practice followed in a large plant for producing magnesium parts as die-castings and in permanent and semi-permanent moulds, stressing the need for close control of the casting cycle, especially ejection. He also describes a magnesium die-casting alloy with improved ductility and impact strength.—J. H. W.

Gating Magnesium Alloy Castings. H. E. Elliott and F. G. Mezoff (*Amer. Foundryman*, 1947, 11, (5), 71-79).—A modification of the side-gating method is described. The main feature of this method is an annular screen loosely filled with coarse steel wool through which the metal flows before entering the slot gate. Soundness and freedom from inclusions in the casting are claimed to result from the unidirectional solidification and non-turbulent flow of metal which are obtained by the application of this type of gate.—V. K.

Elektron Moulding Boxes. — (*Found. Trade J.*, 1947, 83, (1624), 127-128).—A brief account of the design, manufacture, and utilization of Elektron moulding boxes.—J. E. G.

Melting Aluminium Scrap in the Low-Frequency Induction Furnace. (Tama). See p. 164.

*[Ageing of] **Aluminium Sand-Casting Alloys.** (Quadt). See p. 164.

Fluidity Testing of Foundry Alloys. K. L. Clark (*Proc. Inst. Brit. Found.*, 1945-46, 39, A52-A63; discussion, A64-A71).—See *Met. Abs.*, 1946, 13, 402.—J. E. G.

Standard Test Bars for the Non-Ferrous Foundry. Frank Hudson (*Proc. Inst. Brit. Found.*, 1945-46, 39, A72-A78; discussion, A78-A88).—See *Met. Abs.*, 1946, 13, 368; 1947, 14, 26, 223.—J. E. G.

Duplex Pump Castings. R. H. Brown (*Proc. Inst. Brit. Found.*, 1945-46, 39, B4-B14).—See *Met. Abs.*, 1946, 13, 309.—J. E. G.

The Technological Principles of Casting Design. Victor M. Shestopal (*Proc. Inst. Brit. Found.*, 1945-46, 39, B51-B63; discussion, B63-B65).—See *Met. Abs.*, 1946, 13, 100, 309.—J. E. G.

Gates and Risers. Nathan Janco (*Amer. Foundryman*, 1947, 11, (6), 57-60).—A method of calculation of sizes of gates and risers is suggested. The ratio of the area of section of casting to the perimeter of the same section is defined as its cooling factor, and this must be smaller than the cooling factor of the riser, or gate which serves as a riser.—V. K.

***New Process Chemically Treats Moulding Sand.** Thomas W. Curry (*Amer. Foundryman*, 1947, 11, (6), 51-56).—Large-scale trials on specially treated moulding sand were carried out under industrial conditions. The sand is initially mulled with a high carbon resin which is soluble in suitable chemicals (the compositions are not given). It is claimed that the sand so treated gives better moulding and casting properties, resulting in an overall saving in production costs.—V. K.

***Foundry-Sand Reclamation.** J. M. Cummings and W. M. Armstrong (*Amer. Foundryman*, 1947, 12, (1), 35-39, 65).—Small-scale experiments

were carried out to determine the costs of full reclamation of foundry sands. It was found that a satisfactory process requires three stages, viz. scrubbing, classification, and calcining, and that it becomes economically advantageous when transport charges are considerable.—V. K.

***[Testing of] Moulding Sands.** C. R. Gardner (*Amer. Foundryman*, 1947, 11, (6), 34–38).—Standard properties of two types of synthetic sands were measured as functions of moisture content and degree of ramming. G. suggests that the graphs thus obtained could be used as a basis for non-destructive testing of sand in a mould.—V. K.

Determination of "Gas Content" of Sand Cores. — (*Proc. Inst. Brit. Found.*, 1945–46, 39, A192–A194).—See *Met. Abs.*, 1946, 13, 336.—J. E. G.

Sand Supply to Moulding Machines for Overhead Hoppers. N. C. Blythe (*Proc. Inst. Brit. Found.*, 1945–46, 39, B1–B2; discussion, B2–B3).—See *Met. Abs.*, 1946, 13, 136.—J. E. G.

Mould and Core Materials. N. J. Dunbeck (*Western Metals*, 1946, 4, (Sep.), 51–52, 54–56, 58–62; and *Nassau*, 1947, 9, (4), 3–11; (5), 3–11).—A review, presented to the Southern California Chapter of the American Foundrymen's Association.—J. L. T.

Liquid Phenolic Resins for Casting. C. R. Simmons (*Amer. Foundryman*, 1947, 11, (5), 94–96).—The technique of producing patterns in phenolic resins is discussed.—V. K.

Making Plastic Patterns. E. J. McAfee (*Amer. Foundryman*, 1947, 12, (1), 26–31).—The technique of producing mounted and unmounted patterns in various types of phenol plastics is described. Such patterns could be used for hand or machine moulding and have certain advantages over standard pattern materials, with which they are also competitive for duplication, intricate work, and mass production.—V. K.

The Application of Ethyl Silicate to Foundry Practice. Clifford Shaw (*Proc. Inst. Brit. Found.*, 1945–46, 39, B99–B101; discussion, B101–B104).—See *Met. Abs.*, 1946, 13, 136.—J. E. G.

Abrasive Blasting of Castings. R. L. Orth (*Amer. Foundryman*, 1947, 12, (2), 22–25).—Blasting equipment, its selection, operation, and maintenance are discussed.—V. K.

The Handling and Transport of Materials in a Modern Factory. W. L. Beeby and W. Symes (*Trans. Manchester Assoc. Eng.*, 1946–47, 147–163; discussion, 164–172).—See *Met. Abs.*, this vol., p. 56.—J. L. T.

Hampton Court Clock. — (*Found. Trade J.*, 1947, 83, (1620), 54).—Notes regarding restoration work carried out on the Hampton Court clock and facts about early bell-founding are given.—J. E. G.

The Present Position of Centrifugal Casting. [—II]. Jacques Boucher (*Fonderie*, 1947, (15), 553–563).—Cf. *Met. Abs.*, this vol., p. 56. B. reviews recent developments in this field. Mention is made particularly of the casting of thin-walled tubes on horizontal slow-speed machines, with special reference to small-diameter tubes (18–25 mm.) in lengths up to 3 m. Compositions for permanent moulds in cast iron (carbon 3–3.2, silicon 1.5–2, manganese 0.9–1%; or carbon 3.2, silicon 2.3, manganese 0.7, nickel 3.5, molybdenum 0.5%) and in steel (various steels with carbon 0.25–0.4, molybdenum 0.25–0.5%, with or without chromium and vanadium) are given. The casting of bronzes in semi-permanent graphite moulds is described. Examples of centrifugal-pressure castings, e.g. gear-wheels and squirrel-cage rotors, are discussed. Speeds range up to 300 m./min.—S. M.

The Formation of Banded Structures in Horizontal Centrifugal Castings. H. O. Howson (*Proc. Inst. Brit. Found.*, 1945–46, 39, B110–B118; discussion, B118–B121).—See *Met. Abs.*, 1946, 13, 135, 309.—J. E. G.

Precision-Casting Small Aluminium Impellers. Eugene M. Cramer (*Amer. Foundryman*, 1947, 12, (2), 36–38).—The technique of casting small impellers

of an aluminium alloy containing zinc 5.25 and magnesium 0.5%, in a plaster mould, is described. A combination of centrifugal and static methods was applied.—V. K.

Casting Reflections. D. Howard Wood (*Proc. Inst. Brit. Found.*, 1945-46, 39, A17-A20).—See *Met. Abs.*, 1946, 13, 335.—J. E. G.

Castings and Weldings. (Sir) Claude D. Gibb (*Proc. Inst. Brit. Found.*, 1945-46, 39, A21-A27).—See *Met. Abs.*, 1946, 13, 335.—J. E. G.

Technical Records in the Foundry. R. D. Lawrie (*Proc. Inst. Brit. Found.*, 1945-46, 39, B82-B84; discussion, B84-B91).—See *Met. Abs.*, 1946, 13, 309.—J. E. G.

Apprentice Training in the Foundry. John B. Longmuir (*Proc. Inst. Brit. Found.*, 1945-46, 39, B66-B70).—See *Met. Abs.*, 1946, 13, 336.—J. E. G.

Foundry Education and Recruitment. D. H. Ingall (*Proc. Inst. Brit. Found.*, 1945-46, 39, B92-B95; discussion, B95-B98).—See *Met. Abs.*, 1946, 13, 309.—J. E. G.

XVI.—SECONDARY METALS : SCRAP, RESIDUES, &c.

Melting Aluminium Scrap in the Low-Frequency Induction Furnace. Manuel Tama (*Iron Age*, 1947, 160, (10), 77-78).—T. describes low-frequency melting and explains its advantages in producing high recovery rate (96%) in melting aluminium scrap. He also discusses the characteristics of oxide-coated particles and their effect on heat transfer in the furnace.—J. H. W.

XVII.—FURNACES, FUELS, AND REFRACTORY MATERIALS

A Lead-Melting Furnace. — (*Engineer*, 1947, 184, (4781), 255).—A description is given of a gas-fired lead-melting furnace for cable sheathing. The melting rate is 7000 lb./hr. when loaded in batches of 1800 lb. Constructional features such as stirrer arrangement and flame control are described.—R. Gr.

Electronic Frequency Converters for Induction Melting Furnaces. S. R. Durand (*Iron Age*, 1947, 160, (13), 64-67, 134).—D. describes several furnace installations, using electronic frequency-changing equipment, for melting both alloy steel and non-ferrous alloys.—J. H. W.

"Infra-Red" Heating by Gas : Its Development and Practice To-Day. [—II]. J. B. Carne (*Metallurgia*, 1947, 36, (215), 245-249).—Cf. *Met. Abs.*, this vol., p. 59. Illustrated descriptions are given of a few industrial, gas-fired infra-red radiant ovens.—M. A. V.

Fuel Saving in Metal Making. Direct Operation Methods. Leslie Aitchison (*Chem. Age*, 1946, 55, (1427), 535-537).—Report of a paper "Fuel Considerations in the Fabrication of Non-Ferrous Metals and Light Alloys", presented at the Conference on "Fuel and the Future" in October 1946.

—M. A. V.

XVIII.—HEAT-TREATMENT

*[Ageing of] **Aluminium Sand-Casting Alloys.** H. A. Quadt (*Amer. Foundryman*, 1947, 11, (6), 39-42).—Q. studied the effect of the time interval between the quenching and artificial ageing treatment on the mechanical properties of artificially aged aluminium casting alloys. He found that the properties of alloys containing Mg_2Si are sensitive to the length of this time interval, the

alloys having a low ductility if artificially aged immediately after the quenching.—V. K.

Heat-Treatment of High-Tensile Aluminium Alloy Sheet. J. G. Gwatkin (*Aircraft Prodn.*, 1946, 8, (97), 527–528).—The properties and heat-treatment of the strong light-alloy sheets covered by specifications D.T.D. 546B (Alclad), and D.T.D. 646, both of which are double heat-treated, and those of the naturally aged sheets D.T.D. 610 (Alclad) and D.T.D. 603 are discussed in relation to shop handling and routine treatment.—H. S.

The Bright Annealing of Copper. Ivor Jenkins and S. V. Williams (*G.E.C. J.*, 1946, 14, (2), 90–96).—The authors discuss: the normal burnt town's gas and burnt-ammonia atmospheres with reference to oxygen and hydrogen; the effect of sulphur contained in rolling oils; and the effect of steam in contact with the annealing chamber ($\text{Fe} + \text{H}_2\text{O} \rightleftharpoons \text{FeO} + \text{H}_2$). Furnace pots can be sprayed with copper or aluminium to prevent hydrogenation of organic sulphur compounds which may be introduced into or formed inside the pot.

—J. B. C.

Classification of Prepared Atmospheres. C. C. Eeles and M. E. Shriner (*Metal Progress*, 1947, 52, (2), 256-B).—Data sheet.—J. L. T.

XIX.—WORKING

Die Design for Aluminium Alloys. E. W. Mason (*Machinist (Eur. Edn.)*, 1947, 91, (20), 632–634).—An abstract of an address to the Toledo district of the Pressed Metal Institute. M. describes the workability of seven wrought aluminium alloys commonly used in metal forming, and discusses die design in relation to the object to be formed.—J. H. W.

Forming of Aluminium Alloys. Use of the Rubber Die Press. — (*Chem. Age*, 1946, 55, (1414), 137–139).—A digest of Aluminium Development Association Information Bulletin No. 11.—M. A. V.

***Dimpling Light-Alloy Sheet [75S].** — (*Aircraft Prodn.*, 1946, 8, (97), 536–540).—Experimental work on hot dimpling of sheets in the high-strength aluminium alloy 75S for flush riveting, at the University of California, is described. The methods include local resistance heating and forming during the last part of the heating cycle between cooled dies, and also forming between hot dies, which provide the heat required. Descriptions of the apparatus used and the operational features are given with illustrations.—H. S.

The Use of Zinc Alloys for Blanking Dies. J. W. Sladden and H. S. Walker (*Machinery (Lond.)*, 1947, 71, (1824), 407–408).—Summary of *Sheet Metal Ind.*, 1947, 24, (239), 567–581, 586; see *Met. Abs.*, 1947, 14, 407.

—J. L. T.

Design and Production Technique. V.—Principles Involved in Pressing. A. J. Schroeder (*Aircraft Eng.*, 1946, 18, (211), 320–323; (212), 357–362).—Cf. *Met. Abs.*, 1944, 11, 273. The production of components by cold and hot pressing of metals is described, as well as the pressing of ceramic materials and plastics. Design features are considered and economic aspects discussed.—H. S.

Aluminium Alloy Machining Practice. — (*Amer. Exporter (Indust.)*, 1946, 139, (6), s32–s33).—Wrought aluminium alloys have considerably better machining properties than commercially pure aluminium because of their complex structure. Most strong heat-treatable alloys containing fairly high percentages of copper can be machined to smooth finishes at high speeds and feeds with a low rate of tool wear.—H. PL.

XX.—CLEANING AND FINISHING

Preparation of Metals for Painting : A Review. R. E. Gwyther (*Corrosion*, 1947, 3, (4), 201–207).—Solvent degreasing, alkaline cleaning, mechanical cleaning, pickling, and flame cleaning methods are reviewed, and the pre-treatment of iron and steel, zinc, aluminium, and magnesium considered in detail.—M. A. V.

Machining and Finishing Die-Castings. Recommendations for Magnesium Alloys. — (*Mech. World*, 1947, 122, (3168), 348–351).—The author describes machining and surface-finishing techniques recommended for magnesium alloys by the Stewart Die-Casting Division of the Stewart-Warner Corporation, U.S.A. Finishing methods discussed include dichromate treatment, “Manodyzing”, and painting.—R. W. R.

XXI.—JOINING

Induction Heating [for Soldering Fuses]. — (*Amer. Exporter (Indust.)*, 1946, 138, (6), s22).—Induction heating is used in soldering the fusing elements of plug fuses to their brass screw shells. Small wedges of solder are inserted between the fusing element and the shell of the assembled plug. The assemblies are then conveyed past an induction-heating coil, and the solder flows down into the element slot.—H. PL.

Application of High-Frequency Heating to Silver Brazing and Silver Soldering. Herman A. Folgner (*Western Metals*, 1946, 4, (3), 35–37; *C. Abs.*, 1946, 40, (11), 3092).—The advantages of induction heating for silver brazing are simplicity of operation, low cost, high speed, and better control of heat. The conductor is usually a coil in which cooling water can circulate. To make a good brazed joint, all surfaces must be heated above the m.p. of the brazing alloy. The coil should be spaced sufficiently far away from the surfaces to be joined to give a slow, soaking heat rather than a surface heat, since the latter causes overheating of the outer surface before the inner surface has been brought up to brazing temp.

Aluminium Parts Assembled by Brazing. — (*Machinist (Eur. Edn.)*, 1947, 91, (19), 585–587).—The materials and technique used in furnace and dip brazing in the assembly of aluminium and aluminium alloy components are described. The method is economical and can often be applied to parts too thin to be welded.—J. H. W.

Surface Treatment in Fusion Welding, Pressure Welding, Brazing, and Soldering. John J. Crowe and F. C. Saacke (*Colloid Chem.*, 1946, 6, 587–593; *C. Abs.*, 1946, 40, (9), 2431).—Chemical treatment of surfaces and the selection and use of fluxes are discussed.

Flying-Boat Repairs. I. W. G. Reynolds (*Aircraft Eng.*, 1947, 19, (216), 63–67).

Welded Magnesium [Aircraft] Tanks. —I, —II, —III. R. J. Cross (*Aircraft Prodn.*, 1947, 9, (99), 28–33; (100), 71–75; (101), 97–102).—(I.—) Low specific gravity, availability, weldability, specific strength, and other features of magnesium alloys are advantages for tank construction. An auxiliary tank for York aircraft having a capacity of 625 gal. has a weight : capacity ratio of 0.167 lb./gal. Another tank for Shetland aircraft has a capacity of 2200 gal. C. gives comparative information on aluminium and magnesium alloy tanks and describes the testing of tanks to meet the requirements. (II.—) For joints in the shell of magnesium alloy tanks, butt

welds are used to avoid risk of flux inclusions. The main members of the tanks are I-beams and other sections, one flange of which is butt-welded into the skin of the tank. The design and arrangement of these members and of baffles are described in detail. Sumps are provided, and these are fitted with inhibitor cartridges containing chromates so that adventitious water does not cause corrosion. (III.—) C. describes the weld test in which a round disc is welded into the centre of a disc firmly clamped round the edges, to gain information on weldability and weld-cracking tendency, if present, in magnesium alloy sheets. Hot pressings and gas welds are used extensively, tacking being avoided by the use of a two-operator technique. Hot hammering is applied to the welds to obtain good form, and rectification of adjoining parts is effected in the same way. The properties in and about the welds are improved by the correct technique. Flux residues have to be removed by thorough washing, after which the tanks are chromate-treated and varnished.—H. S.

Precision Sheet-Metal Work.—II. — (*Aircraft Prodn.*, 1946, 8, (96), 465–476).—Cf. *Met. Abs.*, 1947, 14, 29. Production of gas-turbine assemblies by Joseph Lucas, Ltd., is described and fully illustrated. Nozzle-ring assemblies and exhaust units are dealt with in some detail. High-alloy steel castings and formed pieces of sheet are used, welding being employed extensively.—H. S.

Oxy-Arc Cutting [of Nickel and Copper]. — (*Engineer*, 1947, 184, (4784), 317).—A stream of oxygen is fed through the hollow core of a coated electrode to augment the energy in a high-temp. arc. It is claimed that there is little distortion in the heat-affected zone and that the process has been successfully applied to the piercing and cutting of Monel metal, nickel, and copper, among other metals.—R. GR.

Inert-Arc Welding with Direct Current. R. P. Wyer (*Iron Age*, 1947, 160, (8), 68–70).—W. describes the technique of inert-arc welding for stainless steel, copper, aluminium, and magnesium, and gives details of current, welding speed, helium consumption, electrode size, type of gas, welding generator, electrode and electrode holders, and other equipment best suited to the process.—J. H. W.

Contact Welding. P. C. van der Willigen (*Philips Techn. Tijdschr.*, 1946, 8, (6), 161–163).—W. describes the development of arc contact electrodes, which are permanently held in actual contact with the work-piece. The core is arranged to melt away in advance of the coating. Self-ignition is obtained by incorporating part of the metal, in the form of powder, in the coating.—S. M.

Industrial Electronics. Visit to B.T.H. Rugby Works. — (*Chem. Age*, 1946, 55, (1413), 105–106).—A brief reference is made to an electronically controlled 390-kVA. spot-welding machine.—M. A. V.

Powder Welding. — (*Amer. Exporter (Indust.)*, 1946, 139, (5), s28).—Mixtures of powdered metals, together with suitable fluxes, are projected through the flame cone of a torch on to the work surface. Fuel gas, oxygen, and a processing gas are used together to control the temp. of the flame.

—H. PL.

***Metal-Ceramic Vacuum Seals.** Neal T. Williams (*Rev. Sci. Instruments*, 1947, 18, (6), 394–397).—For certain types of electrical equipment (e.g. magnetrons), insulating vacuum seals having electrical characteristics at least equal to those of glass-metal seals, but more refractory and mechanically more robust, were required. A method of joining a steatite-type ceramic to metal was developed. In order to keep the ceramic always under compression, a 50 : 50 nickel-iron alloy was chosen for ceramic-inside-metal, and a 42% nickel, 5.5% chromium, 52.5% iron alloy for metal-inside-ceramic seals. The ceramic was metallized as follows: the clean material was dipped into

1 : 1 nitric acid and washed, and then painted with a paste containing metal 30 wt.-% (molybdenum 96, iron 4%, both of 3- μ grain-size) and binder 70 wt.-% (10% nitrocellulose in ethylacetate). The parts were then fired at 1400° C. in an atmosphere containing 70% nitrogen and 30% hydrogen. The oxygen contained as an impurity in the commercial nitrogen was an essential feature of the process, in that it oxidized a small proportion of the molybdenum, which then formed the bond. After cooling, the parts were painted with a nickel paste, which was then fired on at 1000° C. in hydrogen for 15 min. After this second firing, the ceramic was hard-soldered to the metal components. Nickel-iron components were previously nickel plated. Hydrogen brazing is the preferred jointing method.—S. M.

A New Jointing Compound. A. T. B. P. Squires (*Aircraft Eng.*, 1946, 18, (213), 379–384).—After making tests and trials of proprietary jointing compounds, the Rolls-Royce Laboratory developed one for use in sealing joints against the action of oil and petrol at 100° C. Tests of various joints in Merlin engines sealed with the new preparation showed it to be effective. The substance retains its elasticity and does not become brittle or hard when maintained for long periods at temp. below its m.p. (195° C.), and is non-corrosive to steel and aluminium and copper alloys. It is insoluble in petrol, paraffin, engine lubricating oils, trichlorethylene, and the more common industrial organic solvents.—H. S.

The British Welding Research Association. Planned Research in the Welding Industry. F. A. Fox (*Metallurgia*, 1947, 36, (215), 264–267).

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***American Welding Society. Recommended Practices for Resistance Welding. (Tentative.)** Med. 8vo. Pp. 47, with diagrams. 1946. New York: The Society, 33 West 39th Street. (50 cents.)

[A collection of recommended practices for the spot- and seam-welding of low-carbon, stainless, and hardenable steels, nickel, Monel metal, and Inconel. Each recommended practice comprises a table of machine settings for current, voltage, time, pressure, and other factors, which will produce welds of specified strength in various thicknesses of materials. Explanatory text on each of the factors is included. There is a section on standard methods for testing resistance welds, which covers tests for tensile properties, shear strength, impact strength, fatigue properties, and hardness. The section includes a description of the test specimens, the equipment to be used, and the procedure to be followed. There is also a section on the control of weld quality by statistical methods.]

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XXV.—BOOK REVIEWS

Les Bases de la Résistance Mécanique des Métaux et Alliages. By P. Laurent, J. Valeur, and S. Bogroff. 25 × 16 cm. Pp. xiv + 288, with numerous illustrations in the text. 1947. Paris: Dunod.

In a rapidly developing field such as that of strength and plasticity, the need for an up-to-date text-book is particularly acute; at the same time, the vast number of poorly connected facts makes the writing of a book very difficult. This is the reason why Schmid and Boas's classical "Kristallplastizität" of 1935 has so far remained the only detailed text-book available. A sizable book on the subject was published in Germany by Kochendörfer in 1941; however, its value is much reduced by the large space given to theoretical speculations resting on a slender experimental basis. Since the boundary between the two is often insufficiently emphasized, Kochendörfer's book may be dangerous to beginners and to theoreticians seeking factual information.

The authors of the present book studied the German literature on strength and plasticity as prisoners of war in Oflag XVIIA; they lectured about the subject in the camp university, and wrote there much of the present work. This begins with a general introduction into crystallography, elasticity, and the dynamics and thermodynamics of crystal lattices (pp. 1-42); it deals with the plasticity and strength of metal single crystals (pp. 43-101); theories of plasticity and strength (pp. 102-130); fatigue and strain-hardening of single crystals (pp. 131-140); plasticity of polycrystals (pp. 141-159); Kuntze's theory of cohesive strength (pp. 160-173); plasticity and strength in technical testing; tensile, hardness, and impact testing (pp. 174-212); creep, plasto-elastic effects, and fatigue (pp. 213-265); and textures in metals (pp. 266-282). The usefulness of the book would be greatly enhanced by the inclusion of an index.

The book is well written and illustrated. Owing to the circumstances in which it arose, it contains mostly second-hand knowledge, and nobody, however able, can be expected to separate the wheat from the chaff in this field after a book-study of 4 or 5 years. Accordingly, the quality of the chapters depends greatly on the source from which they are drawn. The general discussion of crystallography, elasticity, and thermodynamics is good; so is the experimental part of single-crystal plasticity which is based on Schmid and Boas. After this, the influence of books by Kochendörfer, Smekal, and Kuntze becomes prevalent, and inaccuracies abound. It is impossible to give here a complete list of these, but a few instances ought to be mentioned.

It is stated (pp. 66-67) that plastic glide in crystals is always discontinuous (jerky). Actually, jerky extension has been observed only with a few crystals. The treatment of X-ray effects is inadequate; the fundamental difference between phenomena observed with white and with monochromatic radiation is not emphasized. The fact that aluminium shows little line broadening at room temperature is regarded as implying that aluminium crystals do not show Laue-asterism (p. 90). Two chapters on strength are devoted to Kuntze's theories, which have suffered total eclipse as a consequence of recent British and American work. Notch brittleness is attributed to the speed of the deformation, a view that was popular towards the end of the last century, but had to be abandoned when it became clear that brittle fracture also occurs in slow bending. There is no mention of the Ludwik-Davidenkov theory and of the role of tri-axial tension, which are dominating the field at present. In the treatment of creep, the basic distinction between transient (crystalline, "cold") and viscous (amorphous, "hot") creep is ignored, and the fundamental work of Andrade and R. Becker not mentioned. Instead, hazy speculations, based on Kuntze and Kochendörfer, are presented.

These examples could be multiplied for pages. A great part of the book being based on recent German literature, it reflects a sad picture of the decline which German scientific research suffered after 1932.

Throughout the book the term "acrochage" is used for "dislocation"; it has been fashioned after Dehlinger's "Verhakung". The German term, however, means hooking-on after a displacement, while this essential meaning is missing from "acrochage". Since the English "dislocation", introduced by A. E. H. Love, has been taken from geology, where the same expression is used in French, it would have been better to retain this word rather than to adopt an imperfect translation of a German word.

Many authors will find, on reading the book, that some of their best-known achievements have been ascribed to writers of text-books. Thus, Bausch's discovery that pure shear does not give rise to asterism, and Czochralski's observation that asterism is reduced by reverse deformation, are attributed to Kochendörfer (p. 90). The most striking instance, however, is that Griffith's theory of strength, the first classic in this field, as well as the famous formula of Griffith, are attributed to Snehal (pp. 106-108).

The authors apologize in the foreword for the omission of much British and American work to which they had no access in the camp. After reading the book, one wishes that they had deferred publication until after consulting English literature. As it is, the book contains much valuable material for experts who can read it with a critical eye; beginners, and scientists working in other fields, should use it with caution.—E. OROWAN.

Surface Stressing of Metals. Lectures by H. F. Moore, W. M. Murray, J. O. Almen, O. J. Horger, and P. R. Kisting. Med. 8vo. Pp. [iv] + 197, illustrated. 1947. Cleveland, O.: American Society for Metals, 7301 Euclid Avenue. (\$3.50.)

At the Twenty-Seventh National Metal Congress of the American Society of Metals held at Cleveland in February 1946, a series of five educational lectures was delivered on the effect of surface stressing on the endurance of metals under repeated loadings. These lectures have now been recorded in book form and make a useful addition to the literature on the subject. H. F. Moore first discusses the general features of fatigue failure and the effects of cold working of the surface upon the properties of the surface zone. From the fact that shot peening increases the life of fatigue specimens even when the fatigue crack starts in a region of compressive stress, it is concluded that the simple picture of residual compressive stresses resisting applied tensile stresses is not adequate, and that cold working by shot peening must actually strengthen the metal in the surface zone.

W. M. Murray gives a useful descriptive summary of the methods available for the measurement of surface stress, while J. O. Almen discusses the effect of design and internal stresses upon the fatigue of metals. It is refreshing to find that this author, an engineer, commences his article with the categorical statement that fully 90% of fatigue failures are due to faulty design and production defects, and that only the remaining 10%, due to defective material, material specifications, or heat-treatment, can be regarded as the responsibility of the metallurgist. As might be expected, he takes the engineer's viewpoint that the only satisfactory fatigue tests are those done in the full-scale machine parts, and emphasizes the importance of checking the results of such laboratory tests by comparison with service experience. He is fully aware of the difficulties encountered in attempting to apply the results of such tests in design, and the treatment which he gives will be read with interest by those who are concerned with this aspect of the subject.

In the article on "Stressing Axles and Other Railroad Equipment by Cold Rolling", O. J. Horger gives a most interesting account of the methods by which surface compressive stresses can be developed in a wide variety of parts, ranging from axles and connecting rods to threads and oil holes, in which high fatigue resistance is required. Excellent illustrations make the method of working the surface in different cases quite clear.

In the final article, P. R. Kesting describes the "Progressive Stress Damage" which is associated with the initiation and propagation of cracks in gun barrels as a result of the mechanical stresses imposed by repeated firing. During firing, the surface fibres at the bore interface are generally stressed beyond the endurance limit of the material, and a crack system develops during the normal life, which is seldom more than 10,000–20,000 rounds. The conditions in gun barrels have been simulated by hydraulic fatigue tests, and these, together with repeated bending tests, have shown that the sloping curve of the S-N diagram is moved in the direction of shorter life if the impact resistance of the steel is low, although no correlation is possible at lower stresses. Higher impact resistance not only gives increased, though still finite, life, but causes the gun barrel to fissure instead of failing by fragmentation.

The emphasis of all five lectures is on the engineering rather than the metallurgical aspect of fatigue, and most of the examples quoted refer to steel. The series as a whole, however, makes a useful survey of the field, and to the metallurgist it will be of value chiefly because the engineer's viewpoint is expressed so clearly.—A. G. QUARRELL.

Histoire de l'Aluminium. Métal de la Victoire. By Robert Pitaval. Med. 8vo. Pp. 207. 1946. Paris: Publications Minières et Métallurgiques, 86 rue Cardinet (17e). (300 francs; foreign price, 325 francs.)

From the publisher's preliminary announcement, that the history of aluminium is recounted "comme un film passionnant d'intérêt, dont l'apothéose se situe dans un ciel parsemé d'escalades" one would naturally expect a sensational, not to say flamboyant, presentation. Actually, the book is a balanced and well written account of the development of the industry, and is moreover scrupulously fair, giving due credit to the pioneers, of whatever nationalities, and to their successors who manage the industry to-day. It makes no attempt to cover the applications of the metal and its alloys, gives no account of alloy developments, and contains merely the briefest summary of the more important chemical and physical properties.

So far as the reviewer is able to judge, the account given of the development in the various countries is correct and unbiased, and, for so small a book, contains a surprising amount of detail. Statistics are, of course, included, but the pill is well sugared by the interest of the narrative.

The only criticism that can be made is that the spelling of the place names is occasionally in need of revision: one learns, for instance, that the British Isles contains such places as Montmoutshire and Dolgarrod. These, however, are minor blemishes in an excellent presentation.—H. W. L. PHILLIPS.

Conoscere l'Alluminio. By G. Simoni. 1947. Pp. 99, illustrated (lire 380); **Conoscere l'Acciaio.** By I. Bartoli and F. Masi. 1945. Pp. 94, illustrated (lire 350). 23.5 × 17 cm. Milano: Poligono Società Editrice, Via Cesare Battisti 1.

These books give a brief account of the history of the respective industries, followed by a copiously illustrated description of modern fabrication processes, covering all stages from the mining of the ore to the finished product. Sections are included on testing, typical properties, micrography, and applications. The presentation is necessarily brief and is "popular" in character, and the information given is, in general, accurate. A few of the figures quoted should be revised in later editions, as for instance 678° C. for the melting point of aluminium.

—H. W. L. PHILLIPS.

Electronic Methods of Inspection of Metals. Lectures by H. F. Hamburg, J. L. Saunderson, R. S. Segsworth, E. O. Dixon, C. M. Lichy, C. S. Barrett, and H. T. Clark. Med. 8vo. Pp. iii + 189, with 22 illustrations. 1947. Cleveland, O.: American Society for Metals, 7301 Euclid Avenue. (\$3.50.)

This book contains the substance of a series of seven lectures given to members of the American Society for Metals during the Twenty-Eighth National Metal Congress held at Atlantic City in November 1946. A very free interpretation has been given to the term "Electronic Methods", and the subjects covered range from the resistance wire strain-gauge to the Cyclograph and the measurement of steel bath temperatures by quick-immersion techniques. The treatment throughout is purely descriptive, and the most complete chapters are those on "Spectrochemical Analysis of Metals and Alloys by Direct Intensity-Measurement Methods", by J. L. Saunderson, and "The Electron Microscope and Its Application to Metals", by C. S. Barrett. The first of these, after outlining the basis of spectrochemical analysis and the advantages to be gained by replacing the photographic plate by a direct-recording method, describes the electron-multiplier photo-cell and its use in both the scanning and integrating methods of analysis. Details are given of the performance of the direct-recording equipment used by the author at the Dow Chemical Company.

In his well illustrated article, C. S. Barrett gives a review of current practice in the application of electron microscopy to metals, and his clear descriptions of the various replica methods should prove useful to many who wish to know more about the technique without practising it. The author does not attempt to minimize the difficulties associated with electron metallography, but discusses many of the applications to date and gives a useful selected *bibliography*.

Articles on the Cyclograph, supersonic methods of testing, and the determination of seams in steel by magnetic analysis consist chiefly of examples of the successful use of these techniques rather than of descriptions of the methods themselves. No doubt some readers will find this useful because it may suggest possible methods of investigating their own problems, but the general reader is left with the feeling that this is an ill-assorted collection of articles which is unlikely to fill any real need, and which, for the most part, do not justify the excellent production standard usually associated with A.S.M. publications.—A. G. QUARRELL.

Cold Working of Brass, with Special Reference to Cartridge (70 : 30) Brass.

By L. E. Gibbs. Med. 8vo. Pp. vi + 104, with 54 figures, including 6 illustrations in colour. 1946. Cleveland, O.: American Society for Metals. (\$2.00.)

This book is published in a neat and good binding. The printing is on good paper, in a bold and clear type, and the book is well furnished with diagrams and illustrations. The micrographs, which include some Kodachrome photography, are particularly clear. The index is comprehensive, but it might lead the reader to expect much more complete treatment than is given in the 104 pages which comprise the book. The style of writing is good, and the English clear and precise.

Coming now to the subject of the book, the reader who expects to find detailed information upon the cold working of brass, or even especially of 70 : 30 brass (as indicated in the subtitle), will be disappointed. No information at all is given on the details of cold working, although the principles underlying that subject are very clearly dealt with. It is somewhat difficult to see for what class of reader the book was intended, as the metallurgical student will already have access to the information in general metallurgical text-books.

On matters of detail, the influence of ready-to-finish grain-size is well brought out, and its importance very properly insisted on. The most interesting chapter is No. 3, dealing with 20-mm. cartridges. The micrographs, in this case, are particularly good, but the magnification is not always stated.

In Chapter 5, on Season Cracking, the detailed statement on the effect of amines on the cracking of 70 : 30 brass seems hardly suitable for this type of book.

In Chapter 6, the reference to Fig. 28 should be omitted, as it does not refer to that Figure in the present book.

The colour photographs are very good, but in some cases they appear to have been inserted more because of their excellence than because of their relevance to the subject of the book.

While the publication of this book could be justified in the United States, where paper and materials are more plentiful, this would hardly be the case in England, under our own austerities.—E. A. BOLTON.

Dictionary of Machine-Shop Terms. By Arthur C. Telford. $5\frac{1}{4} \times 3$ in. Pp. [vi] + 292. 1946. Chicago, Ill.: American Technical Society, Drescel Avenue and 58th Street; London: Technical Press, Ltd., Gloucester Rd., Kingston Hill, Surrey. (5s. net.)

The definitions in this American dictionary are terse and generally very clear, but many of the words included are by no means peculiar to the engineering trade. The omission of such commonplace words as "period", "perfection", and "perform", to quote three that appear on the same page, would have made room for the inclusion of genuine engineering terms such as "toolmakers' button", "tommy bar", and the apparently contradictory "taper parallel".

In the preface to the dictionary, stress is laid on the fact that every trade has a language of its own; it is equally true that, although English is the common tongue of America and Britain, the engineering terms in the two countries are often vastly different. For example, the American use of "bulldozer" for "forging press", "frozen" for "seized", and "hay" for "swarf" would confuse the English reader.

However, despite these few criticisms, this pocket-sized volume covers a wide field and should be of considerable help to a newcomer to the American engineering trade.—T. R. OAKLEY.

Welding Symbols. By Vincent C. Gourley. Demy 8vo. Pp. ix + 115, illustrated. 1947. Milwaukee, Wis.: Bruce Publishing Company. (\$2.50.)

The review of any book, whether technical or otherwise, should consider first the plot or subject matter, and second the style or method of presentation, the latter, in the case of

technical books, duly taking into account illustrations, examples, tables, &c., supplementary to the text. In the present case, however, the subject matter is purely the use of an already-existing American system of nomenclature, the merits and disadvantages of which have been frequently reviewed in the past; and it is, therefore, logical for the method of presentation to be considered as the primary object of the review.

The book is divided into three parts, the first consisting only of one brief chapter summarizing the "dos and don'ts" for draughtsmen, the second dealing with arc- and gas-welding symbols, and the third being devoted to symbols used in resistance welding. Being an American publication describing an American system, it is no doubt primarily intended for American use, which explains why some of the "dos and don'ts" are at variance with British practice, at any rate in so far as structural work is concerned; at the same time, this can scarcely be a cause of criticism, for the same reason.

The addition of two Appendices, clearly showing the difference between welds and joints, would appear to indicate that there is, in this respect, some confusion in the U.S.A. as well as in this country; and the author is to be congratulated on clarifying the position and thus removing the main source of frequent misunderstandings. The inclusion of an index, an uncommon feature in a volume of this size, is another welcome addition which will make this work a reference book as well as a text-book.

The subject matter is described in simple and direct language and the text is profusely illustrated throughout. The illustrations, moreover, are invariably in two parts: the first showing how the welds and joints will be seen on the drawing, and the second providing a visual explanation by means of an isometric sketch. There is thus no possibility of misunderstanding the way in which the symbols are intended to be used, and there is little doubt that this method of presentation will be welcomed by all the many different types of students for whom the book is intended.

The welding symbols, a description of which forms the subject of this book, have been put forward by the American Welding Society and are said to be accepted in the U.S.A. as a standard for mechanical and structural drawings. The system has been in existence for some time and has often been described, criticized, and referred to in the technical press in this country as well as in the U.S.A. Its merits and disadvantages are still distinctly controversial matters so far as this country is concerned, and it seems doubtful whether this system would be acceptable in England because of the complete re-education of both drawing-office and shop personnel which such acceptance would necessarily entail. This opinion would appear to be substantiated by the fact that a somewhat similar system, introduced in this country as a British Standard in 1933, has found only a very limited application, and the whole subject of welding symbols and nomenclature is at present under revision by the British Standards Institution.—S. M. R.

Modern Assembly Processes: Their Development and Control. By J. L. Miller. With a foreword by E. A. Watson. Second edition, revised. Demy 8vo. Pp. xii + 199, with 170 illustrations. 1946. London: Chapman and Hall, Ltd. (18s. net.)

It is encouraging to find that a revised edition of this excellent primer, reviewed originally in *Met. Abs.*, 1941, 8, 355-356, has been needed. The opportunity has been taken to incorporate an account of some recent developments in welding and riveting methods and to enlarge all the chapters slightly. The sections on soft and hard soldering and brazing, though now more detailed, are still perhaps not treated so extensively as they should be for engineering students. In general, the book remains an excellent introduction to the study of mass-production methods of joining small parts, clearly written, and noteworthy for the attention given throughout by the author to first principles.—J. C. CHASTON.

Vocabulaire Technique Anglais-Français et Français-Anglais: Métallurgie, Mines, Électricité, Mécanique, Sciences. By Francis Cusset. Second edition. Foolscap. 8vo. Pp. 591. 1947. Paris: Éditions Berger-Levrault, 5 rue Auguste-Comte. London: H. K. Lewis and Company, 136 Gower Street, W.C.1. (12s. 6d.)

The compiler has done a useful service in preparing this small dictionary of technical terms, and the ground it covers is probably adequate for the majority of users. Unfortunately, however, it lacks completeness. For instance, in a dictionary published after the war it is strange to find no mention of "isotopes", "neutrons", or "fission"; such commonly used terms as "filage à la presse", "alliage mère", and "sidérurgique" are overlooked; and that stumbling block of our youth, "hydrogen peroxide", is ignored. The reader will also be surprised to learn that the only kind of "phial" recognized is the "Leyden jar", and that the normal English equivalents of "être en équilibre" are "to be in equipoise" or "to librate". Proof reading also leaves a little to be desired; we are, for instance, given such phonetic renderings as "clockwise" and "bleeching".—H. W. L. PHILLIPS.



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