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LIEUT.-COLONEL S. C. GUILLAN

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Sir William Henry White, K.C.B., LL.D., D.Eng., Sc.D., F.Inst.Met., F.R.S., 1908–1910 (*deceased*).

Sir Gerard Albert Muntz, Bart., 1910–1912 (*deceased*).

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Professor Alfred Kirby Huntington, A.R.S.M., 1913–1914 (*deceased*).

Engineer Vice-Admiral Sir Henry John Oram, K.C.B., F.Inst.Met., F.R.S., 1914–1916 (*deceased*).

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Professor-Emeritus Thomas Turner, M.Sc., A.R.S.M., F.Inst.Met., 1924–1926.

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William Robb Barclay, O.B.E., F.Inst.Met., 1936–1938 (*deceased*).

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Baillieu Research Laboratory, The University, Melbourne, N.3, Victoria.

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O. W. Ellis, D.Sc., Ontario Research Foundation,
43 Queen's Park, Toronto 5, Ont.

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Professor P. A. J. Chevenard,
39 boulevard Raspail, Paris 7e.

India.

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Kennaway House, Proctor Road, Girgaon, Bombay.

South Africa.

G. H. Stanley, D.Sc., A.R.S.M.,
24 Duncombe Road, Forest Town, Johannesburg, Transvaal.

Sweden.

Professor Dr. C. A. F. Benedicks, Metallografiska Institutet,
Drottninggatan 95 B., Stockholm.

Switzerland.

Professor Dr.-Ing. A. von Zeerleder, Rosenbergstrasse 25,
Neuhausen a./Rheinfall.

Union of Soviet Socialist Republics.

Professor N. W. Ageew, Met.Eng., Dr.Ch.Sc., Ulitsa Frunze 9/12,
kv. 2, Moscow 19.

United States of America.

Cyril Stanley Smith, D.Sc., Institute for the Study of Metals, University of
Chicago, Chicago 37, Ill.

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THE INSTITUTE OF METALS

MINUTES OF PROCEEDINGS

ANNUAL GENERAL MEETING

The Thirty-Ninth Annual General Meeting of the Institute of Metals was held in the Halls of the Institution of Civil Engineers and of the Royal Institution of Chartered Surveyors, Great George Street, London, S.W.1, on Wednesday, Thursday, and Friday, 5, 6, and 7 March 1947. The President, Colonel P. G. J. Gueterbock, C.B., D.S.O., M.C., T.D., D.L., J.P., M.A., occupying the Chair.

Wednesday, 5 *March* 1947.

The President, in opening the meeting, said: This is our first peace-time Annual Meeting, and we had hoped that it would be well attended on a scale worthy of the Institute, but the weather is against us. I offer a hearty welcome to you all, and I should like to extend a special welcome to any of our Service members who have come here this morning, and also to those who have come back from the Services and returned to their peace-time work, whether they are here or not. We hoped to have some members from overseas with us, and we are glad to welcome Dr. Rohner, from Switzerland.

With regard to the staff, I know that you will wish to extend a cordial welcome to Colonel Guillan, who has now returned to us, and who has thrown himself heart and soul into his peace-time work.

I have had a telegram from Sir William Griffiths regretting his inability to be present and sending his best wishes for a most successful meeting.

The Minutes of the previous General Meeting, held in London on 10 and 11 September 1946, were taken as read and signed by the Chairman.

Report of Council.

The President, in moving the adoption of the Report of Council,* said: I regret that, owing to the ban on the printing and distribution of periodicals, the Report of Council has not been in your hands before this meeting, and that you have not been able to study it as you would normally have done. Copies have been distributed to you this morning and I must ask you to take it as read.

It is not an unsatisfactory record of the activities of the Institute, in spite of what has been a rather difficult period of post-war adjustment—a period which is by no means at an end, and which I am afraid may affect our activities for the next twelve months. We have not, perhaps, achieved all that we could have wished, but, although that may be disappointing, it is no reflection on the energies and the zeal of your Council and staff; they have tried their utmost and have done noble work. You will agree, I am sure, that it is always well to fix a target rather beyond what you hope to achieve, and that is what we have done.

We have published during the year a number of original papers of great

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* See this volume, pp. 421–426.

merit, and I am particularly glad that our Local Sections are all operating again very successfully.

You would probably like to know the latest position with regard to the Mond Nickel Fellowships. The foundation was announced twelve months ago, and the legal documents have been approved by all the five operating societies and by The Mond Nickel Company, Ltd. The formality of signature will be completed in the very near future, and it ought to be possible in a few weeks' time to make a public announcement and invite applications for Fellowships with a view to awarding at least one or two during the current year.

So far as other matters are concerned, the Report is on normal lines and speaks for itself.

Dr. C. J. **Smithells**, M.C., M.Sc. (Member of Council): I beg to second the motion. I used to look on the Report of Council as an extraordinarily dull document; it does not really indicate the enormous amount of work which the members of the Council and the staff do. Before I became a member of the Council I had very little respect for the Annual Report, but I now appreciate the vast amount of work which is carried out.

I should like to draw attention to one thing which the Meetings Committee have done. We have tried, I hope successfully, to meet the wishes of the members with regard to the present meeting. At the last Autumn Meeting we held two sessions concurrently, in order to be able to deal with more papers, but there was a feeling on the part of many members that they wished to be in two places at the same time. On this occasion, therefore, we have decided to take only two or three papers at each session, and we are debarring authors from reading their papers or presenting them at any length. This will give much greater opportunity for discussion. We intend to give each author at least ten minutes in which to reply. We have also added a day after the May Lecture for more papers. We want to give members an opportunity to discuss every discussable paper which is presented, and we hope that we have found a solution to this problem, because there has been a good deal of criticism in the past.

The motion was put to the meeting and carried unanimously.

Report of the Honorary Treasurer.

Mr. H. S. **Tasker**, B.A. (Honorary Treasurer): In submitting the accounts, and my report * thereon, for the financial year ended 30 June 1946, it is necessary for me to make only a few general remarks; I need not go into the details of the accounts. There is nothing of great moment to which to call attention so far as the past year is concerned, and perhaps the best thing that I can do is to read part of my report.

(The Hon. Treasurer then read the last four paragraphs of his report, and continued:)

That is the simplest way of putting before you the position of the Institute as it stands to-day. The Council is giving most earnest consideration to the situation; meanwhile, we have a certain amount of breathing space owing to the existence of the War Emergency Fund, which amounts to about £7000. I think that that will tide us over until we can arrange for new sources of revenue. That War Emergency Fund was provided by the generosity of many industrial firms, and we shall have to be very careful to see that we do obtain further sources of income by the time that it is exhausted. I am

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* See this volume, pp. 427–431.

very anxious that members should understand the position, and I have pleasure in moving the adoption of the accounts.

Mr. J. CARTLAND, M.C., M.Sc. (Vice-President): I beg to second the motion. I think that the position is a very satisfactory one. We have realized the situation for some time, and although we have accumulated funds there has been an increasing drain on them as the facilities are restored for publication. We anticipated that that would be the case.

If you look around you, you will see that the cost of everything has increased; you will find very few things the cost of which has not gone up by at least 50 per cent. The subscription to the Institute of Metals is one of those which has not risen; we are now giving the same service—and, in fact, an improved service—for a subscription which has been in force since 1920. Whether we shall be able to maintain that position or not is a matter which the Council must decide.

I should like to couple my seconding of this motion with the proposal of a vote of thanks to the Hon. Treasurer, Mr. Tasker, who combines the most meticulous attention to detail with a broad view of future policy.

The PRESIDENT: I endorse what Mr. Cartland has said of the great debt which we owe to Mr. Tasker for the good work which he is doing in looking after the financial side of the Institute. I am glad to see that Mr. John Fry, one of our past Hon. Treasurers, is here to-day. He will appreciate what an arduous task it is, especially in these times of uncertainty.

The motion was put to the meeting and carried unanimously.

RE-ELECTION OF AUDITORS.

On the motion of Mr. JOHN FRY (Fellow), seconded by Lieut.-Colonel Sir JOHN GREENLY, K.C.M.G., C.B.E., M.A. (Past-President), Messrs. Poppleton and Appleby were elected Auditors for the ensuing year.

ELECTION OF OFFICERS FOR 1947–48.

The SECRETARY announced that the undermentioned members had been elected to fill vacancies on the Council for 1947–48:

President:

Colonel P. G. J. GUETERBOCK, C.B., D.S.O., M.C., T.D., D.L., J.P., M.A.

Vice-President:

JOHN CARTLAND, M.C., M.Sc.

Members of Council:

Professor LESLIE AITCHISON, D.Met., M.Sc.
JOHN ARNOTT.
MAURICE COOK, D.Sc., Ph.D.
A. J. MURPHY, M.Sc.

The PRESIDENT: I should like to say how much I appreciate the honour of being elected for a second year of office. The confidence which you have thus shown in me will be a great encouragement to continue my work and my efforts to increase the usefulness of the Institute and the well-being of the members and of the industry which we serve. I feel sure that Mr. Cartland, our new Vice-President, and the new Members of Council, would wish me on their behalf to thank you for the way in which you have received the announcement of their election. I can assure you that all of us will do our very best to serve the Institute in every possible way.

VOTE OF THANKS TO THE RETIRING OFFICERS.

The PRESIDENT: Under our rules, certain Members of Council have to retire by rotation. I regret to have to announce that as a result Mr. G. L. Bailey retires as a Vice-President, and that Sir Clive Baillieu, Dr. A. G. C. Gwyer and Dr. C. Sykes retire as Members of Council. Mr. Bailey's services will not be lost to us, because he has been appointed an Honorary Member of Council, to represent the Institution of Metallurgists. Although he will therefore continue to serve us in this capacity, I would wish his name to be included in the vote of thanks which I now have pleasure in proposing to these gentlemen for the great services which they have rendered during their terms of office.

The vote of thanks was carried with acclamation.

ELECTION OF MEMBERS, ASSOCIATE MEMBERS, AND STUDENT MEMBERS.

The SECRETARY announced that since the last General Meeting the undermentioned 194 members had been elected.

ELECTED ON 20 NOVEMBER 1946.

As Ordinary Members.

BALICKI, Marian, Dr. Ing.(Met.), Temporary Professor, Polish Board of Technical Studies, London.

BARLOW, Charles David, Kingswinford, Staffordshire.

BJÖRKMAN, Per O, Metallurgist, Laboratories, ASEA, Västeras, Sweden.

BOTH, Gerardus Jan Jacobus, Jr., Mech. Eng., General Manager, N.V. Nederlandsche Aluminium Maatschappij, Hilversum, Holland.

BROOKS, Richard Rodney, Metallurgist, Commonwealth Aircraft Corporation Pty., Ltd., Fisherman's Bend, Port Melbourne, Australia.

CAMPBELL, George, B.Sc., A.R.T.C., Metallurgist, Plessey Company, Swindon, Wiltshire.

CLARKE, Sydney George, Ph.D., D.Sc., Scientific Investigator, Armament Research Department, Woolwich, London.

COHEUR, Professor Pierre, Associate Professor of Physical Metallurgy, University of Liège, Belgium.

COXON, Wilfred Francis, M.Sc., Ph.D., Technical Consultant, London.

DAVIS, George Leonard, B.Sc., Metallurgist, Tungsten Manufacturing Company, London.

DHAR, Murli, B.Sc., Metallurgist, Laboratories, Bombay, Baroda and Central India Railway, Ajmer, India.

FOGG, Albert, M.Sc., Director of Research, Motor Industry Research Association, Brentford, Middlesex.

HALE, Stanley, B.Sc., B.A., Chemical Engineer, National Metal Company, Toronto, Ont., Canada.

HANSON, Victor Cyril, Technical Engineer and Administrator, Coopers Mechanical Joints, Ltd., Slough, Buckinghamshire.

HAYES, Frank E., Assoc.Met., Metallurgist, Ministry of Supply, London.

JONES, Edward Henry, Manager, Capper Pass and Son, Ltd., Bristol.

Jordan, Neville Thomas, Assistant Chemist, De Havilland Aircraft Company, Ltd., Edgware, Middlesex.

Lamb, John, B.Sc., Metallurgist, Dorman, Long and Company, Ltd., Middlesbrough, Yorkshire.

Larroudé, Enrique, Civil Engineer, Compañia Anónima Basconia, Bilbao, Spain.

McDermid, Ian Douglas, Dipl. R.T.C., Student of Metallurgy, Royal Technical College, Glasgow.

Maréchal, Marcel, Ing. des Mines Electricien, Directeur des Usines d'Auby de la Compagnie Royale Asturienne des Mines, Auby (Nord), France.

Niewiadomski, Cyryl, Dipl. Ing., Technical Manager, Walcownie Metali, Spółka Akcyjna, Dziedzice, Poland.

Öhman, Einar, Chief Metallurgist, A.B.W. Dan Bergman, Södertälje, Sweden.

Partridge, Geoffrey Beech, Production Metallurgist, Elektron Foundries, Birmingham Aluminium Casting (1903) Company, Ltd., Smethwick, Staffordshire.

Penrod, R. Earl, Engineer of Tests, Bethlehem Steel Company, Gautier Division, Johnstown, Pa., U.S.A.

Ramamurthy, Subramanya, B.Sc., Research Metallurgist, Jyoti, Ltd., Post Alembic Chemical Company, Baroda, India.

Smoliński, Flight-Lieut. Józef, Inz. Mech., Metallurgist, Royal Aircraft Establishment, Farnborough, Hants.

Stewart, James McGregor, Metallurgist, Douglas (Kingswood), Ltd., Bristol.

Stokes, Reginald, Chief Examiner, A.I.D. Test House, Ministry of Supply, Harefield, Middlesex.

Swift, Roy Erwin, M.S., Consulting Engineer, Metallurgy and Mining, New Haven, Conn., U.S.A.

Taylor, Captain Frederick Thomas, Inspecting Engineer and Assessor, B. Taylor and Son, Beeston, Nottinghamshire.

Turner, Captain Argo John Morrison, Staff Captain, Directorate of Engineer Stores, War Office, London.

Watson, Trembath, Works Metallurgist, Clyde Engineering Company, Granville, N.S.W., Australia.

Whatmough, Edwin Charles, Chief Sales Engineer and Assistant General Manager, The Head Wrightson Machine Company, Ltd., Middlesbrough, Yorkshire.

As Student Members.

Allen, Norman, Metallographist, Research Department, English Electric Company, Ltd., Stafford.

Allen, Robert Charles, A.M.C.T., Junior Metallurgist, Metropolitan-Vickers Electrical Company, Ltd., Manchester.

Cameron, James Adam, B.Sc., Dipl. R.T.C., Metallurgist, Magnesium Elektron, Ltd., Manchester.

Cox, (Miss) Gwendoline Mary Lily, B.A., Metallurgical Investigator, Aluminium Laboratories, Ltd., Banbury, Oxfordshire.

Deeming, Arthur Geoffrey, Research Assistant in Metal Powders, Staveley Coal and Iron Company, Chesterfield.

Goddard, Dennis Raymond, B.Sc., Research Student in Physics, Physics Department, The University, Birmingham.

Grant, John Donald, Student, King's College, Cambridge.

Greenough, Arthur Peter, Student, Queens' College, Cambridge.

Harrington, John Frederick, W. H. Allen, Sons and Company, Ltd., Bedford.

Haworth, John B., Student of Metallurgy, The University, Sheffield.

HAYNES, Frank Grenville, B.Eng., Junior Metallurgist, Metropolitan-Vickers Electrical Company, Ltd., Manchester.

HOOPER, Brian, Chemist and Metallurgist, Hard Metal Tools, Ltd., Wolverhampton, Staffordshire.

HOULDCROFT, Peter Thomas, Junior Research Metallurgist, British Welding Research Association, London.

IRVINE, Kenneth James, B.Sc., Assistant Lecturer in Metallurgy, The University, Leeds.

JAMES, Victor Leonard, Metallurgist, S. Smith and Sons, Slough, Buckinghamshire.

KING, Christopher Stanley, Research Assistant, Murex, Ltd., Rainham, Essex.

MA, Peter Henry, Trainee (Metallurgy), Rolls-Royce, Ltd., Derby.

McHUGH, Thomas, B.Sc., Metallurgist, Low Moor Alloy Steelworks, Ltd., Bradford, Yorkshire.

McINTYRE, Malcolm, Assistant Metallurgist, Standard Telephones and Cables, Ltd., London.

MILLS, Joseph Frederick, B.A., Student of Metallurgy, St. John's College, Cambridge.

OSBORNE, David Gerald, Student, Battersea Polytechnic, London.

PARISH, John R., B.A., Metallurgical Technician, Fry's Diecastings, Ltd., London.

ROBERTS, Joseph Patrick, B.A., Junior Scientific Officer, Royal Aircraft Establishment, Farnborough, Hampshire.

SACHS, Kurt, B.Sc., Research Metallurgist, The Mond Nickel Company, Ltd., Birmingham.

STANSFIELD, Lawrence, B.Met., Metallurgist, Research Department, English Electric Company, Ltd., Stafford.

TIMLIN, Edward John Bogue, B.A., Metal Sales, Imperial Chemical Industries, Ltd., London.

WALKER, Frank, Assistant Metallurgist, British Insulated Callenders Cables, Ltd., Prescot, Lancs.

WALKER, Lancelot Henry, B.Sc., Metallurgy Department, King's College, University of Durham, Newcastle-on-Tyne.

WATKINS, Brychan, Student, University College, Swansea.

WELSH, Norman Clifford, Student, King's College, University of Durham, Newcastle-on-Tyne.

ELECTED ON 30 DECEMBER 1946.

As Ordinary Members.

BOEX, John Justin, Anodizer and Processor of Aluminium, Oxford.

BRADLEY, John Newsum, B.Sc., A.R.S.M., Metallurgist, M.E.D., H.M. Dockyard, Portsmouth, Hampshire.

CASTRO, René Jacques, Ing.E.C.P., Head of Laboratories, Aciéries Électriques d'Ugine, Ugine (Savoie), France.

DASS, J., B.Sc., Chief Engineer, The Jaipur Metal Industries, Ltd., Jaipur, India.

GEACH, George Alwyn, M.Sc., Ph.D., Research Worker, Research Department, Metropolitan-Vickers Electrical Company, Ltd., Trafford Park, Manchester.

GREENFIELD, Stanley, Chemist, Stewarts and Lloyds, Ltd., Bilston, Staffordshire.

HOSE, Alfred G., B.S., Chemist, Lindsay Wire Weaving Company, Cleveland, O., U.S.A.

JENKINSON, Horace Arnold, Director, W. G. Jenkinson, Ltd., Sheffield.

LEDWITH, Richard John, B.Sc., Chemist, Cellon, Ltd., Kingston-on-Thames, Surrey.

McLEOD, John M., Ph.D., B.Sc., A.R.T.C., Lecturer in Metallurgy, Royal Technical College, Glasgow.

MURRAY, William Alexander, Technical Representative, Bound Brook Bearings (G.B.), Ltd., Birmingham.

NEWBY, Harold Thomas, Chief Chemist, Birmingham Aluminium Casting (1903) Company, Ltd., Birmingham.

PAÏDASSI, Jean, Ing. Civil Mines, L. es Sci. phys., Research Engineer, Ste. des Aciéries de Longwy, Paris, France.

As Associate Member.

BANERJEE, Bani R., B.Met., Graduate Student in Metallurgy, Yale University, New Haven, Conn., U.S.A.

As Student Members.

ANDREWS, Douglas Roy, Metallurgist and Industrial Radiographer, Bristol Aeroplane Company, Ltd., Aircraft Division Laboratory, Bristol.

ATTERTON, David Valentine, Undergraduate, Peterhouse, Cambridge.

AYTEKIN, Veli, B.Sc., Metallurgical Department, The University, Birmingham.

BAKER, John Pearce, Undergraduate, Queen's College, Cambridge.

BERGMANN, Josef, Student, Battersea Polytechnic, London.

BROOK, Greville Bertram, Student of Non-Ferrous Metallurgy, The University, Sheffield.

BROWN, Anthony Reginald George, B.Sc., Student, University College, Cardiff.

BUCKNELL, George Leonard, Student, Queens' College, Cambridge.

BUTLER, James Morris, Student of Metallurgy, Downing College, Cambridge.

CHATTERJEE, Saurindra Nath, B.Sc., Student, Battersea Polytechnic, London.

CLARKE, Cyril, Student of Metallurgy, The University, Birmingham.

CROSBY, Arthur, Metallurgist, No. 3 District Censorship Station, B.A.O.R., Germany.

DAVIES, David Robson Glyn, B.Sc., Chief Metallurgist, Richard Thomas and Baldwins, Ltd., near Pontypool, Monmouthshire.

DAVIS, Alan George, Student, King's College, Cambridge.

DOWN, Richard Francis, Student of Metallurgy, University College, Swansea.

DUCKWORTH, Walter Eric, Metallurgist, Research Department, English Electric Company, Ltd., Stafford.

DUTT, Ranjit, B.Sc., Student of Metallurgy, Battersea Polytechnic, London.

ELLIOTT, F. Bertram, Student of Metallurgy, The University, Sheffield.

EVANS, Howell Thomas, Student of Metallurgy, University College, Swansea.

FEAR, Geoffrey Charles, Student of Metallurgy, University College, Swansea.

FRANKAU, Anthony McDougall, B.A., Student of Metallurgy, Cambridge University.

FROST, Brian Reginald Thomas, Student of Metallurgy, The University, Birmingham.

GIBBONS, Donald Frank, Student of Metallurgy, The University, Birmingham.

GREGORY, Eric, Student, Cambridge University.

GRIFFITHS, George James Gordon, Student of Metallurgy, The University, Liverpool.

HANSON, Cedric Charles, B.Sc., Assistant Metallurgist, Ever-Ready (G.B.), Ltd., Wolverhampton, Staffordshire.

HARRIS, John Geoffrey, Student of Metallurgy, The University, Birmingham.

HAYWOOD, John Wilford, Student, Pembroke College, Cambridge.

HOLLYHEAD, Leonard Caines, Student of Metallurgy, The University, Birmingham.

HOLT, Lawrence Guest, Student, University College, Swansea.

HOOKER, Eric John, Student of Metallurgy, Cambridge University.

HORSEFIELD, Henry Brian, Student of Metallurgy, The University, Liverpool.

JACKSON, Richard S., Student, Royal School of Mines, London.

JOHNSTON, Thomas Lewis, Student of Metallurgy, The University, Liverpool.

KERSTING, Philip Eric, Student, Battersea Polytechnic, London.

LEEWORTHY, Frederick Charles, Student of Metallurgy, University College, Swansea.

MANNING, Ivor, Metallurgist, David Brown and Sons (Huddersfield), Ltd., Lockwood, Huddersfield, Yorkshire.

OLIVER, Dennis Stanley, Student of Metallurgy, The University, Birmingham.

PRATT, John Nevitt, Student of Metallurgy, The University, Birmingham.

PRINCE, Bernard Williamson, Junior Metallurgist, David Brown and Sons (Huddersfield), Ltd., Penistone, near Sheffield.

PUGH, Gwilym, Student of Metallurgy, University College, Swansea.

RADCLIFFE, Stanley Victor, Student of Metallurgy, The University, Liverpool.

READ, Norman William, B.Sc., Assistant Metallurgist, Research Department, David Brown and Sons (Huddersfield), Ltd., Huddersfield, Yorkshire.

RICKARD, Arthur John, Student of Metallurgy, The University, Birmingham.

SHERMAN, Norman W. J., Electronic Test Assistant, Research Laboratories, Sargrove Electronics, Ltd., Walton-on-Thames, Surrey.

STORMONT, Ronald Stephen, Metallographer, James Booth and Company, Ltd., Birmingham.

THOMAS, Frank Maurice, Student of Metallurgy, University College, Swansea.

THOMAS, William John, Student of Metallurgy, University College, Swansea.

TODD, Brian, Student of Metallurgy, The University, Liverpool.

TRUSCOTT, Peter, Student of Metallurgy, University College, Swansea.

TUCK, Michael John, Student of Metallurgy, University College, Swansea.

TUCKER, Gerald Edward George, Student of Metallurgy, University College, Swansea.

TÜRKDOĞAN, Ethem Tuğrul, Student of Metallurgy, The University, Sheffield.

WILLIAMS, Albert Etheridge, B.Sc., Research Metallurgist, Royal Aircraft Establishment, Farnborough, Hampshire.

WOLSTENHOLME, Gordon Alan, Student of Metallurgy, Cambridge University.

YOUNG, John Gibson, Student of Metallurgy, The University, Birmingham.

ELECTED 23 JANUARY 1947.

As Ordinary Members.

ARBLASTER, Harry Elphinstone, B.Met.E., Chief Metallurgist, Stokes and Sons, Brunswick, Vict., Australia.

BUSHROD, Charles James, M.Sc., Chief Chemist, George Angus and Company, Ltd., Bentham, near Lancaster.

CONRADI, Ingeniør Lorentz Angell, Research Chemist, A/S Årdal Verk, Oslo, Norway.

FEWKES, Henry Chitty, Works Engineer and Production Supervisor, The Tungsten Manufacturing Company, Ltd., London.

HARRIS, Geoffrey Thomas, M.A., Principal Physicist, Wm. Jessop and Sons, Ltd., Sheffield.

HOWE, Robert Morris, B.Sc., Research Physical Metallurgist, Aluminum Laboratories, Ltd., Kingston, Ont., Canada.

JODKO, Herman, Dipl.Eng., Technical Manager, Zjednoczenie Przemysłu Metali Niezelaznych, Katowice, Poland.

KAPUR, Ram Narain, B.Sc. (Met.), Technical Adviser, Department of Commerce, Indian Tariff Board, Bombay, India.

McCRACKEN, Graeme, B.A.Sc., Metallurgist, Aluminum Company of Canada, Ltd., Shawinigan Falls, Que., Canada.

MISRA, Virendra Nath, B.Sc., Refinery Superintendent, Jaipur Metal Industries, Ltd., Jaipur, India.

PRITCHARD, Ralph, Chief Chemist, Shelton Iron, Steel and Coal Company, Ltd., Etruria, Stoke-on-Trent, Staffordshire.

RASTRICK, Professor Ronald John, B.E. (Mech.), Professor of Mechanical Engineering, Canterbury University College, Christchurch, New Zealand.

STAUFFER, Robert A., B.A., Research Metallurgist, National Research Corporation, Boston, Mass., U.S.A.

STEPIŃSKI, Włodzimierz, Dipl.Eng., Technical Manager, Zjednoczenie Przemysłu Metali Niezelaznych, Katowice, Poland.

As Student Members.

ANDREW, Alfred Tresham, B.A., Research Metallurgist, David Brown and Sons, Ltd., Penistone, near Sheffield.

BILBY, Bruce Alexander, B.A., Research Worker, Metallurgy Department, The University, Birmingham.

BOWLES, Paul John, Student of Metallurgy, The University, Birmingham.

BROXTON, Ernest Samuel, Assistant Metallurgist, George Morgan, Ltd., Longbridge, Birmingham.

CARR, Anthony Louis, Assistant Lecturer and Demonstrator in Metallurgy, University College, Cardiff.

JOHNSTON, Keith Bray, Metallurgical Chemist, A.E.C., Ltd., Southall, Middlesex.

KENT, Donald, Metallurgical Chemist, Evered and Company, Smethwick, Staffordshire.

OLDS, Bernard Francis, Student, Sidney Sussex College, Cambridge.

TUCKER, John Colin, Student, Battersea Polytechnic, London.

ELECTED 4 MARCH 1947.

As Ordinary Members.

ADAM, William Atkinson, Chief Engineer, S.A., The Anglo-Argentine Iron Company, Ltd., Buenos Aires, Argentina.

BROOKS, William Barker, Metallurgist, Alloys Development Company, Pittsburgh, Pa., U.S.A.

CUNNINGHAM, Robert Leonard, M.Sc., Ph.D., In charge of Physical Section, Research Laboratories, Bureau of Mines, Department of Mines and Resources, Ottawa, Canada.

DE DECKER, H. C. J., D.Sc., Chemical and Metallurgical Engineer, Corrosion Department, Shell-Holland, Amsterdam, Holland.

EARNSHAW, Harry, Works Manager, Arc Manufacturing Company, Ltd., Nitshill, Glasgow.

FERGUSON, Peter John, Scottish Branch Manager, British Aluminium Company, Ltd., Glasgow.

GILMORE, Edward J., B.S., Assistant to the Chief Engineer, The Cleveland Graphite Bronze Company, Cleveland, O., U.S.A.

JOHNSON, William A., D.Sc., B.S., Director, Metallurgy Division, Clinton Laboratories, Atomic Energy Commission, Knoxville, Tenn., U.S.A.

MARCHAND, Gilles, B.A., B.Sc., Research Metallurgist, Aluminum Laboratories, Ltd., Kingston, Ont., Canada.

Miller, George Leslie, Ph.D., B.Sc., Director of Research, Murex, Ltd., Rainham, Essex.

Millership, Joseph, Steel Controller, Workington Iron and Steel Company (United Steels), Moss Bay, Workington, Cumberland.

Orowan, Egon, Dr.-Ing., Nuffield Fellow, Cavendish Laboratory, Cambridge University.

Paterson, Andrew Bruce, M.C., City Librarian, The Mitchell Library, Glasgow.

Shaw, Richard Elliott, B.Sc.Eng., Chemist, Imperial Chemical Industries, Ltd. (Paints Division), Slough, Buckinghamshire.

Shell, Frederick Charles, Chemical Engineer, Price Non-Ferrous Laboratories, London.

Smith, Laurence, B.Sc.Eng., Metallurgist, Imperial Chemical Industries, Ltd., Billingham Division, Billingham, Co. Durham.

As Student Members.

Bailey, Norman, Student in Non-Ferrous Metallurgy, The University, Sheffield.

Bishop, Dennis Edmund, Laboratory Assistant, Research Department, Metals Division, Imperial Chemical Industries, Ltd., Birmingham.

Butcher, Benjamin Richard, B.Sc., Research Student, Metallurgy Department, The University, Birmingham.

Davis, Frederick Maurice, Metallurgical Chemist, Jarrow Metal Industries, Ltd., Jarrow-on-Tyne.

Day, Roger Anthony, Student in Metallurgy, The University, Sheffield.

Eccleston, Anthony James, B.Sc.Eng., Metallurgist, Joseph Lucas, Ltd., Birmingham.

Eisner, Stephen Hugo, Student of Metallurgy, Battersea Polytechnic, London.

Evans, Elwyn Llewellyn, B.Sc., Research Chemist and Metallurgist, Metallurgy Division, National Physical Laboratory, Teddington, Middlesex.

Gardner, Arthur George, Metallurgist, British Cast-Iron Research Association, Alvechurch, nr. Birmingham.

Hickley, Roger Hugh, Student in Metallurgy, The University, Sheffield.

Horsley, Geoffrey Winton, Student of Metallurgy, Clare College, Cambridge.

Jepson, Kenneth Stanley, Student of Metallurgy, The University, Sheffield.

Madsen, Peter Emil, Student of Metallurgy, The University, Birmingham.

Metcalfe, Arthur George, B.A., Student of Metallurgy, Queens' College, Cambridge.

Morecroft, Peter George, Student of Non-Ferrous Metallurgy, The University, Sheffield.

Mowat, John Alistair Stevenson, B.A., Student of Metallurgy, Queens' College, Cambridge.

Robinson, John Sydney, Student of Metallurgy, The University, Sheffield.

Robinson, Keith, B.Sc., Research Student, The University, Leeds.

Robinson, Kenneth George, B.Sc., Metallurgist, Ministry of Supply, Farnborough, Hampshire.

Rogers, V. A. B., Student, College of Aeronautics, Cranfield, Bletchley, Buckinghamshire.

Vlantis, Christian, Metallurgical Chemist, Rhodesian Iron and Steel Commission, Bulawayo, Southern Rhodesia.

MAY LECTURE.

The President: The May Lecture will be delivered in London on Wednesday, 21 May 1947, by Sir Wallace Akers, C.B.E., Director of Research of

Imperial Chemical Industries, Ltd., on a subject connected with the peaceful application of atomic energy.

THE FUTURE OF THE INSTITUTE.

The PRESIDENT: You may remember that at the end of my Presidential Address last year I said that my intention in that Address was to provoke thought rather than to suggest any definite plan to increase the scope and value of the Institute. I did this because I realized that any plan which was to be successful must embody the general desires of members, and, in fact, of the whole metallurgical community—both industrial and scientific. I feel that any scheme, however carefully devised, which has been initiated from above—or, let us say more truthfully, from Grosvenor Gardens—would not receive the support essential for success; it would not adequately meet the needs of members unless the members themselves had had an opportunity to think things out and to formulate their ideas.

I felt that, although it might mean some delay, it would in the long run be much better if the wishes of the members should come to our offices at Grosvenor Gardens, so that the Council and the staff would know what was wanted and could frame a plan to meet the needs expressed. With this in view, I planned to visit during the winter session each of our Local Sections, and I am very glad to say that I have succeeded in completing that tour.

It has been most stimulating, and I should like to thank all the Chairmen and Committees of the Local Sections for their kind hospitality and for the excellent arrangements which they made for my visits, and, above all, for a great deal of valuable and constructive criticism and for many well-thought-out and practical suggestions.

The main points which have emerged from these discussions have already been placed before your Council. They include suggested improvements in our *Journal*, ways in which the Local Sections could be helped to a greater degree, and a broadening of the services which we render. The idea is that we should as an Institute serve what I called earlier in my remarks the whole metallurgical community.

We are a very great science and industry, and, rather like agriculture, we embrace every form of activity—the scientific, both academic and applied, the industrial, and, last but not least, the manual workers. That is the non-ferrous metallurgical community which it is the duty of this Institute to serve, and each division of that community is essential to the others and cannot stand on its own.

It became obvious at the very beginning that if we were to move along those lines it would require very efficient administration and throw increased work on our staff and increased expenses on our treasury, as Mr. Tasker has pointed out; but I feel that if we continue to conduct our affairs sensibly, we shall be able to render far greater services without engaging in any wild-cat financial commitments.

With regard to keeping in close touch, which is so essential, with our members in the provinces and overseas, I should like to mention that Mr. G. L. Bailey, who has been one of our Vice-Presidents, has set out for America and will represent the Institute at the forthcoming meeting to celebrate the seventy-fifth anniversary of the foundation of the American Institute of Mining and Metallurgical Engineers. That contact will be very useful. In addition, the present President of the Iron and Steel Institute, Dr. C. H. Desch, who is a Past-President of this Institute, will also be over there, so that British metallurgical interests will be well represented.

I shall not touch further on the financial position, which has already been clearly explained, but I should like to say that I am not afraid of it. I feel that if we render good service to the industry, the members engaged in the science and industry will give us the necessary financial support.

At the beginning of this new year, I hope that the thoughts of the last year may now be turned into definite action. I am certain that we shall not be able to do everything that members want us to do, but I think that we can make a good start. We have ploughed the ground, and I have collected some good seed, especially from North of the Tweed. It has been planted, and I hope that before I lay down my office this time next year I shall have the satisfaction of seeing a good and healthy crop beginning to sprout, if not ready for harvest.

THE INSTITUTE OF METALS (PLATINUM) MEDAL: PRESENTATION JOINTLY TO DR. MARIE L. V. GAYLER (MRS. HAUGHTON) AND DR. J. L. HAUGHTON.

The PRESIDENT: I have to announce that the Council have awarded the Institute of Metals (Platinum) Medal jointly to Dr. J. L. Haughton and Mrs. Haughton, who is well known to metallurgists all over the world as Dr. Marie Gayler. I am glad to find by your applause that you heartily endorse the decision of the Council.

Good wine needs no bush, and the scientific achievements of this lady and gentleman are so well known to you that I need not give you any detailed account of their very brilliant scientific work, which has chiefly, as you know, been connected with the structure of light metal alloys. Suffice it to say that I feel that the Institute, in honouring Dr. and Mrs. Haughton, is honouring itself.

Personally, I am particularly glad that it has fallen to my lot to make this presentation. First of all, I think that this is a unique occasion, in that a husband and wife are both fully qualified to receive and deserving of the highest honour of the non-ferrous metallurgical world. Seldom, if ever, can such intellectual accord have existed between husband and wife and have led to such important scientific results. Apart from all other considerations, we are more than happy to make this award, as it is a visible recognition of a long and happy married life. We hope that Dr. and Mrs. Haughton may both live to enjoy for many years the well-deserved if only partial leisure which they have now achieved.

There is, however, another reason why I am happy to make this presentation, and that is that Dr. and Mrs. Haughton have exhibited a very great degree of wisdom in a direction in which I too feel that I have been wise. Dr. Haughton, like myself, had the misfortune not to be born in Bristol; he was born in Dublin and I in Cheshire; but we were both very wise in coming to Bristol. He was, in fact, earlier than I was in coming there, and he settled a few miles from my present home. Mrs. Haughton was even wiser; she took the precaution of being born in Bristol, and was for some years science mistress at Colston's Girls School there. I have lived and worked for so long in Bristol and its neighbourhood that I feel that I can claim to be a Bristolian, and thus that I shine in a reflected manner with some of the honour which the Institute has conferred on Dr. and Mrs. Haughton. It is very fitting that it should fall to a Bristolian to hand the Medal to them to-day, especially as the city and district of Bristol have been for many years a centre of the metallurgical industry, long before Birmingham was even heard of.

Both Dr. and Mrs. Haughton have had a long connection with the Institute of Metals. Dr. Haughton was elected in 1911, and Mrs. Haughton in 1917.

Dr. Haughton was a Member of Council from 1931 to 1937, and again from 1940 to 1945, when he became a Vice-President. He was Chairman of the London Local Section in 1924–25, and Autumn Lecturer in 1933. His contribution to the management of the Institute has therefore been continuous, and has been of the very greatest help to his colleagues; in fact, he has deserved well of the Institute quite apart from his scientific work.

Both Dr. Haughton and Dr. Gayler have now retired from their appointments on the scientific staff of the National Physical Laboratory, but I am sure you will be glad to know that, by accepting certain consultative appointments, they are still placing their great abilities and experience at the service of the science of metallurgy. In addition, it may not be so well known that Dr. Haughton is an amateur astronomer of very considerable distinction, and I hope that he will also continue his work in that direction. I feel certain that the evening of life of these two eminent metallurgists will be as fruitful and as satisfying as have the years gone by. In presenting this Medal to them, as a token of our appreciation of their work, I wish them on behalf of the Institute many years of health and happiness.

The President then—amid applause—presented to Dr. and Mrs. J. L. Haughton the Institute of Metals (Platinum) Medal awarded in 1947.

Dr. J. L. HAUGHTON: On behalf of Dr. Gayler and myself, I wish to thank the President and the Council of the Institute and our fellow members very much for the great honour which has been conferred on us, an honour of which we should feel that we were completely unworthy but for the fact that in making this award to us we feel that you are also making it to the Metallurgical Division of the National Physical Laboratory; for had it not been for the facilities and the help which we have been given by that establishment we should not be standing now in this very pleasant if somewhat embarrassing position.

While referring to the Laboratory, we should both like to mention one name in particular, that of the late Dr. Walter Rosenhain, who was a Past-President of this Institute and Superintendent of the Metallurgical Division of the National Physical Laboratory. It was his genius, his energy, and, perhaps more than anything else, his enthusiasm that started us on the work which has led to this honour being conferred upon us.

I personally should also like to mention two other names. The first is that of Professor T. Turner, who first directed my metallurgically infant footsteps on to the not perhaps very straight or narrow road of scientific research, and the other is that of Dr. O. F. Hudson, who first introduced me to equilibrium diagrams. To these gentlemen I owe a great debt.

Dr. MARIE GAYLER then delivered an Address on "Some Thoughts on Precipitation" (see pp. 681–691).

The PRESIDENT: We owe Dr. Gayler a debt of gratitude for a masterly Address. Her approach to the subject has been most valuable, and will stimulate further work and application to many problems.

Dr. J. L. HAUGHTON then delivered an Address on "The History of Equilibrium Diagrams" (see pp. 693–704).

The PRESIDENT: In Dr. Haughton's review of the very important subject of the determination of equilibrium diagrams, the basis of all physical metallurgy, it has been particularly interesting to me to hear his references to the work of Heycock and Neville, because I was privileged to be one of Heycock's students, and it was a great regret to us that the exuberance of certain undergraduates at Cambridge destroyed many of the notes and much of the work of Heycock and Neville when the laboratory in which their work was carried out was burnt down. In spite of that destruction, we shall all agree that what remained of it was a classic for the time at which it was produced.

Discussion of Papers.

The undermentioned papers were presented (the first three jointly) and discussed. In each case a hearty vote of thanks to the authors was proposed by the President and carried by acclamation.

" Properties of the Aluminium–Silicon Alloys at Temperatures in the Region of the Solidus ", by A. R. E. Singer, B.Sc., and S. A. Cottrell, B.Sc.

" Hot-Shortness of the Aluminium–Silicon Alloys of Commercial Purity ", by A. R. E. Singer, B.Sc., and P. H. Jennings, B.Sc.

" Hot-Shortness of Some Aluminium–Iron–Silicon Alloys of High Purity ", by A. R. E. Singer, B.Sc., and P. H. Jennings, B.Sc.

" The Influence of Composition on the Adhesion of Tin-Base Bearing Alloys to Steel ", by P. G. Forrester, M.Sc., and L. T. Greenfield, M.Sc.

" Effect of Iron and Silicon Impurities on the Tensile Properties and Heat-Treatment Characteristics of Sand-Cast Aluminium–10 Per Cent. Magnesium Alloy Test-Bars ", by R. T. Parker, Ph.D., B.Sc., A.R.S.M., (Miss) G. M. L. Cox, B.A., and A. N. Turner, B.Sc., A.R.S.M.

Dinner and Dance.

In the evening a Dinner and Dance was held at the Savoy Hotel, Strand, W.C.2, the President occupying the Chair. About 300 members and guests attended. The toast of " The Institute of Metals and the Non-Ferrous Metal Industries " was proposed by Sir Robert Sinclair, K.C.B., K.B.E., M.A., and the President responded. Lieut.-Colonel Ian Fraser, C.B.E., M.P., replied to the toast of " The Guests ", which was proposed by the President.

Thursday, 6 *March* 1947.

Discussion of Papers.

At a morning session the undermentioned papers were presented and discussed. In each case a hearty vote of thanks to the authors was proposed by the President and carried by acclamation.

" A Note on the Selective Corrosion of Phosphor-Bronze in Hot-Water Service ", by W. D. Clark, M.A., M.Sc.

" Magnesium–Cerium–Zirconium Alloys : Properties at Elevated Temperatures ", by A. J. Murphy, M.Sc., and R. J. M. Payne, B.Sc.

" Some Factors in the Reduction of the Iron Content of Magnesium-Base Alloys ", by F. A. Fox, M.Sc., C. J. Bushrod, M.Sc., and S. E. Mayer, Ph.D.

Visits.

In the afternoon members and their ladies visited, by invitation, the Research Laboratories of the British Aluminium Company, Ltd., Chalfont Park, Bucks.; the Research Laboratories of The General Electric Company, Ltd., Wembley; the National Physical Laboratory, Teddington; and the Royal Mint, Tower Hill, London, E.C.

Friday, 7 *March* 1947.

The President : At the business part of the meeting I should have announced that Professor J. H. Andrew, D.Sc., has resigned from the Council, owing to illness in his home and inability to attend the meetings regularly. We appreciate the fact that he has had such a high sense of duty as to resign in these circumstances. The Council will in due course announce the co-option of a member to fill the vacancy caused by this resignation.

DISCUSSION OF PAPERS.

The undermentioned papers were presented and discussed. In each case a vote of thanks to the authors was proposed by the PRESIDENT and carried by acclamation.

" Observations on the Rate and Mechanism of Recrystallization in Copper ", by Maurice Cook, D.Sc., Ph.D., and T. Ll. Richards, B.Sc., Ph.D.

" A Theory of the Age-Hardening of Aluminium–Copper Alloys, Based on Vacant Lattice Sites ", by F. Rohner, Ph.D.

VOTES OF THANKS.

The PRESIDENT : I know that it would be your wish that I should propose, on your behalf, a very hearty vote of thanks to the institutions and firms who have permitted us to visit their works and establishments, to the Institution of Civil Engineers, whose hospitality we enjoyed on the first day of the meeting, and to the Royal Institution of Chartered Surveyors, who have been particularly kind in putting at our disposal this pleasant room in which we have met yesterday and to-day, and who have provided us with accommodation for lunch.

The votes of thanks were carried with acclamation.

The proceedings then terminated.

ANNUAL MAY MEETING

A GENERAL MEETING of the Institute was held at the Institution of Civil Engineers, Great George Street, London, S.W.1, on Wednesday and Thursday, 21 and 22 May 1947, the President, Colonel P. G. J. Gueterbock, C.B., D.S.O., M.C., T.D., D.L., J.P., M.A., occupying the Chair.

Wednesday, 21 *May* 1947.

Sir WALLACE AKERS, C.B.E., delivered the Thirty-Seventh May Lecture to the Institute on " Metallurgical Problems Involved in the Generation of Useful Power from Atomic Energy " (see pp. 667–680), before a large audience.

The PRESIDENT proposed, and there was carried with acclamation, a hearty vote of thanks to Sir Wallace Akers for his lecture.

After the lecture, Sir Wallace Akers was entertained by the Council at dinner at the Savoy Hotel.

Thursday, 22 *May* 1947.

The Minutes of the previous General Meeting, held in London on 5, 6, and 7 March 1947, were taken as read and signed by the Chairman.

RESIGNATION OF THE HONORARY TREASURER.

The PRESIDENT: Our Honorary Treasurer, Mr. H. S. Tasker, has felt it necessary, owing to his other commitments, to tender his resignation, which was received by your Council yesterday with the very greatest regret. We have had, as you know, a succession of great Treasurers, to whom we owe a debt of gratitude. This is perhaps the least spectacular of the offices of the Institute, but it is in many ways the most important. I am sure that you would wish me on your behalf, as well as on behalf of the Council, to thank Mr. Tasker for what he has done, and still more for what he is prepared to do; because, although these commitments have come upon him, he has undertaken to continue in office until we can find a worthy successor. Your Council is now engaged in trying to find someone to shoulder the burden.

APPOINTMENT OF NEW SECRETARY.

The PRESIDENT: As you are aware, some little time ago your Council decided that, in view of the increased work and activities of the Institute, it would be desirable for us again to have a Secretary of our own, instead of a joint Secretary with the Iron and Steel Institute. That means that we shall lose the personal services of Mr. Headlam-Morley, and it will be a great loss, because he has done a great deal for the Institute, and has been instrumental in improving the close liaison and co-operation between the two Institutes. Both Institutes are happy to believe that, although we shall have separate Secretaries in future, this close co-operation will continue. It will be the business of both Councils to see that it does, because it is essential. There is no need, because the machines are separated, for the two Institutes to separate, and the Joint Consultative Committee, which has done useful work in the past, will continue to consider all matters of mutual interest and ensure full co-operation.

We are very grateful to Mr. Headlam-Morley, and also to the Iron and Steel Institute for having placed part of his time at our disposal. I should like to move a very hearty vote of thanks to Mr. Headlam-Morley. We look forward to a long period of co-operation by him with our new Secretary.

The vote of thanks was carried with acclamation.

The PRESIDENT: With regard to the new Secretary, the post was advertised, and your Council has given the most careful consideration to the large number of very excellent candidates who applied. After careful consideration of all the candidates and their qualifications, yesterday we unanimously decided to appoint Lieut.-Colonel S. C. Guillan, who has been, as you know, Assistant Secretary and Editor since he returned from war service. We are quite confident that with his long connection with the Institute, with the great ability that he has shown as Assistant Secretary and Editor, and with the wider experience which he has had during his service in the late war, he will be able to shoulder the burden and carry on the best traditions established by our previous Secretaries. He knows the present Secretary, Mr. Headlam-Morley, well; they have been working and co-operating together, which speaks well for the future.

He will formally take over his duties on July 1 next. We all wish him good luck and success. With his administrative ability and his knowledge of the requirements of our publications, I know that he will carry out his duties efficiently, and I feel certain that he will effectively carry out the other side of the Secretary's duties, the social side, which is most important, and will be approachable by the junior members. Our Secretary, like the secretary of a golf club, must be not merely the head of a good machine but a human being. I know that in Colonel Guillan we shall have not only a good servant but a good friend.

AUTUMN MEETING.

The PRESIDENT: The Autumn Meeting will be held in Glasgow, from Tuesday, 23 September to Friday, 26 September. The programme will very soon be in your hands. The Local Section Committee and the Reception Committee in Glasgow have put in an immense amount of work and have arranged a very interesting programme from every point of view—the discussion of papers, works visits, and, last but not least, the social side.

INCREASE OF SUBSCRIPTIONS.

The PRESIDENT: As you will have seen from the Honorary Treasurer's report for last year, the Council has been very worried with regard to the financial position. I should like to quote from the Honorary Treasurer's report. (Here the President read the last two paragraphs from the Report of the Honorary Treasurer, see p. 427.)

Since that report was written, further large increases in the cost of publication, paper, printing, and so forth have taken place. The result is that we simply cannot carry on unless we make some moderate increase in subscription rates. The standard rate has been £3 3*s.* since 1920, and we all know that £3 3*s.* went a great deal further in 1920 than it does to-day. Your Council feels that at all costs the standard of our publications and services must be maintained, and therefore, with the greatest regret, it decided yesterday that it is inevitable that we must raise the rate for the Ordinary Member's subscription from £3 3*s.* to £4 4*s.*

None of us likes paying four guineas if we can get away with three, but compared with the increased cost of publications and so forth, and our obligations to our staff, with a pension fund, it is a relatively small increase, and I feel that those who are directly interested in the publications and the discussions which take place here will still feel that they are getting a very good four guineas' worth. To those members who are not so technically interested, I would say that if the Institute was worth supporting from the larger point of view of its social contacts and general services to the industry to the extent of three guineas a year, it is worth supporting to the extent of four guineas now.

With regard to the other grades of membership, joint members have been paying £2 12*s.* 6*d.*, and that rate will be increased by one guinea to £3 13*s.* 6*d.* The subscription for Associates and Students, which has been £1 5*s.*, will be increased to £1 15*s.*, while that for joint Associates and Students will go up from £1 1*s.* to £1 11*s.*

We very much regret that we have had to do this, but I can assure you that the services which you will get will be at least as good as, and we hope better than, those which you have had in the past, and we hope that members will meet this inevitable decision in the same way that they have had to meet increases in other directions.

ELECTION OF ORDINARY MEMBERS AND STUDENT MEMBERS.

The SECRETARY reported that since the last General Meeting the undermentioned 87 Ordinary Members and Student Members had been elected:

ELECTED ON 11 APRIL 1947.

As Ordinary Members.

BAILEY, Ronald William, M.A., B.Sc., Technical Adviser, Zinc Development Association, Oxford.

BROMMELLE, Norman Spencer, B.A., Physicist, Research Laboratories, The British Aluminium Company, Ltd., Chalfont Park, Gerrards Cross, Buckinghamshire.

Burgess, Douglas Onslow, Manager, Powder Metals Division, A. Johnson and Company (London), Ltd., Dukes Road, Western Avenue, Acton, London, W.3.

Caney, Richard John Trewhitt, Metallurgical Engineer, Imperial Chemical Industries of Australia and New Zealand, Ltd., 380 Collins Street, Melbourne, Australia.

Chichmanian, Yervant, Production Manager, The Egyptian Copper Works S.A.E., Hagar El Nawafieh, Alexandria, Egypt.

Chowdhury, Bhim Bhowani Roy, B.Sc., Chemist, Metallurgical Laboratory, Test House, B.N. Railway, Khargpur, Bengal, India.

Clayton, Howard Dudley, Junior Chemist, Shropshire, Worcester, and Staffordshire Electric Power Company, Power Station, Stourport-on-Severn, Worcestershire.

Collins, Edward Franklin, B.S., Director of Research, United States Bronze Powder Works, Closter, N.J., U.S.A.

Cullen, Edward, General Manager, The Raisby Hill Limestone Company, Ltd., Coxhoe, Co. Durham.

Davis, Lewis W., B.S., Director and General Manager, Metal Hydrides, Inc., 12–24 Congress Street, Beverly, Mass., U.S.A.

Dudzinski, Nikodem, Metallurgist, Royal Aircraft Establishment, Farnborough, Hampshire.

Dunn, James Kenneth, Remelt Metallurgist, Northern Aluminium Company, Ltd., Rogerstone, Newport, Monmouthshire.

Franklin, Arthur William, B.Sc., Research Metallurgist, The Mond Nickel Company, Ltd., Birmingham.

Freytag, H. E. L., B.Sc., Assistant Information Officer, British Non-Ferrous Metals Research Association, Euston Street, London, N.W.1.

Haywood, Laurence John Arthur, Chief Chemist, Catton and Company, Ltd., Yorkshire Steel Foundry, Hunslet, Leeds, 10.

Hirst, Thomas John, Student, King's College, University of Durham, Newcastle-on-Tyne.

Kilby, John Arthur, Mechanical Engineer, Technical Offices, Colvilles, Ltd., Motherwell, Lanarkshire.

Lennox, James William, Research Engineer, Sintered Products, Ltd., Sutton-in-Ashfield.

Maitland, Ronald James, B.Sc., A.M.C.T., Senior Chemistry Master, Hindley Grammar School, Hindley, nr. Wigan, Lancashire.

Meier, Herbert, Dipl.Ing., Steelworks Manager, George Fischer, A.G. der Eisen und Stahlwerke vormals, Schaffhausen, Switzerland.

Ölander, Professor Arne, Ph.D., Professor of Inorganic Chemistry, Department of Chemistry, University of Stockholm, Stockholm 6, Sweden.

Simmons, Donald MacLaren, A.B., E.E., Eng.D., Vice-President in Charge of Research, General Cable Corporation, Bayonne, N.J., U.S.A.

Skorski, Roman, M.Sc., Research Metallurgist, Metallografiska Institutet, Stockholm, Sweden.

Walters, Bernhardt, M.A., Metallurgist, National Smelting Company, Ltd., Avonmouth, Bristol.

Wiles, Robert Clough, Designer, Chief Engineer, and Working Director, Victor Products (Wallsend), Ltd., Wallsend-on-Tyne.

As Student Members.

Cibula, Alec, B.A., Student of Metallurgy, St. Catharine's College, Cambridge.

Cowan, Arthur, Student of Metallurgy, King's College, University of Durham, Newcastle-on-Tyne.

Davidson, Ian Richard, Student of Metallurgy, King's College, University of Durham, Newcastle-on Tyne.

Denton, Maurice, Student of Metallurgy, The University, Sheffield.

Draper, Alan Richard, A.M.C.T., Junior Metallurgist, Magnesium Elektron, Ltd., Manchester.

Fleming, Robert P. H., Student of Metallurgy, Battersea Polytechnic, London.

Ganapati, Kattuputhur Subrahmanya, B.Sc., Student of Metallurgy, King's College, University of Durham, Newcastle-on-Tyne.

Grainger, Hubert Bernard, Assistant Metallurgist, Northern Aluminium Company, Ltd., Birmingham.

Greenfield, Leslie Thomas, M.Sc., Metallurgist, Tin Research Institute, Greenford, Middlesex.

Holliday, Kenneth Hedley, Student, Manchester College of Technology, Manchester.

James, Frederick John, Technical Assistant, Department of Industrial Metallurgy, The University, Birmingham.

Mackenzie, John, Student of Metallurgy, King's College, University of Durham, Newcastle-on-Tyne.

Neufeld, Helmut, Laboratory Assistant, Research Laboratories, The British Aluminium Company, Ltd., Chalfont Park, Gerrards Cross, Buckinghamshire.

Nichols, Roy Woodward, Student of Metallurgy, The University, Sheffield.

Oliver, Robert, Student of Metallurgy, King's College, University of Durham, Newcastle-on-Tyne.

Parsons, John Alwyn, Assistant Metallurgist, Fry's Metal Foundries, Ltd., Tandem Works, Merton Abbey, London, S.W.19.

Roberts, Henry Tudor, Assistant Metallurgist, Northern Aluminium Company, Ltd., Castle Works, Rogerstone, Newport, Monmouthshire.

Terry, Cyril Albert, Laboratory Assistant, Research Department, Imperial Chemical Industries, Ltd., Metals Division, Birmingham.

West, David Richard Frederick, B.Sc., Postgraduate Research Student, The Royal School of Mines, South Kensington, London, S.W.7.

Williams, William John, Research Worker, British Cast Iron Research Association, Alvechurch, Birmingham.

Wortley, Leonard, Student of Metallurgy, The University, Sheffield.

Elected on 7 May 1947.

As Ordinary Members.

Adams, Orlando Percival, Director of Development, National Tube Company, Pittsburgh 30, Pa., U.S.A.

Ali, Mir Asad, M.Sc., Dipl.Ed., Student, The University, Manchester.

Bufton, John Harry, Director, Bardine Tool Company, Ltd., Sheffield.

Edwards, Alun, Ph.D., B.Sc., Metallurgist, James Neill and Company (Sheffield), Ltd., Sheffield.

Franke, Richard Hugh, Chief of the Raw Material Department, The Renold and Coventry Chain Company, Ltd., Coventry.

Garcia de Tuñón, Jovino Diaz-Pedregal, Licenciado en Ciencias, Chief of Metallurgical Laboratory, Taller de Precision y Laboratorio Central de Artilleria, Madrid, Spain.

Goyns, Hugh Glover, Foundry Manager, Eclipse Tube Mill Liners (Pty.), Ltd., Benoni, Transvaal, South Africa.

Holmes, Thomas Henry, Secretary, The Northampton Polytechnic, London.

Leonard, John Alfred, Director, Townroes, Ltd., Sheffield.

MEARS, Robert B., Ph.D., B.S., Manager, Research Laboratory, Carnegie–Illinois Steel Corporation, Pittsburgh, Pa., U.S.A.

MEUNIER, Professor Francis A., Ingénieur Civil Métallurgiste, Professor of Metallurgy, Faculté Polytechnique de Mons, Mons, Belgium.

NICOL, Robert Andrew, Laboratory Supervisor, Firma-Chrome Plating Company, Ltd., Sheffield.

SCHWARTZ, Donald L., B.S.E., M.S., Research Metallurgist, Carboloy Company, Inc., Detroit, Mich., U.S.A.

SISSONS, Harold Gordon, Director, W. and G. Sissons, Ltd., Sheffield.

As Student Members.

BAUGH, Trevor John, Assistant Metallurgist, James Booth & Company, Ltd., Birmingham.

BROWN, Russell Harvey, Student of Metallurgy, King's College, Durham University, Newcastle-on-Tyne.

CALDICOTT, John, Student of Metallurgy, Central Technical College, Birmingham.

HARTLAND-GARRATT, Gordon, Metallurgist, Delta Metal Company, Ltd., Birmingham.

PEARCE, Roger, B.A., Research Student, Inorganic Chemistry Laboratory, Oxford.

SUNDBACK, Paul Philip, Student, Massachusetts Institute of Technology, Cambridge, Mass., U.S.A.

WEDDLE, William Anthony, Student of Metallurgy, King's College, Durham University, Newcastle-on-Tyne.

DISCUSSION OF PAPERS.

The undermentioned papers were presented and discussed. In each case a hearty vote of thanks to the authors was proposed by the CHAIRMAN and carried with acclamation.

" The Mechanism of the Embrittlement of Deoxidized Copper by Bismuth ", by E. Voce, Ph.D., M.Sc., and A. P. C. Hallowes, B.Sc.

" The Microstructure of Wrought Non-Arsenical Phosphorus-Deoxidized Copper Containing Small Quantities of Bismuth ", by T. H. Schofield, M.Sc., and F. W. Cuckow, B.Sc.

" Investigations of the Effect of Zinc on the Corrosion of Some Magnesium Casting Alloys ", by F. A. Fox, M.Sc.

ANNUAL AUTUMN MEETING

THE THIRTY-NINTH ANNUAL AUTUMN MEETING of the Institute of Metals was held in the Rankine Hall of the Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow, from Tuesday to Friday, 23–26 September 1947.

Tuesday, 23 *September* 1947.

The meeting opened at 8 p.m., when Sir James Weir French, D.Sc., Honorary President of the Reception Committee, occupied the Chair.

The CHAIRMAN, on behalf of the Reception Committee; COUNCILLOR ANDREW HOOD, J.P., on behalf of the Lord Provost of the City of Glasgow; PROFESSOR R. HAY, Ph.D., B.Sc., on behalf of the Principal of Glasgow

University; and Mr. W. H. Marr, President of the Glasgow Chamber of Commerce, welcomed the members and their ladies to the City of Glasgow, and the President replied to the speeches of welcome.

The President, Colonel P. G. J. Gueterbock, C.B., D.S.O., M.C., T.D., D.L., J.P., M.A., A.D.C., then took the Chair.

The President introduced Professor G. Wesley Austin, O.B.E., M.A., M.Sc., Professor of Metallurgy at Cambridge University and a Vice-President of the Institute, to deliver the Eighteenth Autumn Lecture on " The Metallurgical Resources of Scotland " (see *Journal*, 1947, vol. **74**, pp. 149–157).

At the conclusion of the lecture, a vote of thanks to the lecturer was proposed by Mr. A. Craig Macdonald, Vice-Chairman of the Scottish Local Section; seconded by Mr. A. B. Graham, Chairman of the Scottish Local Section, and carried with acclamation.

The meeting then adjourned, and members and their friends were entertained to light refreshments, by invitation of the Reception Committee.

Wednesday, 24 *September* 1947.

BUSINESS MEETING.

The meeting was resumed at 9.45 a.m., the President occupying the Chair.

The President announced that messages expressing good wishes for the success of the meeting, and regrets that they were unable to be present, had been received from Sir William Griffiths, Sir Arthur Smout, and also from Professor T. Turner and Mrs. Turner. He reminded the members that Professor Turner was the oldest living Past-President of the Institute and that he had occupied the Chair on the occasion of the last meeting held in Glasgow, in 1925.

The minutes of the last General Meeting, held in London on 21 and 22 May 1947, were taken as read and signed by the Chairman.

NOMINATION OF OFFICERS FOR 1948–49.

The President announced that, as required by Articles 20 and 21, the following officers were due to retire at the 1948 Annual General Meeting, and would not then be eligible for re-election.

President :

Colonel P. G. J. Gueterbock, C.B., D.S.O., M.C., T.D., D.L., J.P., M.A., A.D.C.

Vice-Presidents :

Roosevelt Griffiths, M.Sc.
J. L. Haughton, D.Sc.

Ordinary Members of Council :

W. H. Henman.
Stanley Robson, M.Sc., D.I.C.

As required by Article 22, and as already notified to members by circular letter, the Council made the following nominations to fill these vacancies and to confirm two appointments (those of Mr. W. A. C. Newman and Mr.

D. P. C. Neave, respectively) made by the Council to fill vacancies caused by resignations that had been received since the last Annual General Meeting.

As President :

Sir Arthur Smout, J.P.

As Vice-Presidents :

S. F. Dorey, C.B.E., D.Sc., Wh.Ex.
A. J. Murphy, M.Sc.
H. S. Tasker, B.A.

As Honorary Treasurer :

W. A. C. Newman, B.Sc., A.R.S.M., A.R.C.S.

As Ordinary Members of Council :

D. F. Campbell, M.A., A.R.S.M.
A. Dando.
T. M. Herbert, M.A.
D. P. C. Neave, M.A.
A. R. Powell.

The President reminded members that, as provided for in Article 22, any ten members could make other nominations in writing before the termination of that meeting, and that, if any such nominations were received, a ballot would take place in due course.

Election of a Fellow.

The President : As you know, it is the custom of the Institute from time to time to confer the distinction of Fellowship on a member who has rendered signal service to the Institute. The number of these Fellowships is limited to twelve, a very small number out of our total membership. You will thus appreciate that this is one of the highest honours which the Institute can confer on a member.

Your Council have decided, in the exercise of their powers, to confer this honour on Mr. H. H. A. Greer, J.P. Mr. Greer is very well known in the metal trades, and especially in the metal trades of Scotland, and has been connected with the industry for over fifty years. For twenty years he was in business with his father, Mr. James Greer. He afterwards became sole partner in the firm of James Greer and Son, of Glasgow, who have been for many years associated with Messrs. A. Cohen and Co., Ltd., of London. In 1918 he joined the Board of Directors of the latter Company, but has retired.

He is an Original Member of the Institute. He took a large part in the formation of the Scottish Local Section in 1918. He was a member of the Committee of that Section from 1918 to 1944, Honorary Local Secretary from 1918 to 1928, and Chairman in 1931 and 1932. He was a member of the Council of the Institute from 1928 to 1936, a member of the Reception Committee for the first Glasgow meeting of the Institute, in 1910, and Honorary Secretary of the Reception Committee for the second meeting held here, in 1925.

In the early days of the formation of the British Non-Ferrous Metals Research Association, Mr. Greer was its only member in Scotland, and acted as its Honorary Correspondent in Scotland. He is an Associate Member of the Institution of Engineers and Shipbuilders in Scotland, and also a member of certain ancient Incorporations of Glasgow. He held the position of Preses (Chairman) of the Weavers' Society of Anderston, Glasgow, which was founded in 1787, is a Justice of the Peace for the County of Ayr, and has been a member of the Parish Council of West Kilbride, Ayrshire. Not only, therefore, has he led a busy life in his profession, but he has done much public service in other bodies besides the Institute.

I feel confident that you will endorse the action of the Council in recognizing Mr. Greer's great public service by making him a Fellow of the Institute.

Mr. H. H. A. Greer, J.P.: I can scarcely express to you, Sir, and to your Council and all the members my great appreciation and thanks for the signal honour which you have done me. I am not a scientist, but, as a business man, I consider very strongly that the business men of Glasgow and other centres ought to pay special attention to the scientific side of the industries in which they are interested, for two reasons. The numbers of scientific men are limited, and an Institute such as this could not carry on if confined solely to the scientists; and we as business men benefit very largely by the developments which are brought about by the scientific world.

It has been a great pleasure to me, therefore, to be associated with the Institute for so many years, but I do not think that it is on my own account alone that the Institute has elected me a Fellow. I am glad to say that our numbers in Glasgow, which were very small to begin with, have grown year by year. The second world war has intervened and caused delay in getting on with programmes in some cases, but I am thankful that around me in the work which I have been able to do I have had a very happy, delightful band of co-workers in the members of the committees with which I have been connected and in the members who have attended the meetings of our Section. I like to think, therefore, that it is as an honour not only to myself but to the Scottish Section that the Council have elected me a Fellow.

I am proud of our Section here in Glasgow. It may interest you to know that we have had some very distinguished men as Chairmen. Our first Chairman was Dr. C. H. Desch, F.R.S., and another was the equally celebrated metallurgist and scientist Dr. J. H. Andrew, now of Sheffield. We have also had as Chairman Dr. R. Hay, the Professor of Metallurgy in the Technical College of Glasgow, and also Professor G. Wesley Austin. These gentlemen have found in Glasgow stepping-stones to the most important offices which they now hold, and we are proud to think that they all have been Chairmen of our Local Section.

I should like to make a plea for a larger membership. We should like to have much larger numbers at our Sectional meetings. We have tried to make them not too formal. I have often said, " Gentlemen, try to make fools of yourselves, as I often do; because sometimes out of foolishness wisdom comes, and a simple question asked by a man requiring information may lead to a discussion which may be very important ". I hope that we shall have increased numbers, more especially of the younger men. Apart from anything else, by coming to the meetings, standing up and learning to express themselves, they will get very valuable help towards success in the scientific work in which they are engaged.

Election of Members, Associate Members, and Student Members.

The President announced that, since the last General Meeting of the Institute, there had been elected the following 51 Ordinary Members, 1 Associate Member, and 39 Student Members. He appealed to members to do all that they could to increase the membership of the Institute during the current financial year. The usefulness of the Institute, he said, must depend very much on the membership subscriptions, and he emphasized the importance of having as members not only professional metallurgists but also all those who were interested in metals from industrial or commercial points of view.

ELECTED ON 6 JUNE 1947.

As Ordinary Members.

BROWN, Marshall H., M.S., Ph.D., Metallurgist, E. I. du Pont de Nemours and Company, Inc., Wilmington, Delaware, U.S.A.

CLUBLEY, George Harley, Plant Manager, Davy and United Roll Foundry, Ltd., Billingham, Co. Durham.

FANNING, Lawrence Bede, I.S.O., Director-General of Posts and Telegraphs, Commonwealth of Australia, Melbourne, Vic., Australia.

FOSTER, Edward Mitchell, Dipl.Ing., Technical Manager, Beryllium and Copper Alloys, Ltd., London.

HACKETT, John F., Vice-President and General Manager, The Riverside Metal Company, Riverside, N.J., U.S.A.

LAGERQVIST, Ing. Joel, Director of the Chemical Laboratory, Sieverts Kabelverk, Sundbyberg, Sweden.

LEWANDO, Mario Ernest, Metal Supplies Department, Marks and Spencer, Ltd., London.

LITTMANN, Martin, Managing Director, Compound Electro Metals, Ltd., London.

LORD, George William, General Manager, No. 11 R.P.C./M.O.S., Ace Lorry and Engineering Company, Ltd., Aldershot, Hampshire.

RICE, Warner G., Director, Ann Arbor General Library, University of Michigan, Ann Arbor, Mich., U.S.A.

SHANKAR, Mysore Basaviah, M.Sc., M.Met., Deputy Development Officer (Metals), Directorate-General of Industries and Supplies, Government of India, New Delhi, India.

SIMPSON, Arthur Horrox, B.Sc., Senior Assistant, Mineral Resources Department, Imperial Institute, London.

TORRAS, Francisco, Indust.Eng. (Madrid), Managing Director, Minero Metalurgica del Estaño S.A.E., Madrid, Spain.

TUCK, Leonard Gordon Charles, Foundry Manager, Dualloys, Ltd., Croydon, Surrey.

WHITAKER, (Miss) Marjorie Elsie, B.Sc., Investigator, British Non-Ferrous Metals Research Association, London.

WINTREBERT, Léon, Ingénieur en Chef du Génie Maritime et S/Directeur de l'Établissement d'Indret, Indret (Loire-Inférieure), France.

WRÓBEL, Stanisław A., Dipl.Ing.Met., A.R.S.M., Metallurgist, Swindon, Wiltshire.

As Associate Member.

ATWOOD, David Lee, B.E., M.A., Research Metallurgist, Ekco Products Company, Chicago, Ill., U.S.A.

As Student Members.

AKROYD, Brian Anthony, Student of Metallurgy, Central Technical College, Birmingham.

GAD, Gamal-el-Din Mohamed, B.Sc., Research Student in Chemical Engineering, Imperial College of Science, London.

KEMSLEY, Douglas Sinclair, Metallurgical Research Worker, Council of Scientific and Industrial Research, Melbourne, Vic., Australia.

LYTTON, Frank Andrew, Student of Metallurgy, Battersea Polytechnic, London.

PALMER, Samuel Wallace, A.R.I.C., Research Metallurgist, British Cast Iron Research Association, Alvechurch, Birmingham.

RAO, Kilaru Nageswara, Student, University College, Cardiff.

REES, Norman, Laboratory Assistant, I.C.I. Metals, Ltd., Swansea.

SUMMERS-SMITH, James Denis, Student of Metallurgy, Royal Technical College, Glasgow.

TEGART, William John McGregor, Metallurgical Assistant, Council of Scientific and Industrial Research, Melbourne, Vic., Australia.

WALKER, Laurie, B.Sc.Tech., Research Metallurgist, English Electric Company, Ltd., Stafford.

WILKINSON, Derek Hilary, B.Met., Metallurgical Assistant, R.O.F. (3), Birtley, Co. Durham.

WOODFINE, Bernard Charles, Honours Metallurgy Student, The University, Sheffield.

ELECTED 23 JULY 1947.

As Ordinary Member.

DAY, Julian Wentworth, Proprietor, The British Industrial Development Organization, Walsall.

ELECTED 7 AUGUST 1947.

As Ordinary Members.

BARRY, William Cyril, B.Sc., Research Manager, W. T. Henley's Telegraph Works Company, Ltd., Gravesend, Kent.

BILLINGHAM, Frederick William, Managing Director, F. and E. Billingham, Ltd., Gloucester.

BLANC, Dr. Georges Gaston Jules, Ingénieur, Chef de la Métallurgie des Alliages Cuivreux au Centre Technique de la Fonderie, Paris, France.

BRADLEY, Richard S., B.S., Director of Research, A. P. Green Fire Brick Company, Mexico, Miss., U.S.A.

CHALLANSONNET, Jean, Ingénieur, Conservatoire National des Arts et Métiers de Paris, Suresnes (Seine), France.

EGGINTON, Harold Horace, Electrochemist, Pyrene Company, Ltd., Brentford.

EL-SHERIF, Ibrahim Mohammed Ibrahim, M.Sc., Assistant Chief Chemist and Metallurgist, Egyptian State Railways, Cairo, Egypt.

FIGIEL, Jan, B.Sc., A.R.S.M., Student of Metallurgy, Royal School of Mines, London.

FOWLER, Ernest Alastair, B.Sc., A.R.T.C., Chief Metallurgist, Scott's Shipbuilding and Engineering Company, Ltd., Greenock, Renfrewshire.

GARDAM, George Euan, Ph.D., Director of Research, Design and Research Centre for the Gold, Silver, and Jewellery Industries, London.

GUZZETTI, Enrique, General Works Manager, H. M. Hobson, Ltd., Cordoba, Argentina.

HARDING, Peter, B.Sc., Student of Metallurgy, Royal School of Mines, London.

HARLAND, Robert Main, A.R.S.M., Assay Master, The Assay Office, Sheffield.

HUTIN, Edmond, Ingénieur Metallurgiste, Snecma (Gnome-et-Rhone), Paris, France.

JOHN, Ian Roger, Metallurgist, M. B. John Pty., Ltd., Ballarat, Vic., Australia.

MARDELL, Edmund C. H., Assistant Metallurgical Chemist, Dyson and Company, Ltd., Ponders End, Middlesex.

PASCHEK, Franciszek Stefan, B.Sc., A.R.S.M., Student of Metallurgy, Royal School of Mines, London.

REXWORTHY, Desmond Ramsay, B.Sc., Deputy Editor of *Research*, and Scientific Adviser to Butterworth's Scientific Publications, Ltd., London.

RODÉS, Professor Rafael Calvo, Professor of Metallurgy, Departamento de Materiales y Talleres, Instituto Nacional de Técnica Aeronáutica, Cuatro Vientos, Spain.

ZEDNÍK, Professor Vladimír, D.Sc., Eng. Met., Assistant Professor, State College of Mining and Metallurgy, Ostrava, Czechoslovakia.

As Student Members.

CHARLES, James Anthony, B.Sc., A.R.S.M., Student of Metallurgy, Royal School of Mines, London.

CRANE, John Rupert, B.Sc., Assistant Technical Officer, Imperial Chemical Industries, Ltd., Metals Division, Witton, Birmingham.

ECKERSALL, Antony Irving, B.Sc. (Eng.), A.R.S.M., Student of Metallurgy, Royal School of Mines, London.

FERENDINOS, Speros, Learner Metallurgical Chemist, Rhodesian Iron and Steel Commission, Que Que, Southern Rhodesia.

GRAY, Phillip Malcolm James, B.Sc., A.R.S.M., Student of Metallurgy, Royal School of Mines, London.

HARRIS, Colin Frank, B.Sc. (Eng.), A.R.S.M., Student of Metallurgy, Royal School of Mines, London.

HEALEY, Richard, B.Sc. (Eng.), A.R.S.M., Student of Metallurgy, Royal School of Mines, London.

HERRING, George Henry Paul, Metallurgical Assistant, Powers Accounting Machines, Ltd., London.

HOULDEN, Brian Thomas, B.Sc. (Eng.), A.R.S.M., Student of Metallurgy, Royal School of Mines, London.

JAMES, Edward Lionel, Assistant Metallurgist, Forgings and Presswork, Birmingham.

LEE, (Miss) Anna Ling, B.Sc., Research Student, Birmingham University.

LOKIER, William John, In charge of Mechanical Testing Laboratory, Imperial Chemical Industries, Ltd., Metals Division, Gowerton, Swansea.

LORETTO, John Carlo, Student of Metallurgy, Royal School of Mines, London.

MACDONALD, Neil Fraser, M.A., Research Physicist, Research Laboratories, The British Aluminium Company, Ltd., Gerrards Cross, Bucks.

MECHEM, Dennis Victor, B.Sc. (Eng.), A.R.S.M., Student of Metallurgy, Royal School of Mines, London.

MULLER, Lee D., Learner Metallurgical Chemist, Rhodesian Iron and Steel Commission, Que Que, Southern Rhodesia.

POLLARD, William Ambrose, Student of Metallurgy, Royal School of Mines, London.

ROBLIN, Lyndon Daniel, Test House Supervisor, Richard Thomas and Baldwins Iron and Steel Company, Ltd., Port Talbot, South Wales.

SELF, Alan John, B.Sc., A.R.S.M., Student of Metallurgy, Royal School of Mines, London.

VAN DE WIEL, Peter Donald, Senior Metallurgical Laboratory Assistant, Standard Motor Company, Ltd., Coventry.

ELECTED 9 SEPTEMBER 1947.

As Ordinary Members.

ALEXANDER, Martin, B.Sc., Metallurgist, Ministry of Supply, Department of Atomic Energy, Risley, Warrington, Lancashire.

BARR, William, A.R.T.C., Executive Director and Chief Metallurgist, Colvilles, Ltd., Motherwell.

BEVER, Professor Michael B., Sc.D., Assistant Professor, Department of Metallurgy, Massachusetts Institute of Technology, Cambridge, Mass., U.S.A.

EASDALE, Robert Muir, Metal Merchant and Refiner, Glasgow.

HANDS, Charles Henry, Chief Chemist, Hoover, Ltd., Perivale, Greenford, Middlesex.

LACOMBE, Paul Jean Gilbert, Dr. es Sci., Laboratoire Central des Traitements Chimiques, Centre National de la Recherche Scientifique, Vitry-sur-Seine, France.

McLEAN, John Campbell, Superintendent-in-Charge, H.M. Assay Office, H.M. Mint, Calcutta, India.

MURRAY, Herbert Spencer Stanley, Managing Director, Electro-Platers, Ltd., and associated companies, Glasgow.

MURRAY, Stanley Alexander James, Analytical Chemist; Director, Electro-Platers, Ltd., and associated companies, Glasgow.

ROBERTS, Samuel Thomas, Chemical Engineer, International Corrodeless, Ltd., Enfield, Middlesex.

RUIMONTE, Professor Dr. Florentino Gómez, Profesor de Química Aeronáutica, Departamento de Materiales y Talleres, Instituto Nacional de Técnica Aeronáutica, Madrid, Spain.

WHITELEY, Hubert Augustus, Technical Officer, National Association of Drop Forgers and Stampers, Handsworth, Birmingham.

WILLIAMS, Urias, Chief Research Officer, Richard Thomas and Baldwins, Ltd., Light Alloys Section, Briton Ferry, Neath, Glamorganshire.

As Student Members.

BENNETT, Bruce Boyd, Chemist, Metropolitan Gas Company, Melbourne, Vic., Australia.

BUTLER, Ronald, B.Met., Research Metallurgist, Research Laboratories, British Aluminium Company, Ltd., Gerrards Cross, Buckinghamshire.

CHRISTIAN, John Wyrill, B.A., Research Assistant, Inorganic Chemistry Laboratory, Oxford.

COLES, Bryan, B.Sc., Research Assistant (Ministry of Supply), Oxford University.

SALAMY, Stanley George, Student, University of Melbourne, Vic., Australia.

STEINBERG, Morris Albert, Graduate Student of Metallurgy, Massachusetts Institute of Technology, Cambridge, Mass., U.S.A.

THOMPSON, David Laurance, Bramhall, Stockport, Cheshire.

FUTURE MEETINGS.

The PRESIDENT announced that a Symposium on "Internal Stresses in Metals and Alloys" would be held in the Hall of the Institution of Mechanical Engineers, London, on Wednesday and Thursday, 15 and 16 October 1947, and that the next Annual General Meeting would be held in London on Wednesday and Thursday, 17 and 18 March 1948.

DISCUSSION OF PAPERS.

The undermentioned papers were presented and discussed. In each case a hearty vote of thanks to the authors was proposed by the PRESIDENT and carried with acclamation.

"Surface Effects During the Annealing of 70 : 30 Brass", by Ivor Jenkins, M.Sc.

"The Centrifugal Casting of Copper Alloy Wheels in Sand Moulds", by O. R. J. Lee, Ph.D., M.Sc., and L. Northcott, D.Sc., Ph.D.

LUNCH.

A luncheon was held at the Grand Hotel, Glasgow, at which the President occupied the Chair.

The PRESIDENT briefly thanked the Reception Committee and members of the Scottish Local Section for their invitation to the Institute to hold the meeting in Glasgow, and MR. A. CRAIG MACDONALD, Vice-Chairman of the Scottish Local Section, replied.

VISITS.

In the afternoon, by invitation of the Directors, members visited the works of:

The British Aluminium Company, Ltd., Falkirk.
John Brown and Company, Ltd., Clydebank.
Glenfield and Kennedy, Ltd., Kilmarnock.
Henry Wiggin and Company, Ltd., Thornliebank.

Ladies, by invitation, visited:

The Saxone Shoe Company, Ltd., Kilmarnock.
Burns' Cottage, Ayr.

CIVIC RECEPTION.

In the evening, members and their ladies were the guests of the Lord Provost (Sir Hector McNeill), the Magistrates, and Corporation of Glasgow, at a reception at the City Chambers.

The LORD PROVOST, supported by the Magistrates, received the guests and subsequently made a speech of welcome to the members, to which the PRESIDENT replied. SIR JAMES WEIR FRENCH, D.Sc., Honorary President of the Reception Committee, proposed a vote of thanks to the Lord Provost, which was carried with acclamation, and also presented the Lord Provost with a badge that had been supplied for members' use during the meeting.

Thursday, 25 *September* 1947.

DISCUSSION OF PAPERS.

The meeting was resumed at 9.45 a.m., the PRESIDENT occupying the Chair, when the following papers were presented and discussed. In each case a hearty vote of thanks to the authors was proposed by the PRESIDENT and carried with acclamation.

"The Frictional Properties of Some Lubricated Bearing Metals", by P. G. Forrester, M.Sc.

Jointly, three papers on the corrosion of magnesium-rich alloys:

"The Variation in Corrosion Properties Over Two Magnesium Alloy Sheets", by E. R. W. Jones, B.A., and (Mrs.) Marion K. Petch, B.A.

"The Corrosion of Some Magnesium-Base Alloys (High and Normal Purity) in Contact with Other Metals", by F. A Fox, M.Sc., and J. K. Davies, B.Met.

"Note on the Quantitative Implications of Hanawalt's Theory of Corrosion of Magnesium-Base Alloys", by C. J. Bushrod, M.Sc.

VOTES OF THANKS.

The PRESIDENT proposed, PROFESSOR F. C. THOMPSON, D.Met., M.Sc., Member of Council, seconded, and there were carried with acclamation the following votes of thanks:

That the best thanks of the Institute of Metals be and are hereby extended to:

(*a*) The President and Officers of the Reception Committee, members of the Ladies Committee, the members of the Scottish Local Section, Patrons and subscribers for their invitation to hold this meeting in Glasgow, for the arrangements made, and for their most generous hospitality.

(*b*) The President of the Reception Committee, the Lord Provost and Magistrates of the City of Glasgow, the Principal of Glasgow University, and the President of the Glasgow Chamber of Commerce for their welcome.

(*c*) The Lord Provost, Magistrates, and Corporation of Glasgow for their hospitality.

(*d*) The Directors of Works visited by members for their invitations and for their hospitality.

(*e*) The Institution of Engineers and Shipbuilders in Scotland for kindly placing their House at the disposal of the Institute for this meeting.

(*f*) To all others who have contributed to the success of this meeting.

LUNCH.

Members were entertained by the Scottish Local Section to lunch at the Grand Hotel, Glasgow, Mr. A. B. Graham, Chairman of the Scottish Local Section, occupying the Chair.

The CHAIRMAN welcomed the members, and the PRESIDENT briefly replied.

VISITS.

By invitation of the Directors, members visited the works of:

Albion Motors, Ltd., Scotstoun.
Babcock and Wilcox, Ltd., Renfrew.
Barr and Stroud, Ltd., Anniesland.

Ladies paid an all-day visit to the Trossachs, by invitation of the Scottish Local Section.

DINNER AND DANCE.

In the evening, a dinner and dance was held at the Grosvenor Restaurant, Glasgow. Sir James Weir French, D.Sc. (Honorary President of the Reception Committee), and Lady French, and the President and Mrs. Gueterbock received the guests, and Sir James Weir French occupied the Chair.

The toasts were "The City of Glasgow", proposed by Lieut.-Colonel Sir John Greenly, K.C.M.G., C.B.E., M.A., to which Councillor Andrew Hood, J.P., replied; "The Institute of Metals and the Non-Ferrous Metal Industries", proposed by the Chairman and responded to by the President; and "The Guests", proposed by Mr. A. B. Graham, Chairman of the Scottish Local Section", which was acknowledged by Mr. W. H. Marr, President of the Glasgow Chamber of Commerce. Many distinguished guests were present.

During the evening Mrs. Gueterbock presented to Mr. Matthew Hay, a gift, on behalf of the Council of the Institute, in appreciation of his work as Honorary Secretary to the Reception Committee.

Friday, 26 *September* 1947.

By invitation of the Reception Committee, members and their ladies were guests on an all-day steamer trip on Loch Lomond.

The meeting terminated on the return to Glasgow at 6.10 p.m.

SYMPOSIUM ON "INTERNAL STRESSES IN METALS AND ALLOYS"

A General Meeting of the Institute of Metals was held at the Institution of Mechanical Engineers, Storey's Gate, London, S.W.1, on Wednesday and Thursday, 15 and 16 October 1947, on the occasion of a Symposium on "Internal Stresses in Metals and Alloys", organized by the Institute in association with the Faraday Society, the Institute of Physics, the Institution of Mechanical Engineers, the Iron and Steel Institute, the Physical Society, and the Royal Aeronautical Society.

The thirty-six papers (Serial Nos. 1072–1107, inclusive) with reports of the discussions will be published in a separate volume (*Institute of Metals Monograph and Report Series,* No. 5).

Wednesday, 15 *October* 1947.

The President of the Institute of Metals (Colonel P. G. J. Gueterbock, C.B., D.S.O., M.C., T.D., D.L., J.P., M.A., A.D.C.) occupied the Chair at the opening of the meeting, and gave a brief address, after which the subject of the Symposium was discussed under three main Sections.

Section I.—The Measurement of Internal Stresses.

The Chair was taken by Dr. C. Sykes, F.R.S.

The Chairman called on Mr. D. A. Oliver, M.Sc., to address the meeting as rapporteur for Section I. A discussion then took place on the following papers :

"Mechanical Methods for the Measurement of Internal Stress", by Hugh Ford, Wh.Sc., Ph.D.

"The Investigation of Internal Stresses by Physical Methods Other Than X-Ray Methods", by R. King, B.Sc.

"Measurement of Internal Stresses by X-Rays", by D. E. Thomas, M.A., B.Sc.

"Some Fundamental Aspects of the Application of X-Rays to the Study of Locked-Up Stresses in Polycrystalline Metals", by W. A. Wood, D.Sc.

"The Principles of the Interpretation of X-Ray Photographs of Imperfect Crystals", by H. Lipson, D.Sc., M.A.

SECTION II.—THE ORIGIN, CONTROL, AND REMOVAL OF INTERNAL STRESSES.

The Chair was taken by Professor Leslie Aitchison, D.Met., M.Sc.

The Chairman called on Professor H. O'Neill, D.Sc., M.Met., to address the meeting as rapporteur for Section II. A discussion then took place on the following papers :

" Classification and Nomenclature of Internal Stresses ", by E. Orowan, Dr.Ing., F.R.S.

" Lászlό's Papers on Tessellated Stresses : a Review ", by F. R. N. Nabarro, M.B.E., M.A., B.Sc.

" The Relation of Composition to Stress-Corrosion Cracking in Copper Alloys ", by Maurice Cook, D.Sc., Ph.D.

" Internal Stresses in Steel Castings ", by H. Ellis, B.Met., Ph.D.

" The Stresses in Large Masses of Steel Cooling from the Austenitic Region ", J. E. Russell, M.A.

" Stress in Electrodeposited Metals ", by A. W. Hothersall, M.Sc.Tech.

" Residual Stresses Due to Welding ", by R. Weck, Ing.

" Internal Stresses Produced by the Sliding of Metals ", by F. P. Bowden, Sc.D., Ph.D., and A. J. W. Moore, B.Sc.

" Some Internal Stresses in Turbine Rotors ", by M. C. Caplan, B.Sc., L. B. W. Jolley, M.A., and J. Reeman, B.Sc.

" Residual Stresses in Beams After Bending ", by G. Forrest, B.Sc.

" Internal Stresses in Glassware ", by W. C. Hynd, M.Sc.

" The Relief of Internal Stresses in Aluminium Alloys by Cold Working ", by W. Betteridge, B.Sc., Ph.D.

" Stress Relief Treatment of Iron Castings ". Report of Sub-Committee T.S.17 of the Technical Council of the Institute of British Foundrymen.

" Stresses Induced by Shot-Peening of Leaf Springs ", by J. C. W. Humfrey, O.B.E., M.Sc., M.Eng., M.A.

" The Production of Favourable Internal Stresses in Helical Compression Springs by Pre-Stressing ", by D. G. Sopwith, B.Sc.Tech., Wh.Sc.

" Autofrettage ", by A. G. Warren, M.Sc.

Thursday, 16 *October* 1947.

SECTION III.—EFFECTS ASSOCIATED WITH INTERNAL STRESSES.

(*a*) EFFECTS ON A MICROSCOPIC AND SUB-MICROSCOPIC SCALE.

The Chair was taken by Dr. Maurice Cook.

The Chairman called on Dr. A. G. Quarrell to address the meeting as rapporteur of Section III (*a*).

A discussion then took place on the following papers :

" Effects Associated with Stresses on a Microscopic Scale ", by Professor Sir Lawrence Bragg, O.B.E., Sc.D., F.R.S.

" Internal Stresses Arising from Transformations in Metals and Alloys ", by Professor F. C. Thompson, D.Met., M.Sc.

" A Note on the Effect of Internal Stresses on the Rates of Transformation in Iron–Nickel Alloys ", by C. C. Earley, B.Sc.

" Diffusion and Precipitation in Alloys ", by F. R. N. Nabarro, M.B.E., M.A., B.Sc.

" Note on the Effect of Cold Work on the Rate of Precipitation in Aluminium–7% Magnesium and Aluminium–8% Magnesium–1% Zinc Alloys ", by E. C. W. Perryman, B.A.

" Age-Hardening ", by Marie L. V. Gayler, D.Sc.

" Internal Stresses and the Formation of Hair-Line Cracks in Steel ", by Professor J. H. Andrew, D.Sc., and Hsun Lee, Ph.D.

" The Experiments of Boas and Honeycombe on Internal Stresses Due to Anisotropic Thermal Expansion of Pure Metals and Alloys ", by F. P. Bowden, Sc.D., Ph.D.

" A Photoelastic Approach to Stress Modifications Caused by Inhomogeneities ", by B. Sugarman, M.Sc., D.I.C.

SECTION III.—EFFECTS ASSOCIATED WITH INTERNAL STRESSES.

(*b*) EFFECTS ON A MACROSCOPIC SCALE.

The Chair was taken by Dr. H. J. Gough, C.B., M.B.E., F.R.S.

The Chairman called on Dr. N. P. Allen, M.Met., to address the meeting as rapporteur of Section III (*b*).

A discussion then took place on the following papers :

" Influence of Residual Stress on Chemical Behaviour ", by U. R. Evans, Sc.D., M.A.

" Chemical Manifestations of Internal Stress ", by F. H. Keating.

" Note on Stress-Corrosion Cracking of Steels in the Presence of Sulphur Compounds ", by W. P. Rees, M.Sc.

" Internal Stresses in Railway Materials ", by Professor H. O'Neill, D.Sc., M.Met.

" Delayed Cracking in Hardened Alloy Steel Plates ", by E. H. Bucknall, M.Sc., W. Nicholls, B.Sc., and L. H. Toft, B.Sc.

" The Stress System Causing Hard-Zone Cracking in Welded Alloy Steels ", by J. A. Wheeler, Ph.D.

VOTES OF THANKS.

The Chairman proposed, and there were carried by acclamation, the following votes of thanks :

That the best thanks of the Institute be and are hereby extended to :

(*a*) The authors of all papers presented at this Symposium.

(*b*) The rapporteurs for their introductory addresses.

(*c*) The Councils of the Faraday Society, the Institute of Physics, the Institution of Mechanical Engineers, the Iron and Steel Institute, the Physical Society, and the Royal Aeronautical Society for their interest and help in the organization of this Symposium.

(*d*) The Council of the Institution of Mechanical Engineers for kindly placing their Hall and other accommodation at the disposal of the Institute for this meeting.

(*e*) All others who have contributed to the success of this meeting.

PAPERS

FURTHER CORRESPONDENCE ON MR. A. J. MURPHY AND MR. R. J. M. PAYNE'S PAPER: "MAGNESIUM–CERIUM–ZIRCONIUM ALLOYS: PROPERTIES AT ELEVATED TEMPERATURES."

(*J. Inst. Metals,* this volume, pp. 105, 753.)

Mr. J. B. Wilson,[*] B. Eng. (Student Member): The effect of cerium "mischmetall" on the properties of magnesium-base alloys at elevated temperatures seems to be of some theoretical interest, and does not appear to be dependent entirely on a continuous β-network. Although it seems an attractive theory to suggest that the enhanced behaviour of magnesium alloys containing cerium "mischmetall" is in some way linked with the "geodetic" structure exhibited by the β-phase in the authors' range of alloys, work on magnesium-base alloys in which the cerium is in solid solution or at least finely dispersed, has demonstrated that the network is not essential to enhanced high-temperature behaviour.

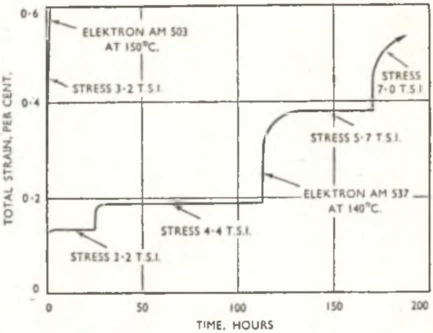

Fig. B.—Total Strain *versus* Time for Elektron AM503 at 150° C. and Elektron AM537 at 140° C.

Beck[†] has reported unpublished work by Vosskühler on the wrought Elektron alloy AM537 (magnesium–1·5% manganese–0·5% cerium). Vosskühler used a stepped-load test on the AM537 alloy and compared it with Elektron AM503 (magnesium–1·5% manganese); his results are shown in Fig. B. Although these results seem to demonstrate a clear effect in the absence of a second constituent, it would be of interest to hear from Mr. Murphy and Mr. Payne whether they consider a continuous network of β-phase essential in cast alloys for high-temperature work.

While it is recognized that the extreme simplicity of the authors' equipment does not justify a precise comparison between the quantitative results obtained, the variation in both observed creep rates and initial strains between the results illustrated in Figs. 9 and 12 seems worthy of comment. Fig. 9 refers to a bar of magnesium–cerium–zirconium alloy from a melt having low room-temperature properties. An initial strain of 0·22% is found in the Mg–Ce–Zr sample, followed by a short period of primary creep up to 0·31% strain, after which no further creep is observed. Under the same conditions, namely 3 tons/in.^{2} and 200° C.,

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[*] Metallurgist, Magnesium Elektron, Ltd., Clifton Junction, near Manchester.

[†] A. Beck, "The Technology of Magnesium and its Alloys". London: **1940** (F. A. Hughes and Company, Ltd.).

a bar having good room-temperature properties (Fig. 12) shows a lower initial strain (0·12%), which rises to 0·21% after 120 hr., when the creep rate is $3{\cdot}2 \times 10^{-6}$ in./in./hr. However, it is to be noted that closely similar variations were observed between the respective " R.R. 50 " samples tested in tandem under the same conditions. If sufficient reliance can be placed on the results, it would appear that the lower room-temperature properties may slightly favour improved creep resistance. Figs. C, D, and E are reproductions of the authors' Figs. 9, 10, and 12, with a superimposed curve, by the present writer, made under similar conditions on creep-testing machines of fairly high precision. Table A shows the compositions and grain-sizes of the test bars used in these tests.

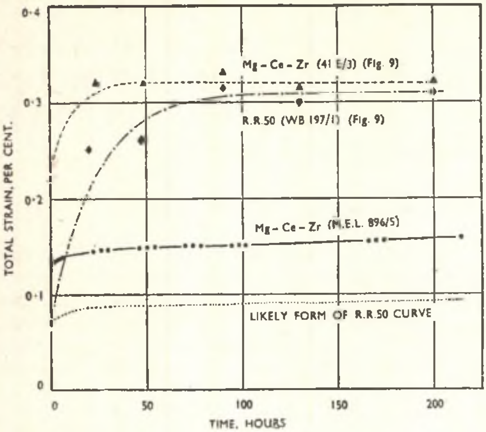

FIG. C.—Total Strain *versus* Time for Magnesium–Cerium–Zirconium Alloys and " R.R. 50 " Alloys at 3·0 tons/in.² and 200° C.

The melts are seen to be closely comparable with respect to cerium content. The grain-size of the melt used in Fig. 9 was presumably much coarser than that of the other two. It would be of interest to know whether the authors regard the differences between the results shown in Figs. 9 and 12 and the Magnesium Elektron, Ltd., tests as attributable to the differences in grain-size or merely to experimental error. In this connection, some knowledge of the equi-cohesive temperature for the magnesium–cerium – zirconium alloys would be of considerable value.

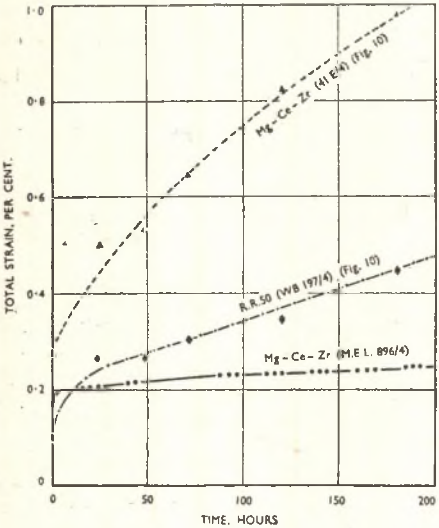

FIG. D.—Total Strain *versus* Time for Magnesium–Cerium–Zirconium Alloys and " R.R. 50" Alloys at 4·0 tons/in.² and 200° C.

In order to supplement the paper, a number of Magnesium Elektron, Ltd., results are given in Table B. All the tests were carried out at 200° C.

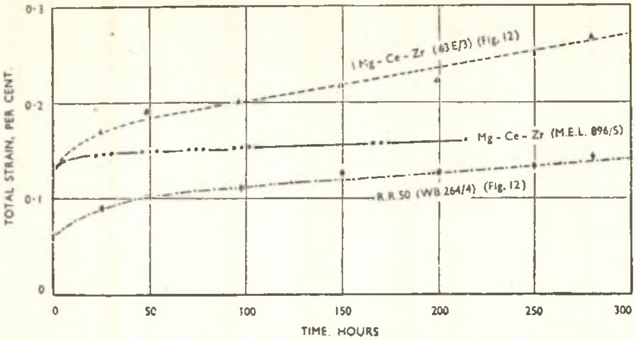

FIG. E.—Total Strain *versus* Time for Magnesium–Cerium–Zirconium Alloys and "R.R. 50" Alloys at 3·0 tons/in.² and 200° C.

TABLE A.

Test Bar.	Grain-Size, mm.	Cerium (as total rare earths), %.	Zirconium, %.
As used in Fig. 9 . . .	...*	2·67	0·4
As used in Fig. 12 . . .	0·025–0·03 †	2·57	0·49
Magnesium Elektron, Ltd., Melt 896	0·03–0·05	2·58	0·66

* From room-temperature properties, this bar probably had a grain-size of about 0·1 mm.

† Derived from the authors' Figs. 5 and 6.

TABLE B.

Alloy.	Stress, tons/in.²	Total Strain at 120 hr.	Creep Rate, 100–200 hr.
Mg–Ce–Zr *	3·0	0·151 (0·32; 0·21)	4×10^{-7} (0; $3·2 \times 10^{-6}$)
	4·0	0·235 (0·82)	$2·0 \times 10^{-6}$ (29×10^{-6})
	4·5	0·390	$7·7 \times 10^{-6}$
	5·0	approx. 0·8	36×10^{-6} †
Mg–Ce–Zn–Zr ‡	3·0	0·135 (0·32)	$2·2 \times 10^{-6}$ (0)
	3·0	0·135 (0·32)	$1·6 \times 10^{-6}$ §
	4·0	0·243	$3·3 \times 10^{-6}$
	4·5	0·329	$5·8 \times 10^{-6}$
	5·0	0·9	22×10^{-6} †

* Nominally magnesium–3% cerium–0·5% zirconium.
† Rate at 150–200 hr.
‡ Nominally magnesium–2·5%cerium–2·5%zinc–0·5%zirconium.
§ Rate between 200 and 800 hr.

Where available, Murphy and Payne's values are given in parenthesis.

It will be seen that in all cases the authors' values are " pessimistic ", and that the creep properties of the alloy are in reality superior to the very encouraging values given in Murphy and Payne's paper. The apparent difference between the zinc-free and the zinc-containing alloy is not felt to be of any significance, since broadly speaking the orders of creep rates are comparable and the differences not constantly in favour of one alloy or the other. So far as is known, this also applies to the " R.R. 50 " alloy, and an approximate curve for " R.R. 50 " is given for comparison in Fig. C. In general, it would appear that while the relative values given by the authors' tests are correct, for some unexplained reason the conditions are such that excessive values are reported for both creep rate and initial strain.

Commenting on the values given in Fig. 15 on p. 121, we have not experienced any tendency towards loss of ultimate tensile strength at 200° C., and in certain melts have actually observed an increase. It is suggested that the ultimate-tensile-strength–temperature curve should be horizontal, or practically so, up to a temperature of 200° C., falling off smoothly thereafter more or less as indicated by the authors. We are in complete agreement with the form of the elongation–temperature curve.

The AUTHORS (*in reply*): Mr. Wilson's communication raises a number of interesting points regarding the creep properties of magnesium alloys containing cerium.

It is interesting to speculate as to how cerium produces its beneficial effects upon the high-temperature properties of magnesium alloys and whether the intercrystalline eutectic network is of special significance in this connection. It is agreed that Beck's work shows that alloys containing cerium, in amounts which would be either in solid solution or present as a fine dispersion, exhibit better creep properties than the ordinary magnesium–aluminium–zinc alloys. It is, however, to be remembered that Beck was working with wrought materials (alloy AM537) and that the temperature used for his creep test was comparatively low (140° C.). Had the AM537 alloy been tested at 200° C. (as used in our own tests) its creep-resisting qualities might not have been thought outstanding. A further point to be noted from Beck's work is that even better creep performance is obtained with a 6%-cerium alloy (alloy AM6), which contains far more Mg_9Ce than can be held in solid solution.

In our own work with cast materials so far, we have found really good creep resistance only in alloys with fairly high cerium contents (2·5% or more); cast alloys containing amounts of cerium similar to that in the AM537 alloy (0·5%) show indifferent creep properties. The compositions which show a high resistance to creep all contain considerable amounts of the second phase, which in the case of magnesium–cerium–zirconium alloys appears in the form of a largely-continuous intercrystalline network. Annealing treatments at 350° C. or over, which tend to break down the continuity of the network structure, impair the creep resistance of the materials. The indications of our work are, therefore, that the more or less continuous envelope of eutectic around the magnesium grains, which appears to be characteristic of magnesium–cerium–zirconium alloys, is a significant factor in connection with their good creep properties.

The simple and relatively crude creep-testing apparatus used in our work was regarded as suitable for the rough classification of alloys which constituted its *raison d'être*, but was not looked upon as a satisfactory alternative to the more accurate equipment conventionally used. The apparatus justified itself by showing the potentialities of the magnesium alloys containing cerium, at a time when more accurate and elaborate machines were not available; and, taken broadly, the conclusions reached from our work are reliable. It would, however, be unwise to base firm conclusions regarding, say, minute differences in creep rate as between one alloy and another, on the results obtained, and tests with equipment of higher precision are obviously called for; in any case those with experience in creep testing will know that the order of reproducibility of results is frequently such as to discourage hair-splitting comparisons, and that conclusions are most safely based on tests using a fair number of specimens.

The apparent difference between the creep performance of alloys of a high and low degree of grain refinement upon which Mr. Wilson comments is an obvious case calling for tests with apparatus of higher precision than that used in our first survey of the cerium containing-alloys, and for tests on more than one sample. We planned many months ago to carry out such tests to establish definitely whether a very high degree of grain refinement really acted to the detriment of good creep resistance, but this has been crowded out by more pressing calls upon our creep machines. We had regarded it as a matter of considerable theoretical interest but, at the present stage of development of the alloys, of secondary practical importance. Even if it could be shown that some slight advantage as regards creep performance was to be derived by using material with only a moderately fine grain, the indifferent mechanical properties at ordinary temperatures would make the material unattractive to designers, and formidable problems of grain-size control would be encountered in the foundry.

Mr. Wilson will be interested to know that since the paper was published we have carried out many creep tests on cerium-bearing alloys, using more refined creep machines. With these machines, the specimens were maintained at temperature throughout the course of the test, and were continuously under load: the results are therefore comparable with those obtained in other laboratories. These later tests confirmed that our earlier work had placed the different materials in the correct order, but, like Mr. Wilson, we found that the creep-resisting properties of all the alloys we had tested were actually better than as represented in the original paper. Our results generally agree quite well with those given by Mr. Wilson for magnesium–cerium–zirconium alloys in Table B, and in particular confirm the excellent creep behaviour of the 3%-cerium alloy under a stress of 4 tons/in.^{2} at 200° C. Our values for creep rate and creep strain for the alloy tested under these conditions appear below; the values given represent the mean of four independent determinations.

Creep Performance of Magnesium–Cerium–Zirconium (Cerium 3, Zirconium 0·6%) at 200° C. Stress: 4 tons/in.^{2}

Creep rate after 120 hr. . . .	$2{\cdot}1 \times 10^{-6}$ mm./hr.
Total strain after 120 hr. . . .	0·22%

It is difficult to find a completely satisfactory explanation for the marked differences between creep curves made for the same material using our simple apparatus and equipment of more conventional design. Among the factors which may have had a bearing on the differences in the curves produced are these:

(1) With the simple equipment, the stress is applied in the cold and before the test proper commences. With regular creep-testing equipment, stress is applied to the specimen after temperature has been stabilized, a process usually involving heating for about 24 hr.; in the course of these preliminaries considerable precipitation-hardening can take place with an alloy such as R.R. 50, and this may have a marked effect upon the creep behaviour of the material.

(2) The shoulders on the test specimens used with the simple creep apparatus may have led to some concentration of stress at the radii. No abnormal reduction of cross-sectional area of the specimen was observed at

these points, but the stresses may, nevertheless, have been higher than was intended.

(3) The interruption of the creep test using the simple apparatus may not have been without effect upon creep performance.

Factor (1) will have had the predominant influence in respect to the R.R. alloy, and a further point to be noted in making comparisons between Figs. 9 and 12 is that the materials relating to Fig. 12 were given a long annealing (68 hr.) treatment at 200° C. before the test began.

Mr. Wilson's suggestion regarding the true form of the curve relating ultimate stress and temperature for the magnesium–cerium–zirconium alloys is noted. An explanation of the different results obtained in the two laboratories may lie in the salts used for incorporating zirconium in the melt; our own tests were made using salts based on the chlorides of the metal and Mr. Wilson's tests with the more complex mixtures developed at a later date.

JOINT DISCUSSION ON MR. E. R. W. JONES AND MRS. MARION K. PETCH'S PAPER: "THE VARIATION IN CORROSION PROPERTIES OVER TWO MAGNESIUM ALLOY SHEETS"; DR. F. A. FOX AND MR. J. K. DAVIES'S PAPER: "THE CORROSION OF SOME MAGNESIUM-BASE ALLOYS (HIGH AND NORMAL PURITY) IN CONTACT WITH OTHER METALS"; AND MR. C. J. BUSHROD'S PAPER: "NOTE ON THE QUANTITATIVE IMPLICATIONS OF HANAWALT'S THEORY OF CORROSION OF MAGNESIUM-BASE ALLOYS." *

(*J. Inst. Metals*, this volume, pp. 129, 553, and 567.)

Dr. H. Sutton † (Member): Rarely do we have such a feast on the science and technology of magnesium corrosion as these three papers provide. They all bear on the very intriguing subject of the corrosion properties of magnesium-rich alloys, and they touch in a very important manner on the influence of various factors on those corrosion properties.

I should like to refer first to the paper by Mr. Jones and Mrs. Petch. It might well be asked whether the particular sheet of magnesium–manganese alloy on which the authors worked was abnormal in its variation in apparent corrosion-resistance from part to part in the sheet. It is realized, of course, by all readers of the paper that under the conditions used by the investigators there was a very substantial variation, or apparent variation, in corrosion-resistance from part to part in that particular sheet. The authors refer in the paper to previous observations on another sheet which led to the experiments which they themselves made, and they were quite well aware of big variations in the corrosion-resistance of sheets of this particular alloy at that time; it would be interesting if they could comment on that in a general way—they probably have more information than they were able to put in the paper.

From the date of the experiments it seems to me probable that the sheet had been rolled from extruded stock, and it is quite probable that sheet made by modern technique from d.c. cast stock would show very much less variation of iron content at the surface over the individual sheets. I believe, however, that such sheets were not available commercially at that time.

Presumably, the abbreviation "app." in Table I represents the word "approximately". As it occurs between two values of iron content there, it would be useful to know whether it refers to both of these, or only to one. This paper does bring out in a very useful way the great importance in modern

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* Discussion at the Annual Autumn Meeting, Glasgow, 25 September 1947.

† Ministry of Supply.

metallurgical technique of knowing as accurately as possible the amount of impurities present. The fact that the magnesium alloy sheets to specification D.T.D. 120A showed only moderate variation in corrosion-resistance from place to place under the conditions used by the authors may have been due to the general iron content being very much higher than the tolerance limit for iron under their test conditions. It may be that at a higher iron content the degree of corrosion would be substantially greater. What do the authors feel about that, and was their iron content in the D.T.D. 120A alloy already so high that a slight variation would not influence the results very much? Hanawalt, Nelson, and Peloubet place the tolerance limit for iron in this class of alloy at about 0·002%.

A point of special interest is the correlation of iron content and corrosion-resistance shown in the authors' experiments with the magnesium–manganese type of sheet. I think that Fox and Bushrod, in earlier work, found that iron-content variations were not by any means critical in this alloy, but their conditions of test were very different. I hope that they will comment on this apparent discrepancy between the work of Jones and Petch and their own earlier work.

The apparent tolerance limit for iron shown by the work of the present authors is somewhat lower than, but not far removed from, that shown for specially prepared magnesium by Hanawalt, Nelson, and Peloubet, the American investigators. It is desirable always to bear in mind a few factors which may have great influence. The present authors used chromate-treated samples. I would not criticize that, because magnesium alloys are commonly used in the chromate-treated condition; but other investigators have not consistently used chromate-treated samples.

Another factor is the condition of the corrosion tests. Fox and Bushrod, and Hanawalt, Nelson, and Peloubet have used immersion tests or alternating-immersion tests very extensively and usefully, whereas Jones and Petch have used the spray tests, which are also very informative under suitable conditions.

Had Jones and Petch been commissioned to study tolerance limits, I am sure that they would have proceeded quite differently. They were not setting out, however, to determine tolerance limits. Their experiments show that there is indeed a very considerable variation in corrosion-resistance, showing very steep gradients across the sheet; and they would be the first to agree that a material of that class would be by no means ideal when setting out to make studies of tolerance limits.

The fact that the magnesium alloy sheet to specification D.T.D. 120A showed only moderate variation in corrosion-resistance may, of course, have been due to the fact that I mentioned, of its iron content being already rather high. There has been some interesting Canadian work in this connection. I was privileged to see in Canada in February last some work by Rogers and Dingley, of the National Research Council. These gentlemen worked on high-purity magnesium alloys of the aluminium-bearing type, with 8% aluminium, and they discovered that, under the conditions of their tests, the addition of small amounts of silver and lead to the 8%-aluminium alloy, with small and normal additions of zinc and manganese, gave an improvement in corrosion-resistance. A particularly interesting point is that additions of lead or silver should improve the corrosion-resistance in such circumstances.

It may be that lead in series is a very bad cathode; its potential is so disposed that it is a cathode, but it may be a very bad one. I should like to ask the authors of all these papers whether they do not feel that cathodic control by lead might be arranged in such a way that in a high-purity alloy corrosion could be restrained by providing a bad cathode in the form of lead, the overvoltage (H) being high and of benefit.

Dr. Fox and Mr. Davies have given some interesting results in their paper.

The conditions of their tests are, of course, very severe, and I would caution potential users of magnesium from outside the industry not to be too discouraged by some of the pictures of their corrosion samples. I should like to ask the authors whether, in reference to the influence of cathodic points in their pictures of M5A, they would not expect the provision of a really good cathode, in the form of a brass attachment, for instance, to mask the cathode–anode effects on the surface of the magnesium itself, especially under total-immersion conditions? They observe less gas evolution from cathodic points under the latter conditions, and I can see no reason for expecting otherwise; but possibly they can.

They favour zinc as a metal to be allowed to be in contact with magnesium, but I would remind them that under humid tropical conditions zinc is very prone to develop "snow" and corrode itself. It requires chromate treatment and other restraints under tropical conditions. Have the authors of all the papers had any experience of the contact of lead with high-purity magnesium or magnesium alloys?

Mr. Bushrod's paper is very interesting, and his curves certainly show a very pleasing correspondence between his own observed results and the results calculated from his analysis. I gather from his paper that some of the more recent curves show decreasing rates of corrosion with increase of time, and I would remind him that some of the curves recorded by Dr. Whitby a few years ago also showed that tendency.

Dr. F. A. Fox: I should like first to make a few remarks about the paper by Mr. Davies and myself, because its practical implications have not yet been brought out. The practical consequences seem to be these: if the risk of galvanic corrosion is great, and is likely to be decisive, then the use of a high-purity magnesium alloy would not seem to be justified. If, however, for other reasons the use of a high-purity magnesium alloy seems to be justified, and if, at the same time, galvanic contacts are unavoidable, and if those galvanic contacts are to be of aluminium alloys, then the aluminium alloys must themselves also be of high purity, otherwise any advantage in having selected the high-purity type of magnesium alloy is lost. If the galvanic contacts are other magnesium alloys which are less noble than the magnesium alloy under consideration, for example, if one is coupling Elektron AM503 to the alloy which was principally reported on in our paper, Elektron M5A, then the use of the high-purity alloy would be justified.

I should like now to say something about the paper by Mr. Jones and Mrs. Petch. This paper is rather difficult to comment on, because while the results are clear enough I find the interpretation not so easy as do the authors. The interest naturally centres round the effect of iron on the corrosion-resistance of the magnesium–manganese alloy sheet. It is to be noted that the Americans, when they brought out their "high-purity" specifications, did not lay down any iron limits for the magnesium–manganese alloy, although they did for all other types of magnesium alloy; and the work of Peloubet,* involving atmospheric-exposure tests, also pointed to the conclusion that the influence of iron on the corrosion of the magnesium–manganese binary alloy is not of decisive or even noticeable importance. The work which we did at Magnesium Elektron, Ltd., under conditions of immersion, led to the same answer, namely that the influence of iron in this alloy is of negligible importance.

This other evidence, which is strong and self-consistent, makes the correlation which is put forward in this paper difficult to explain. It seems to me that there are other causes of variation in the corrosion performance of a sample of sheet which may be of greater importance than variations in the iron content.

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* J. A. Peloubet, *Metals and Alloys*, 1945, **21**, 1327.

There could be, for example, local composition and impurity variations in nickel or in aluminium, or even in manganese. There could be local metallographic variation in the form of occurrence of iron or aluminium, if that is present as an impurity, or in manganese inclusions. There could also be a variation in superficial impurities such as rolled-in dirt or aluminium or even rolled-in iron particles on the surface, and there could be variations in the mechanical state, such as local differences in work-hardening, twinning, or orientation. The situation is, therefore, probably a good deal more complicated than might be imagined from just looking at the variations in iron analyses.

The authors claim that the contour maps given in Figs. 1 and 2 show that the iron variation is the main cause of the varying corrosion behaviour, but I do not think that their results justify as close a relation as they would suggest. The weight of this part of the paper seems, in fact, to be based on three results. If Figs. 1 and 2 are critically examined, it will be seen that in the upper right-hand part of the sheet, where the contours of Fig. 1 bulge outwards, there is only a 70% increase in corrodibility for an increase in iron content of from 0·0068 (presumably the figure of 0·0668% shown in Fig. 2 is an error) to 0·0128%, while in the lower right-hand part of the sheet there is an increase in corrodibility of 600% for an increase in iron content which is closely similar, i.e. from 0·007 to 0·0179%. The results, therefore, are not self-consistent, and the whole point of the discussion rests on the test results of three specimens, I17, L13, and L17.

The authors also assume at the beginning of section 3 (p. 136) that a corrosion contour map will appear on any magnesium alloy sheet. This may be so, but remains to be demonstrated by many more tests than the authors have reported. A further important question here is the one which Dr. Sutton has just touched on, and that is whether the authors consider the high or the low corrosion rates observed to be typical of the sheet alloy? The point is that D.T.D. 118 usually carries about 0·02–0·03% iron, which is a higher iron content than the highest which the authors recorded. If the authors are right, and corrosion performance is a direct and exclusive function of the iron content, the worst of the specimens reported should still be better than the average performance for this particular alloy, since their highest iron content was 0·0179%.

The authors claim that their results are supported by those of Hanawalt, Nelson, and Peloubet,* and show in Fig. 3 a curve derived from the work of these authors. However, it must be emphasized that this curve is not for material equivalent to D.T.D. 118, but applies to magnesium sheet free from alloying additions except iron. Moreover, even if Hanawalt, Nelson, and Peloubet's curve had not been inappropriate, the authors' statement that their results are in agreement with it seems to be incorrect. According to the American researchers' curve reproduced in Fig. 3, the whole of the sheet dealt with in Figs. 1 and 2 would have given similar and satisfactory corrosion performance, again with the exception of the three high results in the bottom right-hand corner, since the Americans maintain that the corrosion rate of magnesium and of magnesium containing 1% of manganese is independent of iron content, if this is below 0·017%. There is an essential difference between the authors' curve and that of Hanawalt, Nelson, and Peloubet; the latter, in fact, consists only of a vertical line cutting the iron-content abscissa at 0·017%, while the curve which the authors have drawn shows a gradual change in corrodibility with iron content. Moreover, Hanawalt, Nelson, and Peloubet say (on p. 7 of their paper) that though on adding 1% manganese the tolerance limit of magnesium for copper and iron is unchanged, the "increase in corrosion rate due to copper or iron above their respective tolerance limits is considerably reduced by the presence of about 1·0% of manganese or zinc". Two of the three critical specimens have iron contents below the Hanawalt limit of 0·17%, while the

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* *Trans. Amer. Inst. Min. Met. Eng.*, 1942, **147**, 273.

third, with 0·179%, only just exceeds it, and, in view of the above-mentioned remark of the American workers, would not be expected to involve a heavy corrosion increase of the order of 600%. Agreement with American work therefore seems very meagre.

I would also direct attention to a recent publication,* in which, as a result of a considerable amount of work on Elektron AM503, my collaborators and I bring forward further evidence that, under conditions of total immersion, there is no significant correlation between iron content and corrosion rate for the cast alloy. It is to be expected that similar results would obtain for wrought material of similar composition, such as the authors have examined.

There is, therefore, something obscure in the interpretation of the results of this paper, which after all, is concerned with the behaviour of only two sheets, one of which was not abnormal. The weight of evidence indicates that there was something peculiar about the magnesium–manganese sheet used by the authors, rather than that any general relationship, between iron contents of the amounts concerned, and corrosion behaviour, can be inferred for this alloy.

As far as the paper by Mr. Bushrod is concerned, I should like to congratulate him on a very elegant piece of work in attempting to deal with the Hanawalt theory of corrosion on a semi-mathematical and statistical basis.

DR. BRUCE CHALMERS † (Member): I wish to make one point in connection with one of these papers, namely that by Jones and Petch, and it is in relation rather to technique than to results. It has often been the practice in corrosion investigations to carry out tests on the duplicate or multiplicate specimens, take the average result, and try to correlate that with the other conditions under investigation. Here we have a case in which the scatter was investigated between results for what had previously been thought to be replicate specimens, and this is an essential factor in using the modern statistical technique of investigation on a problem of this kind. The scatter between results from the same sheet has been investigated rather closely in this case, and certain results have been shown by approved statistical methods to be significant.

It cannot be denied that there is in fact a correlation between iron content and the rate of corrosion. That does not suggest that this is the only factor, and I do not think that the authors imply that in any way; but the paper makes it quite clear that one of the factors which control the rate of corrosion, under the conditions of test here in question, is the iron content of the sheet at the point where the corrosion test is made, unless one is prepared to say that a probability of less than 1 in 999 is not significant. For most practical purposes and for most theoretical purposes as well, one is absolutely content with such a probability.

DR. F. A. CHAMPION ‡ (Member): I shall confine my remarks to the paper by Fox and Davies. Dr. Fox has already directed attention to the interesting effect of the purity of the aluminium when in contact with magnesium of different purities. I should like to clear up, therefore, an unfortunate confusion in the paper regarding the terms normally used for those purities of aluminium. The terms are correctly given in the penultimate paragraph on p. 554, namely "super-pure" aluminium and "high-purity" aluminium, but in the remainder of the paper different terms are used. That is of some importance, in view of

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* F. A. Fox, C. J. Bushrod, and S. E. Mayer, *J. Inst. Metals*, this volume, p. 55.

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‡ Research Laboratories of the British Aluminium Company, Ltd., Chalfont Park, Bucks.

the fact that the super-purity aluminium which is shown to be advantageous is now available in greater quantities than it has been in the past.

It seems probable also that the corrosion observed with aluminium is rather on the high side, since the authors have used 5% hydrochloric acid for cleaning the specimens after corrosion. That acid does attack aluminium, and it seems certain that some further loss would be incurred in that way. Personally, I would recommend concentrated nitric acid, preferably containing 5% chromic acid, at a temperature not exceeding 30° C., for cleaning aluminium and aluminium alloys after corrosion.

I should like to utter a word of warning with regard to Table IV. For comparison with the coupled specimens it is essential to know the corrosion which has occurred with uncoupled specimens, and the immersion times have been adjusted correspondingly; but, since the authors have actually calculated the corrosion rate without pointing out that that is the mean corrosion rate for the times which they have used, there may be a tendency for some readers to use that Table for a general comparison of the corrodibility of the different metals listed. With many of those materials, the corrosion rate will vary with the time of exposure (see, e.g. Table V), and therefore such a comparison is quite unjustifiable.

MR. C. J. BUSHROD : I wish to make a few comments first of all on the paper by Mr. Jones and Mrs. Petch. I have read it several times with great interest, largely because I find the results very mystifying. I have been searching for some loophole which would show why it is that their results are so very different from those which we obtained in our laboratories. We have had the opportunity of very free discussion with the authors, and we have in fact repeated their tests, cutting up a large number of sheets of this type and making corrosion tests by continuous-immersion methods and atmospheric methods, but in no case have we observed any variations of the type which the authors have obtained. As far as we could ascertain, these particular alloys are very insensitive to the presence of iron.

Nevertheless, there are very difficult facts to explain, in that two samples from a standard sheet of this alloy, one from the middle of the sheet and one from the bottom right-hand corner, corroded at rates which differ by a factor of 12. That is an enormous difference, and it is all the more difficult to explain because we have had no success at all in trying to reproduce it. However, those are the facts, and the authors have tried to relate them to the varying iron content of the sheet. That is what I should like to criticize, because from Fig. 3 we see that plotting the corrosion rate against the iron content gives a cloud of points through which a rather optimistic curve has been drawn.

The authors have applied statistical analysis to this. It is an elegant method, but it is not necessary, because if one looks at the points at the bottom of the curve it is obvious that there is a relationship between corrosion rate and iron content.

There is one point which I should like to make about the statistical analysis. The correlation coefficient of 0·681 is, the authors say, very strong, and only in less than 0·1% of cases would chance effects produce this apparent association. Dr. Chalmers has suggested that this method leads one to feel that the results are on a very sound basis, but the point is that a correlation coefficient, however strong, does not tell one the amount of association; it does not say how much the corrosion increases for a given increase in iron content. Nor is it evidence of causation, and that is the most important point of all. There are some extraordinary correlations which can be made. For example, the decrease in crime between the wars coincided closely with the drop in attendance at services of the Church of England, but no one would seek to find a real association there, although the correlation was stronger than this one. What I am driving at is that although the correlation is strong, I do suggest that there is some other factor, associated with the iron, which causes a varying corrosion rate.

We have in fact observed this kind of thing, and the results were published in a paper by Dr. Fox, Dr. Mayer, and myself. We poured a large billet of Elektron AM503 and allowed it to cool slowly in order that any manganese particles present might settle to the bottom. Segregation of iron also occurred, resulting in the lower portions of the billet being rich in iron. Corrosion specimens machined from the bottom of the billet corroded more rapidly than those from the top. Strong correlations were found to exist between iron content and corrosion rate, between manganese-particle concentration and corrosion rate, and between manganese-particle concentration and the incidence of iron. On further examination of these relationships, it was found that the increase in corrosion rate apparently associated with increasing iron content was in reality associated with the increasing manganese-particle concentration; the effect of iron became insignificant and reduced the question to a fairly simple issue. I cannot understand the results obtained by Jones and Petch, and I have tried to put forward some alternative explanation merely because we found it quite impossible to duplicate them.

The paper by Dr. Fox and Mr. Davies is a most interesting one, the most interesting of its type which I have read, and it has a tremendous practical impact. In going through it, I was particularly interested by the comparisons in Table IV, where Elektron magnesium-base alloys are compared with other alloys, including some noted for their very good corrosion-resistance. The comparison is very striking, and should do much to dispel pessimism with regard to magnesium alloys, if any still exists.

In Table VI, some very interesting results are quoted where M5A alloy of normal purity was coupled with various other metals, using small and large washers. The corrosion rate of the magnesium-base alloy is in all but the last two cases independent of its purity and of the nature of the washer separating it from the coupling metal. With zinc-plated and cadmium-plated mild steel, the corrosion rate drops considerably. There is convincing evidence here that the corrosion of M5A is, as the authors suggest, cathodically controlled. Normally when a corroding metal is subject to cathodic control, one assumes that the anodes are virtually unpolarized; however, in the case of magnesium alloys the potential of the corroding alloy (about — 1·4 V.) is so much higher than the standard electrode potential of magnesium (about — 2·5 V.) that there must be considerable anodic polarization. This fact was emphasized by Gatty and Spooner,* and they suggested that the origin of the anodic polarization lay in the ohmic resistance of the electrolyte filling the pores in the anodic film. The results given in Table VI are of very great significance, and, turning to the Plates relating to Table VI (Figs. 4 and 5, Plates LIII and LIV), it can be seen that the attack on the specimens coupled to brass, aluminium bronze, and mild steel is very severe, particularly near the junction, while in the case of the specimens coupled to the cadmium-plated and zinc-plated materials the attack is more or less uniform. In short, in cases where the heavy metal provided a low overvoltage channel of escape for the hydrogen, corrosive attack on the magnesium was greatly accelerated, particularly at points close to the junction. On plating mild steel with materials (cadmium and zinc) possessing high overvoltages, the attack was only accelerated appreciably when the magnesium specimen was of high purity, and even then the rates were much less than for the other similar specimens coupled to the unplated metals. This shows conclusively that the cathodic polarization is even more marked than the anodic when magnesium alloys corrode in aqueous salt solutions, and this is particularly true of the high-purity alloys.

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* O. Gatty and E. C. R. Spooner, " The Electrode-Potential Behaviour of Corroding Metals in Aqueous Solutions ". London : **1938**.

The results recorded in Table VII, of the corrosion of specimens of coupled M5A and aluminium, are of particular interest, and the authors' suggestion that the alkali developed at the cathodic aluminium is responsible for the attack on this metal is at once ingenious and convincing. I should like to stress, however, that the results show that when high-purity M5A is coupled to high-purity aluminium, the magnesium-base alloy receives considerable protection; it would thus seem that, in spite of the authors' discussion on p. 564, the magnesium alloy is definitely cathodic to the aluminium.

I do not feel that it is quite legitimate to use the corroding potentials of partially immersed specimens in interpreting the results of complete-immersion corrosion tests. The error introduced may not be of importance with magnesium alloys, where the cathodic process is almost inevitably a hydrogen-evolution reaction. With more noble metals, aluminium bronze is a particularly good example, conditions of partial immersion allow the access of oxygen, and the corroding potential is correspondingly raised. In addition, when potential measurements are used to assess the effect of coupling two corroding metals, it is probable that the measurement of the potentials of the two metals before and after coupling is more informative than the method used by the authors, in so far as the observed potential shift of each metal permits a fairly accurate deduction to be made as to the role played by each metal in the corroding couple.

MR. J. K. DAVIES: I should like to say a few words on the paper by Mr. Jones and Mrs. Petch. I do not agree with the authors' conclusion that the variation in corrosion-resistance over the Elektron AM503 sheet was directly associated with the variation in iron content. As previous speakers have said, there are other factors which influence the corrosion-resistance of this alloy. Probably the most important of these other factors was noticed by the authors in X-ray- and micro-examination, namely that the structure of the sheet had not completely recrystallized during the annealing treatment and areas of twinned crystals remained. The authors also observed that the specimens which corroded worst showed a greater number of twinned crystals.

It is well known that in the case of Elektron AM503 alloy, strained areas behave cathodically to unworked or less-strained areas. A familiar example of this is that when an Elektron AM503 corrosion-test specimen is stamped with an identification number, no matter how severe the corrosion the stamp will always remain perfectly clear, even though the rest of the specimen may be corroded away nearly completely. In contrast, the stamped area in aluminium-containing alloys is the very first to be attacked, and this frequently leads to considerable difficulty in identifying the specimens after corrosion testing.

The variation in hardness over the sheet might possibly account entirely for the scatter in the corrosion results. It is of interest to note that the "contour map" of corrosion losses shows a lower corrosion-resistance at the edge of the sheet than at the centre. This could easily be associated with the greater effective rolling reduction towards the edges of the sheet, which is, of course, quite normal in rolling practice.

There is, however, another factor, to which Mr. Bushrod has directed attention, namely the possible variation in the number of free manganese particles from specimen to specimen. Whitby in 1933 showed that particles were undesirable since they caused galvanic corrosion, and, in fact, the nominal manganese content of Elektron AM503 was reduced by Magnesium Elektron, Limited, in 1939 from 2·2% to its present value of 1·5%, with the object of reducing the number of primary manganese particles. The idea is, therefore, not new, but I should like to show a few slides taken from work carried out by Mr. Bushrod at Magnesium Elektron, Ltd., illustrating the importance of manganese particles with regard to the corrosion-resistance of this alloy.

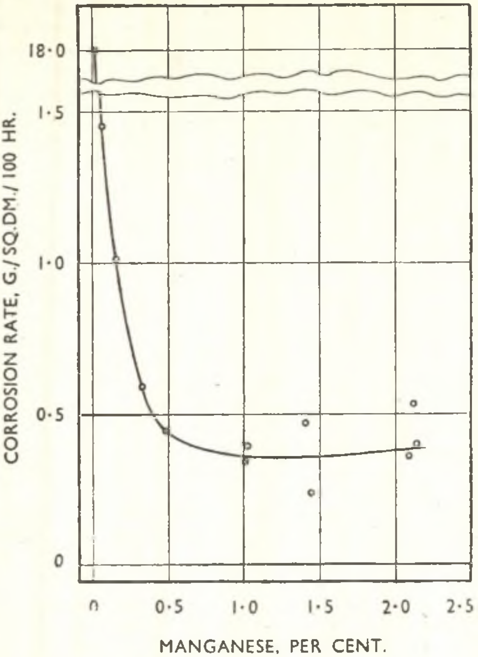

Fig. A.—The Corrosion Rate of Magnesium–Manganese Alloys as a Function of Manganese Content.

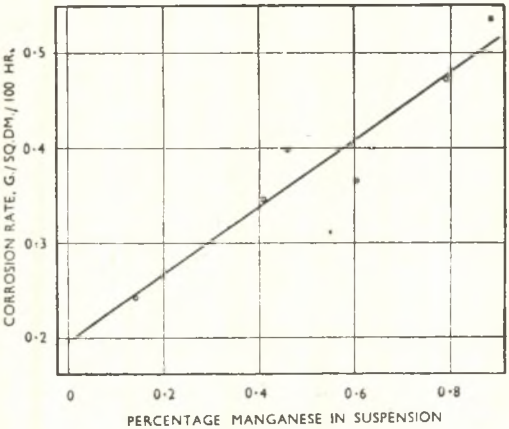

Fig. B.—The Influence of Manganese Particles on Corrosion Rate.

Fig. A shows the corrosion rates of a series of binary magnesium–manganese alloys plotted against the manganese content. It can be seen that up to about 1% manganese the corrosion rate decreases, at first rapidly and then more slowly as the manganese content increases; but in the range of 1–2% manganese there is considerable scatter, and the corrosion rate appears to be independent of the manganese content. In this range, the alloys had a constant iron content of 0·03% and were free from flux inclusions and microporosity, so that the observed scatter could not be attributed to these factors.

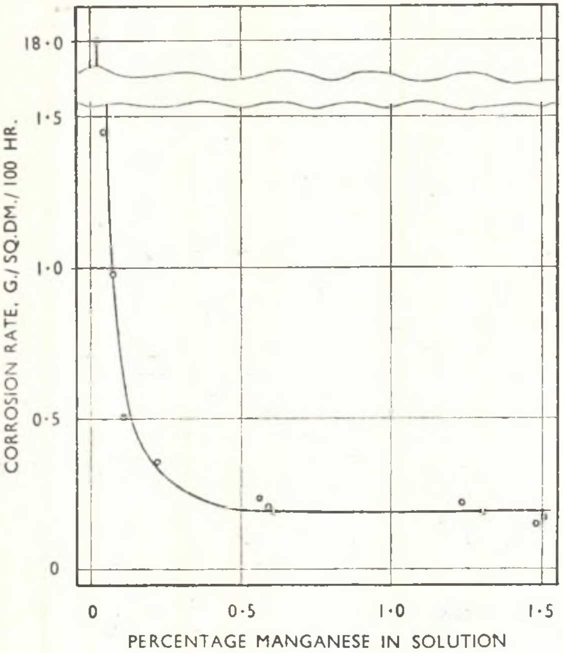

Fig. C.—Calculated Corrosion Rates in Homogeneous Magnesium–Manganese Alloys.

Mr. Bushrod developed a method of estimating the amount of manganese in suspension by a microscopic technique, and he applied the method to these results, plotting the corrosion rate against the amount of manganese in suspension as primary particles. As will be seen from Fig. B, the points fell on a straight line, and, as a result, it was possible to assess from the graph the fraction of the observed corrosion rate which was due to the galvanic-corrosion effect of the manganese particles. A correction was made to all the observed corrosion rates shown in Fig. A, and they were re-plotted against the amount of manganese actually in solution in the alloy. This is shown in Fig. C, and it can be seen that the scatter has been very largely eliminated.

It is true that the results shown in these three graphs are not strictly comparable with those from the work done by Mr. Jones and Mrs. Petch, since the tests were carried out on as-cast material. However, since it is not possible to remove manganese particles by solution treatment &c., they do suggest that the distribution of manganese is an important factor influencing the corrosion-resistance of Elektron AM503 alloy, especially when considering an alloy containing as much manganese as that used by the authors, i.e. 1·8%.

I have one question to put to Mr. Bushrod, arising from his paper. The correlation between his mathematical reasoning and practical corrosion-test results is remarkably close, and it would appear that Hanawalt's theory had been proved. However, as is stated at the end of the paper, this theory is, in all probability, incorrect. It therefore seems that the author, in writing the paper, has worked from an unwarranted assumption, and I should like to ask Mr. Bushrod which of his assumptions was unwarranted.

MRS. MARION K. PETCH,* M.A.: In discussing Mr. Bushrod's paper, I would not like to criticize his mathematical processes; I am sure they are correct. If, however, one studies the equation at the bottom of p. 568, it would seem that for a corrosion rate which increases with time, such as one does apparently get in practice, it would be necessary for $N - \frac{1}{V}$ to be positive. This means that NV must be greater than 1, which, if taken to the limit, implies that more material must ultimately corrode than is present in the original material. We can only assume that one of the author's original assumptions is incorrect. This may be due to the fact that he has applied a necessarily continuous approach to a process which is inherently discontinuous.

There is, however, another possible source of error. The author in his analysis must have made one of two assumptions—either that the distribution of iron particles in the plane parallel to the surface of the material is very different from that in planes perpendicular to the surface, or that the corrosion pits due to individual particles are considerably deeper than they are wide. One or the other of these assumptions is involved in the supposition that the spheres of influence of corroding particles in the surface do not overlap, yet further particles are revealed by the removal of metal by corrosion due to the original particles. These two possibilities are illustrated in Fig. D. It would be of interest if the author could tell us which of these two assumptions was made, and what reasons he had for making it.

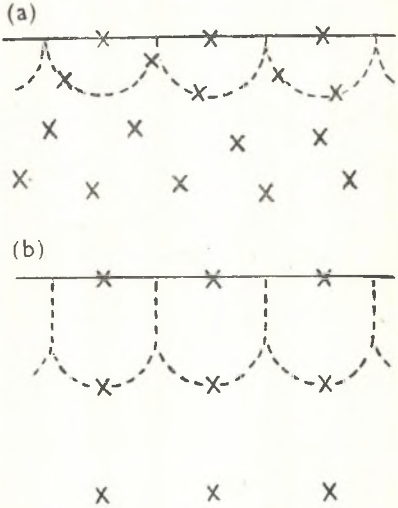

FIG. D.—(*a*) Hemispherical Pits; closer packing perpendicular to surface than parallel to it. (*b*) Equally Spaced Particles; deep pits.

It is not clear whether the *n* used in the paper refers to the number of particles exposed per square centimetre of original surface or of corroded surface.

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The actual surface area would be by no means constant, and corrosion rates based on n would not represent experimentally determined corrosion rates unless n refers to original surface. In this case, it is difficult to visualize n changing exponentially with time. It might be expected that more particles would be exposed during the initial stages of the corrosion process, but it seems likely that the curve of n plotted against time would become undulating as the corrosion proceeded and particles were exposed and fell out.

The author also assumes that V, the amount of corrosion due to any particle, is constant during the corrosion process. If the number of particles exposed is increasing, as is demanded by the mechanism under consideration in order to give an increasing corrosion rate, it seems very likely that V will not be constant, as the spheres of influence of an increasing number of particles are almost certain to overlap.

It seems, therefore, that the corrosion process, whatever it may be, is controlled by far too many unknown factors to be considered by a simple mathematical treatment such as Mr. Bushrod's, and the application of rigid mathematics is inclined to lead to untenable conclusions.

Mr. E. R. W. Jones * : I am in general agreement with Mrs. Petch on the subject of Mr. Bushrod's analysis, but I should like to ask him about the applications of it to the experimental results. Firstly, has he any evidence that this exponential curve is actually a better fit than any of the other curves one can think of which give an increase in corrosion with time, such as a power series, $C = at + bt^2 \ldots$ and so on. A second major point is the constancy that Mr. Bushrod has assumed for his $N - \frac{1}{V}$ in comparing the results on the two iron contents. He has not said whether N has been shown to be roughly constant, say by micro-examination, and I cannot see why V should remain roughly constant when one gets, if N is constant, a two-fold change in radius. I would expect that V would be a function of the radius of the particle which was being corroded out; in the limit, if corrosion proceeded neatly all round the particle, V would be proportional to R^2. In view of these points, I cannot help feeling rather doubtful about the agreement between the theoretical figure of 2 and the practical ratio of 1·92, and I should like some further details.

CORRESPONDENCE.

Dr. W. F. Higgins † : I have read the paper by Mr. Jones and Mrs. Petch with great interest, but it occurs to me that an appeal to methods of statistical analysis is quite out of place in experiments involving a mere score or so of specimens. Though such a device conforms to the modern fashion, a common-sense inspection of the results reveals all that is significant in the experiments. That an increase in iron (and other impurities) may lead to an increased rate of corrosion of magnesium alloys in general is too well attested to require comment. If the impurities of a large sheet vary from place to place, then the corrosion rate of the various sections is likely to vary too, and this is all that the experiments have shown to occur. Indeed, it is quite probable that as the impurity content alters over the whole area, a corresponding variation in

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† Magnesium Elektron, Ltd., Manchester.

corrosion rates will take place, but it is quite another matter to obtain the necessary data to draw a contour map of this effect.

If I have understood the paper correctly, analyses were made on the samples after they had been corroded. It is doubtful whether this procedure is permissible: the impurities leading to the particular corrosion which occurs are located in the surface and are removed to a greater or lesser degree in the process of corrosion; the analysis of the remainder of the specimen, therefore, is not necessarily a true indication of its *previous* corrosion rate. It frequently happens also, and this is in some degree connected with the above objection, that if a specimen once corroded is cleaned and submitted to the same process of corrosion again, then a quite different corrosion rate results—usually a lower rate in the case of sheet alloys such as Elektron AZM and Elektron AM503.

It is quite possible that the authors' contour maps are correct; on the other hand, I do not think they have proved their case. They had, and possibly still have, an opportunity of confirming their maps in a spectacular manner, and it is difficult to understand why they did not carry out the very obvious experiment of measuring the corrosion rates of other sections of the sheets lying on the contour lines (for they had many such available) and showing that they agreed with their previous findings.

My own opinion is that though contour phenomena of this type must exist in the nature of things, very much more refined methods of corrosion-rate measurement—and possibly of analysis too—are required before such maps can be drawn and their indications turned to good account.

The actual method of corrosion also seems open to some objection. It would surely have been better to have determined rates on bare metal surfaces rather than on chromate-protected specimens. The protection afforded by the chromate film is not of a high order, and is certainly variable. To measure rates of corrosion of specimens so protected, therefore, involves an extra and unnecessary variable which can serve only to confuse the issue.

Finally, terms such as AM503 and AZM are meaningless unless preceded by " Elektron ", indicating the nomenclature of a particular manufacture.

Dr. U. R. Evans,* M.A. (Member): The following remarks deal with the paper by Mr. Bushrod. Although the establishment of the existence of " tolerance limits ", by Hanawalt, Nelson, and Peloubet, constituted an important step forward in our understanding of the corrosion of magnesium alloys, it is possible that their original interpretation may require slight modification. Mr. Bushrod's note is to be welcomed, and p. 572, where he raises doubts as to whether the points from which hydrogen bubbles are evolved really represent particles of iron or similar metal, deserves special attention.

If the hydrogen is evolved from particles of impurities present in the original alloy, the tolerance limit should depend on their distribution, being lower for an alloy in which such particles are sporadically dispersed than in one where they tend to be concentrated along lines or in planes; one would like to know whether this is the case. Again, if hydrogen is evolved from pre-existing particles, the question as to whether corrosion will increase or decrease with time should, for any given alloy, receive the same answer for all concentrations of a given corrosive solution. In the research on the evolution of hydrogen from magnesium exposed to sodium chloride solution, carried out by Lewis and the writer,† the curves for concentrated solutions showed a falling off with time, while those for dilute solutions showed acceleration with time; doubtless this could be explained in more than one way, but it would seem that the

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* Cambridge University.

† K. G. Lewis and U. R. Evans, *J. Inst. Metals*, 1935, 57, 231.

situation is more complicated than the Hanawalt theory in its original form suggests.

Some information may be obtained from knowledge of the attack of acid upon zinc. Here we meet with three types of impurities :

(i) those present as a separate phase at the outset;
(ii) those present in solid solution; and
(iii) those originally present in solid solution, but later redeposited as a separate phase.

The writer's early work * on the behaviour of zinc in 1·3N-hydrochloric acid suggested that the impurities originally present as a separate phase may promote hydrogen evolution in the opening stages; microscopic observation showed that the bubbles came principally from a black network of residual impurities, which soon appeared along the grain boundaries. In the later stages, it was fairly certain that redeposited impurities were playing the main part in the evolution of hydrogen, which became very rapid. The work of Vondráček and Izák-Križko † showed that 0·5N-sulphuric acid attacked pure zinc at a fairly constant rate, but if the zinc contained about 1% of copper, iron, or antimony (metals of relatively low over-potential, which afford good liberating points for hydrogen), the velocity increased with time as the second metal accumulated on the surface. The alloy containing tin was at the outset attacked more slowly than pure zinc, probably because part of the tin was in solid solution, which would shift the potential of zinc in the noble direction, thus diminishing the e.m.f. of the corrosion element. As the tin entered the acid solution and was redeposited as a second phase, it was able to form cathodic points favourable to the liberation of hydrogen, and the rate of hydrogen production became far greater than that of pure zinc. Zinc containing lead, which, at the outset, will be present partly as a separate phase and partly in solid solution, showed an initial rate of attack far below that of pure zinc, although the rate increased with time. Apparently, the retarding effect of lead in solid solution outweighed the acceleration due to lead present as a separate phase.

If it is considered that, on magnesium, the points from which hydrogen is evolved are places where impurities have been *redeposited*, the question then arises whether magnesium containing, say, iron in solid solution, could produce redeposited metal. Supposing that magnesium and iron pass into solution together, two cathodic reactions become possible, the evolution of hydrogen and the redeposition of iron. In acid, or even in neutral, solution, electrochemical principles indicate the evolution of hydrogen as the most probable occurrence. When the solution becomes alkaline, through the presence of magnesium hydroxide, this will militate against the production of hydrogen, but it will also tend to precipitate the iron as hydroxide. The spontaneous formation of an iron nucleus must be regarded as an exceptional occurrence, but the probability of the formation of such a nucleus will greatly increase with the concentration of iron in the liquid layer next to the metallic surface. It is known that electroplating of nickel occurs more easily on nickel than on copper, and the redeposition of iron, once started, would probably occur with increasing readiness; the action would be explosive or autocatalytic. Thus, we have to consider the probability of finding, within a small volume, sufficient numbers of $Fe^{\bullet\bullet}$ ions to produce an effective nucleus, and this probability will increase with a high power of the concentration. Now the

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* U. R. Evans, *J. Inst. Metals*, 1923, **30**, 239; 1925, **33**, 27.

† R. Vondráček and J. Izák-Križko, *Rec. Trav. Chim.*, 1925, **44**, 376; R. Vondraček, *Coll. Trav. Chim. Tchécoslov.*, 1929, **1**, 627. See R. Piontelli, *Chim. e Ind.*, 1940, **22**, 109, for further information regarding the effect of lead in zinc.

mean concentration of $Fe^{\cdot\cdot}$ ions in the liquid next to the metal will be that at which the anodic production of $Fe^{\cdot\cdot}$ ions from the metal is balanced by the removal of iron as hydroxide, or by dissipation into the main body of the liquid, caused by stirring. From this it follows that when the concentration of iron in solid solution is very low, the chance of redeposition of iron as the second phase will also be very low, but that above a certain concentration the probability of iron redeposition may suddenly become high.

If the alloy contains, at the outset, particles of iron as a separate phase, these may act as nuclei for the redeposition of further iron. The tolerance limit will, however, not correspond to the solubility limit, for two reasons :

(i) Owing to supersaturation, a concentration exceeding the solubility limit can exist without the appearance of a second phase.

(ii) Inclusions other than metallic iron might act as nuclei for the redeposition of iron.

The redeposition hypothesis would explain the very low tolerance limit of nickel—believed to be 0·0005% ; this has been attributed to the presence of Mg_2Ni, which is stated to have a low over-potential. It is, however, difficult to think that this body can be present as a separate phase at that very low concentration of nickel, although the solid solubility of nickel in magnesium is known to be low; Haughton and Payne put it at less than 0·1%.* The electrochemical properties of nickel, which undoubtedly possesses a low over-potential, makes its redeposition from a very weak alloy a possibility.

Mr. Bushrod probably has much more information than the writer regarding the form and amounts in which the various impurities exist in magnesium, and would be in a position to state whether the suggestions made above deserve consideration or not.

MR. JONES and MRS. PETCH (*in written reply to the discussion and in reply to correspondence*) : We wish to thank all contributors to the discussion of our paper for their interest. Before replying to the points raised, however, we would like to make a few general comments for which there was no time at the meeting.

The object of these experiments was not to study the corrosion-resistance of magnesium alloy sheet from the point of view of service use. It was simply to ascertain the order of the inherent variation which must be allowed for in using this type of sheet for corrosion tests, and if possible to devise a method of eliminating such effects. The apparent systematic quality of the results obtained led us to look for a specific cause for the observed variation. We do not infer from our results that all magnesium alloy sheets will vary in this way. We have rather put them forward to show what can happen, and to illustrate the necessity for careful design of corrosion experiments. It is perhaps appropriate to point out here that the sheet to specification D.T.D. 118, in which so great a variation was found, was, in fact, a sheet of very high general corrosion-resistance. Even the worst specimens, after a year's exposure, suffered corrosion of the same order as did specimens from the sheet to specification D.T.D. 120A after six weeks.

Several contributors to the discussion made similar suggestions regarding possible causes of the observed variation other than variation in iron content. These amounted to postulating variations in free manganese inclusions, the presence of superficial impurities, or variations in the physical state of the material, i.e. grain-size, presence of twins, preferred orientation, or cold work. As stated in the paragraph starting at the bottom of p. 135, no appreciable variation in quantity or form of the free manganese was observed. This has

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* J. L. Haughton and R. J. M. Payne, *J. Inst. Metals*, 1934, **54**, 283.

been confirmed in a private communication by Mr. Bushrod, who examined our specimens, and observed no variation. In view of this, Mr. Bushrod's curves, quoted by Mr. Davies, though interesting, are inappropriate to the present discussion.

With regard to Dr. Fox's suggestion of rolled-in surface impurities, we may say that though we took no special precautions to remove these, other than scrubbing the surface with pumice, the film formed on chromate treatment was uniform and free from the blemishes caused by inclusions in the surface. Furthermore, we would expect that any effect due to rolled-in surface impurities would be random rather than systematic.

Of the various suggestions regarding variation in the physical state of the material, the only one for which we have found any supporting evidence is variation in number of twinned crystals. Had there been any appreciable cold work or preferred orientation in any of the specimens, the X-ray examination described would have revealed it. The effect of the presence of a greater number of twins in the worst specimen would amount to a smaller grain-size. In our experience, the effect of grain-size on the corrosion-resistance of magnesium alloys is never, even in extreme cases, greater than a factor of two, and in any case, the effect is the reverse of that observed here, a smaller grain-size being associated with greater corrosion-resistance. We might also point out that even if there had been greater cold work in the specimens at the edge of the sheet, as suggested by Mr. Davies, this effect also would have operated in the wrong way, as cold-worked material is known to be more noble than work-free material.

In reply to Dr. Sutton's question about our observation of other examples of variation of corrosion-resistance in magnesium alloys, other cases had been observed, and had led up to the investigation described in our paper, though none were as spectacular as those in question. The abbreviation "app." in Table I does, of course, mean approximately and refers to the sheet to specification D.T.D. 118. The precise values for different parts of this sheet are given in Fig. 2. The reason for the comparative lack of variation in the sheet to specification D.T.D. 120A was not investigated, but we agree with the suggestion that the impurity content of this material was well clear of the tolerance limit. We have already stated in the paper that we consider that some differences in numerical results between groups of workers may be due to differences in experimental techniques. Our own technique was dictated by the underlying intentions of our work.

We have already dealt with some of Dr. Fox's points. His criticism of the self-consistency of our results implies the assumption that the relationship between corrosion rate and iron content is linear, which we have at no time held to be true. Indeed, both our results and those of Hanawalt, Nelson, and Peloubet show this to be far from the case. The increase in iron content from 0·0068 to 0·0128%, involving a change in corrodibility of 70%, does not include the tolerance limit, whereas the increase from 0·007 to 0·0179%, corresponding to a corrodibility increase of 600%, does go through the tolerance limit, and, therefore, includes an exceedingly rapid increase of corrodibility over the range from about 0·014 to 0·0179% iron. As to our conclusions depending on the results of three specimens, we agree that these results show the effect more markedly than the rest at first inspection, but our statistical analysis is based on the results of all our specimens. We apologize for the misprint in Fig. 2 pointed out by Dr. Fox. Another of Dr. Fox's points dealt with the question of the possibility of drawing a corrosion contour map for any sheet. Though we believe that a contour map can be drawn for any set of results however regular or irregular the variation, we had worded our paper in a way which we hoped would avoid this controversy, as we considered it to be irrelevant to the present discussion.

We consider that Dr. Fox is wrong in saying that the results of the American work refer only to pure magnesium. As stated in our paper, Hanawalt, Nelson, and Peloubet obtained results on magnesium containing 1% manganese or 1% zinc, and the curve given in Fig. 4 of their paper and quoted in our Fig. 3 is a composite curve for pure magnesium and the two alloys. We feel that our results agree qualitatively with those of the American workers in that there exists a tolerance limit for iron in these magnesium alloys, below which the change of corrodibility with iron content is small, and above which there is a rapid increase of corrodibility with iron content, and that this tolerance limit is of the order of 0·015% iron. There are sufficient differences in the experimental technique to account for any slight quantitative disagreement. It should be borne in mind that we were not setting out to reproduce the American results.

We agree that there is a grave discrepancy between the results of our work and those quoted in the paper by Fox, Bushrod, and Mayer. We feel that the source of the discrepancy is to be found in their use of emery paper in the preparation of their specimens, in spite of the statement that immersion tests showed no difference due to method of surface preparation of Elektron AM503. The iron content of the specimens on which these tests were done is not stated. Unless their iron contents are known to have varied over the same range as those of the cast material referred to, there is no justification for the assumption that the emery treatment had no harmful effect on it. Dr. Fox states that our work was concerned only with two sheets. On the contrary, since the sheet to specification D.T.D. 120A yielded no very interesting results, our paper is concerned with only one sheet. Our results were obtained from twenty nominally identical specimens differing by a factor of 12 in corrosion behaviour, and it is the cause of this particular behaviour which we were discussing in our paper. We agree with him that there was something peculiar about the sheet in question, but in our opinion the peculiarity was that the iron content varied in a systematic manner over the sheet. We emphasize that we could find no trace of any other peculiarity.

Mr. Bushrod questions the validity of the conclusions drawn from our statistical analysis. Since he himself states that it is obvious from looking at the curve that there is a relationship between corrosion rate and iron content, we cannot appreciate his objection to our arriving at the same conclusion by statistical methods. With regard to the use of the correlation coefficient we agree that it measures the strength of an association on a scale which is independent of the phenomena involved. For our purposes it was, therefore, the correct measure of association. We also agree that the correlation coefficient gives no information on the subject of causation, and that apparent correlation between two variables may be due to correlations with other variables in the way demonstrated by Fox, Bushrod, and Mayer. If, however, one assumes that our correlation between iron and corrosion loss is not real but due to some other factor, one is forced to look for something which is very strongly associated with both. As we have already said in reply to Dr. Fox, we have been unable to find such a factor. We believe that the explanation of Mr. Bushrod's failure to produce results similar to ours when he exposed cut-up sheets to atmospheric and immersion tests is to be found in the fact that the iron contents of his specimens were all above the tolerance limit. We would not, therefore, expect any behaviour such as that observed by us to occur in his tests if, as we believe, the marked variation we observed was due to the fact that our iron content happened to vary over the range including the tolerance limit.

Mr. Davies's points have already been answered in reply to other contributors, but we question his implicit assumption that the existence of twinned crystals in a metal means that recrystallization is incomplete, unless he is using the term " twinned crystals " in a very specialized way.

Mr. Higgins criticizes the use of statistical methods in this type of corrosion problem. We cannot here discuss the principles of small-sample theory, but we confess our surprise at seeing the methods which have been for some twenty years the basis of all precise agricultural and biological experiments described as a " modern fashion ". We are glad to see, however, that Mr. Higgins agrees with our conclusions. We agree with him that it was regrettable that analyses had for the most part to be made on specimens after corrosion. We point out, however, that the iron contents of four specimens (E6, E8, E13, and J17) which had not been corroded are consistent with the contour map drawn for the other results. Moreover, if Mr. Higgins's suggestion were correct, the true correlation between corrosion and iron content would be greater rather than less than the one we measured.

Our use of chromate-treated specimens was essential in view of our objectives. We would have liked to have done confirmatory experiments on the sheet in question, but this was unfortunately impossible. The work was done during a period of extreme shortage of magnesium for research purposes and most of the remaining parts of the sheet had been used for other purposes by the time our results were complete. We were unable to repeat the work when magnesium became more available, as we had by that time left this field of research. We felt that the implications of our results with regard to the design of corrosion tests were sufficiently important to warrant publication in their present form.

DR. FOX and MR. DAVIES (*in written reply to the discussion*) : Dr. Sutton put forward many interesting points in his discussion, among which was a reference to work by Rogers and Dingley, of the National Research Council, showing that the presence of small amounts of lead in an aluminium-containing magnesium alloy was beneficial to the corrosion-resistance. Some work has been carried out at Magnesium Elektron, Ltd., on the effect of this element on corrosion-resistance, and the results indicated that lead had no significant effect one way or the other. One would not expect lead to be particularly detrimental; neither could it, we think, be expected to increase the corrosion-resistance appreciably by a mechanism of providing cathodes of high hydrogen overvoltage. A poor cathode, no matter how bad, is not likely to impair the efficiency of other more suitable cathodes in an alloy.

We have had no experience of the contact of lead with high-purity magnesium, but agree with Dr. Sutton that it would probably behave as well as zinc, and might, under hot humid conditions, be more suitable.

With reference to Dr. Sutton's remarks concerning the hydrogen evolution from local cathodes in a magnesium alloy specimen in contact with a more noble metal, we should like to emphasize that, as stated in our paper, a decrease in hydrogen evolution, such as occurred with Elektron M5A alloy, is the exception rather than the rule. Many workers [*][†][‡][§] have shown that, in general, magnesium exhibits a negative difference effect in neutral salt solutions, i.e. a greater volume of hydrogen is evolved from magnesium when in contact with a more electronegative metal than when immersed in the same solution alone. The commonly accepted explanation for this is that contact with a more noble metal is equivalent, in effect, to an increase in anodic

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[*] W. Kroenig and G. Kostylev, *Z. Metallkunde*, 1933, **25**, 144.

[†] W. O. Kroenig and V. N. Uspenskaja, *Korrosion u. Metallschutz*, 1935, **11**, 10.

[‡] W. O. Kroenig and S. E. Pavlov, *Korrosion u. Metallschutz*, 1934, **10**, 254; 1935, **11**, 89.

[§] A. Thiel, *Z. Elektrochem.*, 1927, **33**, 376.

polarization and, as a result, the anodic evolution of Mg^{++} ions is accelerated. This rapid outflow of Mg^{++} ions is sufficient to break up or enlarge the pores in the oxide film, exposing a greater area of bare metal to the local-action-process involving hydrogen evolution. The suggested reason put forward in our paper why Elektron M5A should behave differently from other magnesium alloys was that the oxide film was unstable initially.

In reply to Dr. Champion, we were undecided as to the terms we should adopt to describe the purity of the aluminium and aluminium alloy specimens used. Remelting in a Salamander crucible must have an effect in reducing the purity, and we did not consider ourselves justified in using the terms " super-purity " and " high-purity " for material which was then below the 99·99% and 99·8% level of purity which those terms imply.

With regard to the method used for cleaning aluminium specimens after corrosion, we did in fact use concentrated nitric acid (without an addition of chromic acid) for some of the specimens, but found that the time taken to clean them thoroughly, especially those which were badly corroded, was excessively long (of the order of 24 hr.), and we used 5% hydrochloric acid in preference. It is true that hydrochloric acid does attack aluminium, but the rate is very slow and would not, in our opinion, affect the total loss in weight significantly.

With reference to Mr. Bushrod's contribution to the discussion, we agree that the corroding-potential measurements of partly immersed specimens may be somewhat unreliable for the non-magnesium alloys. In this connection, it is possible that the rise in corroding potential of the " super-purity " aluminium specimens, due to access of oxygen, was responsible for the discrepancy between the corrosion-test results and the potential measurements. However, as stated in the paper, we finally came to the conclusion, despite the evidence of the potential measurements, that " super-purity " aluminium behaves anodically to Elektron M5A alloy when immersed in a 3% sodium chloride solution saturated with magnesium hydroxide.

MR. BUSHROD (*in written reply to the discussion and in reply to correspondence*) : I fear that in writing the note on the quantitative implications of Hanawalt's theory I have not made my aim sufficiently clear. I designed to show that an equation, derived by a simple quantitative treatment of Hanawalt's basic idea, would fit the observed facts of magnesium alloy corrosion rates if one or two not unreasonable assumptions were made. As certain other experimental results are not, in my opinion, in accord with Hanawalt's hypothesis, I feel that these assumptions are unwarranted. I trust that this statement may help to clarify the position.

With regard to the first point raised by Mrs. Petch, I would assure her that I had already considered the apparent anomaly to which she makes reference, and in fact this is discussed in the final paragraph of my note; to reiterate, if the derived equation is valid it is only valid for the initial stages of the corrosion process. Mrs. Petch proceeds to credit me with having made one of two assumptions which I may fairly say I had not previously considered. The fact is that in a system consisting of particles dispersed randomly throughout a solid matrix, those particles which " outcrop " at any bounding surface have as nearest neighbours (on the average) particles within the solid : this is obvious if one considers the case of very small particles, when very few will " outcrop ", and thus distances between adjacent particles at the surface will be very great. To illustrate by a numerical example, if a specimen of magnesium contains 0·01% iron dispersed randomly throughout the matrix (as spheres of radius $1{\cdot}62 \times 10^{-5}$ cm.), the mean distance apart of nearest neighbours in the surface is $2{\cdot}5 \times 10^{-3}$ cm., whereas the mean distance apart of nearest neighbours, only one of each pair to lie in the surface, is only

$0{\cdot}65 \times 10^{-3}$ cm. Naturally such figures are based on the assumption that the metal does not consist of fragments thin in relation to the particle diameters.

The number of particles exposed per square centimetre of corroding surface (n) refers, of course, to the area of the corroding specimen. If this is very different from the original area of the specimen, Mrs. Petch's criticism is undoubtedly valid. However, unless the course of corrosive attack is accompanied by the formation of deep fissures in the specimen (a phenomenon rarely observed with magnesium-base alloys), it is unlikely that the surface area will change greatly during the initial stages of the corrosion process. Any discussion on the true surface areas of corroding specimens is unlikely to provide much information of direct value, but it should be stressed that perceptible roughening of a surface is by no means a sure indication of increasing area. For example, if a section through a surface presents a saw-tooth contour, the true area is a function of the included tooth-angle only and bears no relation to the depth of the teeth.

I must agree with Mrs. Petch when she states that V will not be constant when the spheres of influence of the particles begin, increasingly, to overlap; as indicated at the end of the note, the true curve (assuming the Hanawalt theory) would be expected to be of sigmoid form, the derived equation only representing the first part (or initial stage of corrosion).

I must apologize to Mr. Jones for not making myself sufficiently clear. My argument was that *if* N were constant in the two alloys *then* we should expect R to have a value of 2; as R actually has a value of $1{\cdot}92$ the assumption of the constancy of N seemed justified. Many a reputable theory has had a much less secure foundation. However, holding as I do that the Hanawalt theory is incapable of explaining all the observed facts of magnesium alloy corrosion, I favour the conclusion that the numerical agreement reported is fortuitous, or is possibly accounted for, as Mr. Jones implies, by simultaneous variations in N and V. As regards the fitting of the curve to the experimental points, a polynomial could, of course, give a much closer fit, but not if restricted to a parabolic form with only two arbitrary constants. The above-mentioned considerations will also provide an answer to the question raised by Mr. Davies.

I should like to thank Dr. Evans for his kind remarks and also for his interesting discussion of the corrosion of zinc in acid solutions, and his extension of the principles so elucidated to the behaviour of magnesium alloys. Dr. Fox and the writer have been convinced for some time that the mechanism by which traces of iron or nickel accelerate the corrosion of these materials must depend on redeposition of the nobler metal, either as metal or hydroxide. It has been shown that surface contamination of magnesium alloys with iron oxide causes increased rates of attack by sodium chloride solutions, and films of ferric hydroxide deposited on the alloy surface also accelerate corrosion.* It is thought that, in consideration of the alkaline conditions obtaining at the corroding metal surface, these facts render the redeposition theory even more acceptable. We have, in fact, a paper in preparation in which we hope to develop the general theory of the redeposition of hydroxides of iron and nickel and also to extend this to account for the immunity of the commercial binary magnesium–manganese alloys from the harmful effects of iron.

With reference to the results, quoted by Dr. Evans, obtained when corroding magnesium sheet specimens in chloride solutions of varying concentrations, it may be of interest to review some similar experiments carried out by the writer.† Sheet alloy specimens were immersed in solutions of alkali and alkaline-earth chlorides of various concentrations, and, although in general the

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* F. A. Fox and C. J. Bushrod, *J. Inst. Metals*, 1946, **72**, 51.

† C. J. Bushrod, *Magnesium Rev. and Abs.*, 1946, **6**, (14), 132.

rate of attack was greater in the more concentrated solutions, the rate of perforation was greater in the dilute solutions. Hanawalt's theory necessarily requires a rate of perforation roughly proportional to corrosion rate.

Dr. Evans's scepticism regarding the appearance of a nickel phase in magnesium carrying 0·0005% of this element is certainly shared by the writer; many specimens containing four times this concentration of nickel have been examined from time to time without revealing any second phase.

Finally, I should like to thank all who have expressed interest in this paper and to add that, however rash the venture may be, any effort to place observed corrosion phenomena on a quantitative basis is calculated to increase the respect for, and value of, corrosion studies.

DISCUSSION ON DR. O. R. J. LEE AND DR. L. NORTHCOTT'S PAPER: "THE CENTRIFUGAL CASTING OF COPPER ALLOY WHEELS IN SAND MOULDS." *

(*J. Inst. Metals*, this volume, p. 491.)

MR. A. J. MURPHY,† M.Sc. (Member of Council): I am a little puzzled to understand why the centrifugal casting of wheels in sand moulds should have been thought to merit so detailed an inquiry. My impression is that the instances of plain wheels being centrifugally cast in sand moulds without any chill must be very few. I can imagine that an all-sand mould might be used for a simple casting such as a wheel cast centrifugally, if a chill mould of the right size were not available, but even in that case it would generally be possible, and certainly be the industrial practice, to insert an iron ring to provide a chill surface at the periphery of the wheel.

It would be interesting to see a comparison between wheels cast centrifugally in all-sand moulds, those cast with a chill ring, and those cast in all-metal moulds. I gather that unfortunately the second method has not been used.

Sand moulds for centrifugal castings are more important in cases where the shape of the article is too complicated to be produced from an all-metal mould, and technically then the question of the strength of the sand mould is of great interest. Did the authors have any indication of mould damage in their experiments? This damage could be caused by thermal shock on entry of the hot metal, by mechanical shock or abrasion by the molten metal striking the mould, and finally, at high speeds, there is the danger of the mould bursting under centrifugal pressure. Inquiry along these lines might give information of even greater interest to the present users and manufacturers of centrifugal castings, to whom reference is made in the introductory paragraph.

The consideration of the effect of the density differential between the constituents on p. 513 is most interesting, but it must be very difficult to assess the influence of surface-tension effects on the movement of a liquid metal along capillary channels. As regards static castings, controversies have raged concerning the explanation of the movement of liquid metal; it cannot be said that the matter is in any way simplified when the mould is rotating. Have the authors observed any tin sweat on the outside of the rim in these centrifugally sand-cast wheels?

On p. 510 the authors give an explanation of the origin of the structure of high-speed centrifugally cast wheels. They set out to show that the eutectoid takes up an intracrystalline position in static casts and an intercrystalline position in centrifugal casts. I find this explanation difficult to accept in the absence of any evidence of where the grain boundaries in the continuous phase are, and in the relevant photomicrographs I cannot see them. I am not surprised that they are not clearly evident, because it is difficult to reproduce them by ordinary technique; but the authors owe it to us, in supporting their theory, to produce some indication of the location of the grain boundaries, in which, or away from which, according to the type of casting, the eutectoid particles are said to be located.

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* Discussion at the Annual Autumn Meeting, Glasgow, 24 September 1947.

† Director and Chief Metallurgist, J. Stone and Company, Ltd., London.

On p. 513 the authors say: "In the high-tensile brass alloy, the primary iron constituent has a density of 7·6 g./c.c. on the basis of an estimated composition of 95% iron and 5% copper". What is the evidence for this estimate of composition of that constituent? It is dangerous to accept that composition and then to build the rest of the theory on that supposition. They continue: "the density of a liquid binary alloy of 45% zinc is 7·42 g./c.c. The complex alloy should be about this value, as it contains less zinc but some aluminium. A slight centrifuging effect was therefore expected." Then the evidence is stated. The authors have rather detracted from the value of their paper by a somewhat reckless construction of this part of their case.

Finally, it is necessary to say something about their remarks on annealing. The three classes of tin bronze, and certainly phosphor bronze, are used very generally in the as-cast state because of their frictional properties; and it should now be known that their frictional properties are very seriously damaged by the annealing process which improves the mechanical properties. The authors ought to have included a warning against these dangers when directing attention to the improvement in strength which can be obtained by annealing.

Mr. W. A. Baker,* B.Sc. (Member): There are several points of considerable theoretical and practical interest in this work, and in the main the authors have discussed them adequately, but there are one or two on which I should like to comment. In Fig. 35 a curve is given for the phosphor-bronze casting, relating the centrifugal pressure to the percentages of voids found in the castings. The high voids in the static casting with no centrifugal pressure are very rapidly reduced by quite small increases in centrifugal pressure. The authors' comment seems to dismiss the matter too briefly by saying that it is simply reduction of the volume of the voids by the application of centrifugal pressure, for it is evident that the change in pressure of the gas in these bubbles would not account for the change in the volumes of the voids.

There are, however, at least two other possible explanations. One is that this alloy, as the authors say, absorbs hydrogen from the sand mould during solidification, and there is a good deal of doubt as to the progress of that absorption during solidification. It is quite possible that the bulk of the gas is absorbed before any voids begin to form; on the other hand, it is quite possible that, as solidification progresses almost to its end, and small voids are formed, the gas is diffusing from the surface of the casting and inflating those voids, in much the same way as gas will diffuse into a piece of steel when welded or otherwise heated in hydrogen—the so-called "flaking" effect. If the latter is the case, the effect of the centrifugal pressure might well be that found by the authors.

Another factor which may be involved is that the presence of a centrifugal-pressure gradient through a sample of metal rotating about an axis, tends to have a degassing effect, because when bubbles of gas reach a size such that surface-tension forces are not of major importance, the pressure in them approximates to the surrounding pressure. Thus if bubbles of gas are produced fairly early in the solidification of the casting, they will form more readily at points near the axis of rotation, and in effect the presence of the centrifugal-pressure gradient will tend to promote diffusion of dissolved gas towards the axis, where it can readily be removed from the solution as bubbles at atmospheric pressure. This effect also might partly account for the authors' results.

In Fig. 20 there is an illustration of a marked segregation of eutectoid in a leaded gun-metal, and I should like to comment on it, although my comments are not strictly relevant to the present paper. The structure shown is very

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* Senior Metallurgist, British Non-Ferrous Metals Research Association, London.

similar to the " banded " structures which one of the authors has described in earlier papers. In these earlier papers, these " banded " structures, which are essentially concentric rings rich in low-melting-point constituent, are attributed to an interrupted process of solidification resulting from occasional suppression of undercooling by vibration of the machine.

I have never really believed that theory, and there is a much more reasonable one, which does not involve any complicated assumptions about undercooling. We know that these alloys freeze over a very wide temperature range, and that they form primary crystals which in the first instance are quite free. In the early stages of solidification, these centrifuge to the outside of the casting, but there must come a stage when they begin to cohere one to another, and it seems likely that, if the bulk of the casting has reached the condition where it is just beginning to cohere, the slightest shock may cause the pasty mass to rupture and residual liquid flows through to heal the break. That, I suggest, is a more likely origin of the " banding " phenomenon.

The illustrations given in the paper of the effect of centrifugal pressure on the tensile properties of these castings seem to be not quite fair, because the values plotted for the castings with no centrifugal pressure are values for static castings made without feeder heads. My main criticism, however, is that on p. 516 there is a sweeping statement to the effect that centrifugal casting virtually eliminated porosity from the tin-bronze castings. It is clear from the authors' own evidence that that was not the case. Their figures show that the castings still contained 0·5–1·0% of voids, and that is by no means a negligible quantity. It is fair to point out, however, that the authors do not make that point in such strong language in their final conclusions.

Mr. Murphy has already directed attention to another point which I had in mind, namely the danger of annealing these alloys and the resultant structural changes in view of their potential applications in bearing and wear-resisting components.

Dr. O. R. J. Lee (*in reply*): I should like to thank Mr. Murphy and Mr. Baker for their comments. Mr. Murphy asked why we had chosen to deal with wheels. This research arose out of a specific work dealing with wheels; therefore, having the patterns and equipment available, it was thought that a wheel would at least be a typical type of casting. We were mainly concerned, of course, in investigating the more fundamental metallurgical effects of centrifugal casting and not in dealing with the practical difficulties arising in the centrifugal casting of a wide variety of patterns.

In a wheel having radial spokes or arms through which the metal must run before it reaches the rim, there is no abrasion effect of the molten metal on the rim portion of the mould; in being flung out along the arms of the rotating mould, the metal automatically takes up the same rotational speed as the mould, and is therefore injected from the ends of the arms into the rim, at a much faster speed, but in a similar manner to a normal static casting.

We had cases of moulds bursting in the early stages, but with steel retaining plates about ¼ in. thick on the top and bottom of the mould, any break-out of the sand was prevented. Though moulds were very often cracked when the top plate was removed, it was not to an extent which would harm the appearance or usage of the casting.

Tin sweat on the outer surfaces of castings was never observed. The point about grain boundaries is appreciated to the full, because it was most disappointing that in one of the illustrations in the paper the grain boundary, which was there in the original photograph as evidence, was not reproduced. It would be imagined from the effects on mechanical properties which were observed in samples of similar soundness that some clear evidence of a change in the microstructure should be apparent. It must be admitted that under the microscope we could not forecast the mechanical properties of a piece of metal of given soundness. In spite of this, we advanced the theory given in the paper because it was the only theory that we could put forward which explained the fact that after annealing to make each static and centrifugal casting similar in structure, we obtained a series of mechanical properties which exactly correlated with soundness. We were therefore driven to the point of view that our previous experience of variations in mechanical properties must have been due to the feature which was removed during annealing, namely variations in microstructure.

We must again agree with Mr. Murphy in his criticism of the precise figures which were quoted, not only for the composition of the primary material in the high-tensile brass, but also for the actual density. Unfortunately, the literature is extremely scanty in data on high-temperature densities, and the procedure adopted was to take the nearest data in the literature, and make an estimate of what conditions were likely to obtain in our particular alloys. These figures were put in to show that, from the data available, severe segregation effects would not be expected.

With regard to the properties of castings after annealing, there is a warning in the paper that annealing will have a bad effect on the proof stress of these alloys, and the frictional properties will certainly be adversely affected; but we had in mind, when mentioning the high strength values obtained after annealing, a usage which was purely concerned with strength properties.

Mr. Baker's remarks on Fig. 35 are very much appreciated. It is said on p. 519—rather a long way from the figure—that in the phosphor bronze, centrifugal pressure closed up the gas voids much more rapidly than can be explained on a simple compressibility basis. A similar point about gas bubbles was raised by Mr. E. A. G. Liddiard at a previous meeting of the Institute,* and my feeling after that discussion was that possibly in centrifugal casting, the pressure acted by preventing the formation of bubble nuclei in the first instance. I agree that further work on the effect might lead to very interesting results.

I cannot fall in with Mr. Baker's suggestion that Fig. 20 shows a banded structure in the gun-metal casting. Banding, such as has been observed in centrifugal chill castings, is definitely a macro-scale phenomenon. One sees the bands most clearly by macro-etching a cross-section of chill castings, and under the microscope quite a gradual transition occurs from the normal structure of the casting into the banded zone, which in phosphor bronze shows a very marked increase in the amount of eutectoid present. In the sand castings, macro-etching failed to reveal any concentrations of eutectoid which could be called " banding ".

CORRESPONDENCE.

Mr. H. H. Symonds * (Member): Do the authors consider that centrifugal casting itself tends to inhibit metal/mould reaction? This is implied in the third paragraph of the Summary and Conclusions on p. 519, where it is stated that: " Centrifugal pressure increases the density markedly and more rapidly than is explainable by a simple compression effect ".

The authors are of the opinion that: " Annealing of centrifugal tin-bronze castings to dissolve the eutectoid results in greater improvement in mechanical properties than in static castings . . .". Can it be concluded that the centri-

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* *J. Inst. Metals*, 1946, **72**, 437.

fugally cast material is more responsive to annealing than the statically cast material? If so, this is presumably connected with the initial quantity and dispersion of eutectoid in centrifugally cast material.

The AUTHORS (*in further, written, reply to the discussion and in reply to correspondence*): In further reply to Mr. Murphy's comments on the precise form which the eutectoid takes in tin-bronze castings, it is surely not an uncommon experience that a second phase tends to occur inside the primary grains when they are large, but is concentrated in the grain boundaries when the primary grains are small. The classic example is, of course, the Widmanstätten pattern of ferrite in pearlite, observed in cast steel of large grain-size.

Mr. Baker comments on the unfair comparison of static castings without heads and centrifugal castings in Figs. 36–47. We would agree with this comment if we had based our estimates of the improvement in mechanical properties obtained by centrifugal casting on these illustrations. When discussing this matter on p. 498, however, reference is made to Table III which quotes the properties of static castings with heads as the basis of comparison, except for the leaded gun-metal and phosphor bronze, where static castings without heads were found to be slightly superior to those with heads.

Mr. Baker's final comment on the "sweeping statement" that centrifugal casting virtually eliminated porosity from tin-bronze castings, did not take into account the rest of the quotation criticized, which ran "provided that attempts are not made to feed thick sections through thin ones". In the wheel castings, attempts of this kind were made to some extent, but in the 4-in.-long bar castings of Table IV a centrifugal casting of 88 : 10 : 2 gun-metal was obtained with 0·1% voids and two leaded gun-metal bars with 0·0% voids, while in the phosphor bronze subject to mould reaction, the soundest bar contained 0·4% voids.

The remarks of Mr. Symonds on mould reaction and annealing are much appreciated, but the points he raises have been covered in the rest of the discussion.

DISCUSSION ON MR. P. G. FORRESTER'S PAPER: "THE FRICTIONAL PROPERTIES OF SOME LUBRICATED BEARING METALS." *

(*J. Inst. Metals*, this volume, p. 573.)

Dr. Bruce Chalmers † (Member): We have a somewhat unusual type of paper before us—unusual for the Institute in the sense that the subject of friction has usually been left by the metallurgist very much to the engineer. There have been various myths in the past regarding what constitutes a good bearing metal and why, and it is only comparatively recently that we have begun to see any rational explanation for some of the facts, and some of the alleged facts have been shown to be quite untrue. A paper such as this seems to go some distance towards putting this matter on a logical basis.

The method of experiment adopted is one which it is perhaps worth examining for a moment. It makes no attempt to imitate the general geometrical conditions which prevail in a bearing when it is moving. Many tests in the past have attempted simply to simulate the condition in the bearing, and have thereby, perhaps, failed to produce the fundamental information on which a proper understanding of the action of bearing metals must be based. In the author's method of experiment, on the other hand, we have a rotating disc on which are pressed three spherical pieces of bearing metal, the disc consisting of metal which is regarded as equivalent to the journal on which the bearing runs. A normal load is applied between the three projections and the bearing surface, and the frictional force is measured directly by means of the friction-balancing load. This allows the influence of speed, the influence of temperature, the influence of the amount of lubrication present, and the influence of the amount of previous running, to be assessed independently; and it is the ability to assess these four things independently which makes it possible for this method of experiment to give results of fundamental value.

It will be seen from the paper that there is surprisingly little difference in the coefficient of friction, under conditions of boundary lubrication, between the four bearing metals which have been investigated. It is pointed out in the paper—and this is the aspect of greatest practical importance—that it is the differing ability of the different materials to keep fluid-film lubrication going that marks the difference in behaviour between these different bearing metals; it is not so much the actual frictional property of the lubricated metal, but the ability of the metal to avoid running into the boundary region where that frictional property seems to matter most.

The author suggests an explanation of the differing behaviour of the four different bearing metals in this respect. On p. 586 he suggests that the real difference between the various materials, where the differences in their frictional behaviour are quite marked, is tied up with a property which he calls "micro-conformability"—the ability of the two surfaces to conform very closely to each other while running is in progress. This is obviously a dynamic property. If one has a wavy surface, and another surface, pressed on to it, is trying to conform with it, then under static conditions presumably the hardness

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* Discussion at the Annual Autumn Meeting, Glasgow, 25 September 1947.

† Head of Metallurgy Division, Atomic Energy Research Establishment, Harwell, Berks.

of the softer material would determine how much conformability there was and how closely the two surfaces did actually coincide geometrically. On the other hand, when one surface moves relatively to the other, other properties than static hardness must have effect; the softer material must be continuously changing its shape, and it seems that would involve a tremendous amount of working of the material if it continues all the time that the bearing is running. Is it possible that it is not the continuous local deformation of the softer material which is the cause of this difference, but the amount by which the softer material is able to grind the surface of the harder material, perhaps by virtue of the hard constituents present in the soft bearing metal?

Perhaps one could devise some sort of test for this property of microconformability. If it is purely a matter of hardness, perhaps combined with capacity not to harden under cold work, then a static test involving a certain amount of deformation, followed by normal pressure of one surface against the other, and then measurements of the relative roughnesses of the steel surface and soft surface, might give some indication of this property of microconformability.

It is important to recognize that there are two quite different aspects of bearings that may be of importance. One is the amount of energy that is lost in friction in the bearings. That can be represented as so much fuel used in turning the machine against its own friction; and that is often comparatively unimportant. Much more important is the amount of damage done to the bearing itself, because that will eventually result in failure.

It seems that little can be done about the coefficient of friction, because there is not a great variation between the possible materials used. The selection of a suitable bearing metal does seem to depend very much more on avoiding damage to the bearing, and that damage is shown to be associated very closely with the distinction between the persistence of fluid film and the appearance of boundary lubrication, which necessarily involves something approximating to metal-to-metal contact, probably local welding, and the breaking away of small areas of one or both of the two surfaces. It is presumably the cumulative effect of such local welding and breaking away that causes eventual failure of the bearing. That, of course, is not under discussion in the present paper, but what is under discussion is the important question of the metallurgical conditions which determine when breakdown of the fluid film occurs.

MR. J. CARTLAND,* M.C., M.Sc. (Vice-President): The author is to be congratulated on his approach to the difficult question of the relationship between boundary and fluid lubrication. It is recognized that when a journal is rotating in a properly designed bearing the rotation develops a hydrostatic pressure which floats the journal up to a central position, and therefore at that time the materials of which the journal and the bearing metal are composed hardly come into the picture at all. On the other hand, many frictional tests have been carried out on dry materials; and, although they are most interesting from the scientific point of view, and from the point of view of some of the points on which Dr. Chalmers touched, they hardly come into the picture either as regards bearing performance.

It is, therefore, this particular point with which the author has dealt, the relationship between boundary lubrication and fluid lubrication, which is of vital interest.

It should be borne in mind, in considering the author's results, that his set-up is entirely different from that of a journal in a bearing. With a

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* Director, Fry's Metal Foundries, Ltd., and Eyre Smelting Company, Ltd., London.

journal at rest in a bearing, there are numerous points of contact between the journal and the lower half of the bearing, and possibly the top half; but in the author's set-up, with a true sphere and a flat plate, if the surfaces are correct there would be a single point of contact and the loading per unit area would be infinity; presumably it is not, in fact, infinity owing to the irregularities of the surfaces. Moreover, the wedge-shaped lead-in for the oil is quite different in the two cases. The author recognizes this in his remarks on p. 577. His set-up is designedly different, but the difference should be borne in mind in considering the author's results from a practical bearing point of view.

Can the author help us to visualize the situation between boundary and fluid lubrication and the effect of surface finish by giving us some general idea of the relative sizes of the uni-molecular film prepared by the method described on p. 578, full fluid-film lubrication thickness, and the excrescences on the three grades of steel?

The uni-molecular film of chain molecules has been described as somewhat like a field of corn, with the roots of the corn bedded in the earth and their tops free to wave and brush over another similar film opposed to the first; and it has been said that if the journal were magnified to the diameter of the earth this field of corn would be about 5 ft. in height. To have a picture of that sort would be interesting and helpful.

It would be interesting if the author would give us his views on the old and vexed question of the value or otherwise of the duplex structure of bearing metal.

In considering the results shown in Figs. 2, 3, and 4, it is a remarkable feature that the friction with the rubbed film is only so little greater than the friction with excess of lubricant; and it is significant that the tin-base bearing metal shows a distinct advantage over the lead-base bearing metal on the rougher-finished steel. Comparing the results in Fig. 5, which are for a tin-base Babbitt on polished steel, with the tin-base results in Fig. 4, also on polished steel, in Fig. 5 the friction is shown as under 0·03 after 5 revolutions, whereas in Fig. 4 at the same speed it is shown as nearly 0·04 after 5 revolutions and 0·035 after 320 revolutions. Another comparison which may be made is between Fig. 7 and Fig. 2. In Fig. 7, with a speed of 2·26 cm./sec., at 20° C., the figure is 0·02, but in Fig. 2, with the same steel and the same speed, the friction coefficient after 320 revolutions is nearly 0·04, and with fresh surfaces nearly 0·05. These discrepancies may appear small, but they do not seem to be consistent with the author's statement on p. 579 that his apparatus is sensitive to a coefficient of friction of 0·0025.

Referring to Fig. 10, the author makes the statement that " The areas for tin- and lead-base Babbitts are almost identical, while cadmium–nickel alloy gives a rather greater area ". Looking at the curves, is that conclusion material or justified?

Finally, the author's study of these frictional properties is most interesting, but when considering bearing practice it should be borne in mind that there are other properties of bearing metals which are of at least equal importance. There is, for instance, the property of bonding to the shell. No high-duty bearing is any good unless the bearing metal is completely bonded to the shell, and the bonding properties vary widely with the composition. Then there are all the usual mechanical properties, and there is also the property of absorbing steel chips, grit, and other material into the bearing in such a way that they do not score the shaft.

Mr. H. G. Warrington * (Member): Every engineer, and nearly every metallurgist, will have come across bearing problems at some time or other,

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* Director, Fulmer Research Institute, Ltd., Stoke Poges, Bucks.

and will have read this paper with much interest, in the search for some more fundamental theory of bearing materials. We still lack fundamental theory on which to base the formulation of new and better bearing alloys.

In this paper, as Mr. Cartland has pointed out, there are one or two discrepancies, one of which concerns the values obtained from the various surfaces equivalent to the journal surface. I would suggest that a better finish for such a surface would have been obtained by electropolishing, so as to obtain a metal surface free from inclusions from the polishing agent and free from a flowed layer, which might provide us with more fundamental data than a mechanically polished surface.

The development of bearing alloys has mostly been due to *ad hoc* work from bearing practice, and not to fundamental theory. Theories of duplex structures have been strongly supported, but at the same time many bearings have been made from pure metals. Many scientific theories have been developed from analogies, and it may be of interest to consider how other materials for bearings than those which have been used by the author might have affected his results.

There is, for example, the silver bearing, which seems to support the author's hypothesis of micro-conformability or "softness" as a fundamental property of bearings. Silver is a bearing metal which is not particularly suited to all bearing conditions. It does not support an oil film very well, so that presumably its micro-conformability is an important consideration. Its surface is disguised by plating it with lead; and, because lead does not resist corrosion particularly well, the lead is plated with indium. We have, therefore, a basic bearing material, silver, and we use one of its properties, completely divorced from any surface effects which are provided by an alloy of other metals. This type of bearing works reasonably well—under most conditions almost as well as a tin bearing, and under some conditions, when a tin bearing is overloaded, it seems to work better.

This appears to be strong circumstantial evidence in favour of the theory of micro-conformability. On the other hand, however, we have new materials in the bearing field which seem to prove the very opposite. There have been many attempts to make aluminium bearings. A good deal of work was done in Germany during the war, following the older duplex-structure theory of a soft matrix with hard supporting particles. It cannot be claimed that any of these bearings were really successful, but in this country Hall and Bradbury developed the Rolls-Royce type of aluminium-base alloys, which were used in car engines and to a certain extent in aircraft engines. These alloys, however, contained a fair amount of tin, about 6%. The equilibrium diagram, although rather out of date, suggests that over 6% tin will be retained in solid solution.

Apart from this, quite recently an American discovery of aluminium bearing alloys has been widely publicized. The American workers also have evolved an alloy which contains about 6% tin, and the remaining elements, presumably for very good reasons, seem to be very similar to those developed by the English school. I have not yet seen the advertisements for these alloys, but no doubt they claim that they have been developed after years of research.

At any rate, we have two schools of thought, and they have both evolved an aluminium alloy which appears to require the presence of a certain amount of tin. What is the function of the tin in this case? It can hardly be said that there is sufficient tin present to produce any effect on micro-conformability, and the equilibrium diagram suggests that it is in solid solution. Is it that tin has some other feature which will produce a surface effect of benefit in bearing materials, even when present to the small extent of 6%, along with some 90% of a material which is normally considered to be quite foreign to any of the properties associated with bearing alloys? Thought on these lines might lead to further development of the fundamental theory of what is a bearing material.

DR. D. TABOR * (contribution read by Major W. G. Askew): I have read this paper with considerable interest, and should like to congratulate the author on the contribution he has made to our knowledge of the frictional behaviour of certain bearing alloys. One of the main points that the author has emphasized is the importance of the "conformability" of the bearing in facilitating the onset of fluid lubrication and, as he has shown, this is largely determined by the hardness of the bearing alloy. In practice, of course, bearings do not run at the very low surface speeds used in these experiments, and at higher speeds of sliding the surface temperatures of the shaft and the bearing may be relatively high.† Consequently, the important factor in determining the conformability will probably be the hardness of the bearing alloy at the running temperatures actually operating, rather than the hardness values at room temperature. It would be interesting to know whether any attempt has been made to correlate the hardness at elevated temperatures with McKee's bearing experiments.

As is well known from the theory of hydrodynamic lubrication, the occurrence of fluid lubrication depends on the ZN/P characteristics of the system. If the viscosity Z of the film is high, fluid lubrication may set in at very low sliding speeds. For this reason, lubricants containing small quantities of fatty acids may facilitate the occurrence of hydrodynamic lubrication. This is because the fatty acid, in general, reacts with the surface to form a thin film of metallic soap which is enormously more viscous than the bulk of the lubricant itself.‡ In experiments with cadmium surfaces, for example, Gregory has found § that the soap film is formed even if the fatty acid is present in a concentration less than 0·001%. It would be interesting to know whether the mineral oil used in these experiments was completely free of fatty acid.

I should like to make a minor criticism of the assumption that the amount of surface damage is associated with the work done against boundary friction. There is no real evidence that this assumption is valid. In general, there appears to be no direct relation between wear and friction. Most of the frictional work appears as heat; the work done in abrading the material at the surfaces is usually a very small fraction of the total frictional work. Consequently, the wear may vary over extremely wide limits without appreciably affecting the friction. For example, some simple wear measurements of unlubricated lead-base and tin-base alloys sliding on steel show that the coefficient of friction is approximately the same in both cases, whereas, under the experimental conditions specified, the wear of the lead-base alloy is 50 times higher than that of the tin-base alloy.‖ Consequently, the calculation given in Fig. 10 for the work done in starting the surfaces sliding does not necessarily provide a direct measure of the amount of surface damage or wear produced.

I would add one general observation about the properties of bearing alloys. In practice, bearing alloys fall into three main groups. The first class is the white-metal type of alloy, consisting of hard particles embedded in a softer matrix. Recent work ‖ shows that the hard particles play no significant part

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† F. P. Bowden and K. E. W. Ridler, *Proc. Roy. Soc.*, 1936, [A], **154**, 640.

‡ F. P. Bowden, J. N. Gregory, and D. Tabor, *Nature*, 1945, **156**, 97.

§ J. N. Gregory, *C.S.I.R. (Australia)*, 1943, **A74**, (28).

‖ D. Tabor, *J. Appl. Physics*, 1945, **16**, 325.

in the frictional properties of the alloy, although they may have a desirable effect in stiffening the alloy and in producing minute crevices where the oil may be secreted. It would seem that the retention of the hard particles in the matrix is largely an accidental result of the historical development of this type of bearing alloy. The second class consists of a hard matrix through which a softer metal is distributed. Experiments show that during sliding the soft metal is expressed and smeared over the matrix, where it functions as a thin metallic lubricant film.* These alloys are relatively hard and function under more extreme conditions than white-metal alloys. The third class is a single metal or a single-phase alloy. Here the frictional process is essentially the same as that of the matrix material of an ordinary white-metal alloy. It is evident, therefore, that there is no single mechanism that explains the action of all types of bearing alloys.

There is, however, one property that is common to a very wide range of bearing alloys that appears to be of great importance: they all contain a constituent of relatively low melting point. It is clear that this characteristic will prevent excessive seizure, since the high local temperatures developed under severe conditions of running will readily cause a local softening or melting of the low-melting constituent at the regions of momentary contact. The molten or plastic material will then be carried round to a cooler portion of the bearing. It follows that, apart from suitable mechanical, frictional, and wear-resisting properties, a very desirable property of a wide class of bearing alloys is that one of its constituents should possess a relatively low melting point.

DR. D. CLAYTON †: I should like briefly to express my support for the author's statement that bearings in general should be designed for fluid-film lubrication, and to say that they are in fact in the vast majority of cases under fluid-film conditions when running. They do, however, have to start and stop; also, they occasionally fail by scoring and seizure, and this can only happen through boundary conditions first occurring. Even under ideal conditions, there are two cases to consider: that in which the load on the bearing increases with the speed (as in internal-combustion engines), and then the starting and stopping is little of a problem; and that of dead-weight loading, in which the starting and stopping are important, and indeed determine the design of the bearing.

It is therefore important to consider boundary conditions for bearing metals. There has been surprisingly little information provided on the subject, and, as the author points out, much of that is empirical. No analysis has been carried out to find out just what are the boundary coefficients. The author started with the idea of measuring them. He has been able to give an explanation (which is always valuable) of what happens under nominal boundary conditions and what has been found by experience; but he has had to word his report, very correctly, so as not to claim boundary coefficients of friction. He says that the evidence points to there not being much difference of coefficient among these four materials, but it is a pity that he has not been able to go a little further and tell us what are the actual boundary coefficients. The constant value in Fig. 7 is promising, but he gives that for only one material.

The point about micro-conformability is I think a good one. The smaller ZN/P value for minimum μ for white metals could be explained as being due to macro-conformability—changes of shape at the load point of the bearings in the tests quoted. It appears, however, that differences of micro-conforma-

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* F. P. Bowden and D. Tabor, *J. Appl. Physics*, 1943, **14**, 141.

† Technical Department, Imperial Chemical Industries, Ltd., London.

bility are significant in the results now presented, and due attention should be paid to this point. It is important for the internal-combustion engines for which this work was originally undertaken. Thus, in so far as the load on the bearing is centrifugal, it acts in one place on the crank-pin (the inside), and runs round the bush. In the special case of the Bristol master-rod big end, the bearing metal is applied as a sleeve on the crank-pin and the loading is in one place—similar to the normal uni-directionally loaded bearing. When, however, the big end is lined with white metal, the load runs all round it. Too much macro-conformability can then be a disadvantage (the bush being ironed out to a larger clearance), but with micro-conformability where there is touching a higher load-carrying capacity can be obtained. I think that the solution is to put the bearing metal on the crank-pin for predominantly centrifugal loads, securing all the advantages of macro-conformability and leaving micro-conformability to accommodate journal irregularities.

Another point which may be mentioned in this connection, and one which affects the paper rather fundamentally because the author did this work in connection with conventional internal-combustion engines, is that in the practical case, steel is rubbing over bearing metal whereas the author is rubbing bearing metal over steel. The two coefficients are in other such cases often not the same, and further work seems called for.

I hope that this discussion will encourage the author to go further and give us the actual boundary coefficients for bearing metals, as well as solve some of the other boundary-lubrication problems.

MR. A. CRAIG MACDONALD,* B.Sc. (Member): I found this paper extremely interesting and helpful. I feel, however, that there is a danger of placing undue importance on the results of friction tests of this kind. Bearings have to work, and the number of factors entering into their satisfactory operation is, of course, very much greater than the number dealt with in the paper. It has been mentioned that this investigation particularly applied to the bearings of internal-combustion engines. In the big-end bearings of modern high-duty engines, bearing metal has to withstand the most severe duty to which it is subjected anywhere, and it is what the engine says that is correct. Work of the kind described in the paper is very valuable in showing us the effects of certain fundamental differences, but in the end what the engine says is what really matters.

That leads me to mention one or two specific points, for example Dr. Tabor's statement that the presence of compounds had no very considerable effect on the frictional behaviour of the lead- and tin-base materials. The engine says that this may not be so. In some of the internal-combustion engines manufactured by the Company with which I am associated, tin-base bearing metal has to do a tougher job than anywhere else in the world. These are the only high-duty compression-ignition engines which are still running with tin-base white-metal linings in the big-end bearings, with one exception, and in that exception the engine is running at a slower speed and the bearings are rather greater in area. This white-metal-lined bearing has, I think, the toughest job of any in the world to-day. In several hundred thousand miles of engine life, as distinct from laboratory tests, we have found that the presence of compounds, while perhaps having no definite effect on the purely frictional behaviour, has a considerable effect on the life of the bearing.

To carry out satisfactorily the job I have described, not only are the compounds required, but a cuboid structure must be used. There is a marked difference in the life of the bearing if the tin–antimony cuboids are not properly

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* Chief Metallurgist, Albion Motors, Ltd., Glasgow.

formed. It may be a difference of 100,000 as against 250,000 miles. Either of these periods in service represents a most extraordinary job of work, and, as far as the bearings themselves are concerned, even the shorter of these lives is a great tribute to metallurgical development.

In order to obtain a satisfactory fatigue life in the bearings, linings have to be approximately 0·004 in. in thickness. Smaller thicknesses are extremely difficult to produce commercially, and any greater thickness reduces the life. The structure has to be so controlled that the cuboids are of a certain size. It is quite possible in cooling white metals of this kind to obtain cuboids 0·002–0·006 in. in width, and, if the lining is to be only 0·004 in. thick, in the final machining operation big cuboids are simply dug out, leaving the tin-copper matrix. When the cuboids are controlled at a width of 0·0005–0·001 in., and the lining is 0·004 in. thick, the life of the bearings is remarkable.

Adhesion has also to receive a great deal of attention. We are concerned always with the functioning of the bearings in the engine, and the frictional qualities dealt with in the paper play a very small part in the actual bearing life—there are other matters of much greater importance.

How were the copper-base alloys, to which the author refers, manufactured? If they were manufactured by the casting method originally used in this country and America, in which the lead is distributed as lakes in the copper, there is a very limited feed of lead to the surface to keep the friction down. If they were made, as in America, by casting on to steel strip so that the copper stands up as trees and the lead is distributed among them, then they will have the properties suggested in this paper. If they are made as interlocked sponges by the sintered-metal process, using copper and lead powder, the strength of the matrix is greater than in the American bearing, and the feed of lead to the surface is much more satisfactory than in the original singly cast bearing.

Reference has been made to putting the bearing metal on the crank-pin surface. The investigation of bearings of this kind should be proceeded with as quickly as possible, because the results are likely to be remarkable. The Germans at the end of the war were experimenting with Bakelite bearings. They found, as we did, that the frictional properties were so poor that they fired up quickly; but when, a few months before the war ended, they tried putting resin-impregnated fabric, subsequently polymerized, on the crank-pin, they obtained very promising results.

MR. H. H. A. GREER,* J.P. (Fellow): I should like to thank the author very much for this paper. I think that Mr. Cartland can bear me out when I say that when dealing with these white metals there seems to be no standard whatever. It seems that the principal standard adopted in making white metals for the mercantile marine is the difference between the price of tin (£437 a ton) and the price of lead (£90 a ton at the highest). We come across vast quantities of white metals which are so totally different from one another that I feel that this paper should be studied by consulting engineers to find out not what is the cheapest but what is the best quality to use.

The Admiralty white metal is tin, antimony, and copper, with no lead. Their under-water white metal contains 27% zinc; I do not know why, because I should have thought that zinc would be very subject to corrosion. On the other hand, there are ordinary mercantile white metals with 11% tin, 11% lead, 4 or 5% zinc, and with every sort of rubbish you can think of put into them. It seems that cheapness is the motto of many consulting engineers, so that their boats may be cheap! I am not speaking of Diesel-engine or motor-car works, but of many other marine engines. The Diesel engines

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* James C. Greer and Son, Glasgow.

which are made for merchant ships use very pure tin, antimony, and copper, with no lead whatever, and they have to be very particular there, because the bearings themselves are steel, not gun-metal or bronze, such as are found in ordinary mercantile ships.

The AUTHOR (*in reply*): I should like to thank all the contributors for their very constructive discussion of the paper. Dr. Chalmers, who himself made a large contribution to the development of the apparatus used in this research, suggests that one explanation of the property which I have called micro-conformability is that the soft material may lap the steel, and therefore change its surface characteristics. I do not think that this is actually the case, because if we run for a little while with white metal on a given steel plate, and then substitute a new plate for the old one, the results are not greatly affected. I think it more likely that continuous conformation of the soft slider to the hills and valleys of the plate takes place. This, as Dr. Chalmers says, will require continuous working of the slider or the bearing metal, so that the working properties at the operating temperature should be considered. There is nothing intrinsically improbable in the hypothesis when we consider the large capacity for cold work of the Babbitt alloys and the fact that the hills and valleys are of small gradient, as the Talysurf instrument will show.

I heartily agree with Mr. Cartland in his emphasis of the importance of tests of boundary lubrication. The loading on the specimens is not, of course, infinite but depends upon the flow pressure of the material. When the slider is first put on the plate, the pressure is instantaneously infinite, and then the material flows until an area of contact is established which is sufficient to support the slider.

I also agree with Mr. Cartland that some idea of the relative sizes of boundary films and surface roughness would be helpful. It is difficult to obtain an estimate of the thickness of a boundary film, but, if we assume that it is of the order of 2 molecules, and that the molecules of mineral oils are of the order of 20 Å, or about 0·1 micro-in., it follows that the thickness of the boundary film is probably of the same order as the discrepancies in the smoothest surface which we have obtained. On the other hand, the film is of very much smaller dimensions than the undulations of the roughest surface which we examined. With regard to the discrepancies between results mentioned by Mr. Cartland, and also by Mr. Warrington, it is necessary to distinguish between the sensitivity of the apparatus and the reproducibility. By a sensitivity of 0·0025 I mean that a change in the friction-balancing load equivalent to this figure brings about a readily observable movement of the light spot. Consecutive determinations using the same specimens rarely show discrepancies greater than this. The chief limitation on reproducibility lies in re-preparing surfaces with sufficient accuracy. The tests are very sensitive to the exact surface finish of the material, and, even with the greatest care in the preparation of surfaces, variations of the order of 10% or more occur, particularly in the lower range of friction.

With regard to Fig. 10, and the relative areas under the curve which I put forward as showing the amount of work done in stopping or starting, Mr. Cartland suggests that there is no evidence to show that the area under the cadmium-base alloy curve exceeds that under the curves for the tin- and lead-base alloys. While there is not a great deal of difference with the velocity range tested, the form of the curves suggests that at high velocities the difference in area will increase continuously.

I have not yet obtained any evidence regarding the value of a duplex structure, but it is hoped that experiments now proceeding may throw light on this controversy.

Mr. Warrington suggests that electropolished finishes would be of considerable interest, and I agree that that would be well worth trying. We have carried out a few experiments with surfaces etched to remove the flowed layer; such surfaces are vastly different in properties from normal machined finishes. His remarks with regard to aluminium–tin bearings and silver–lead bearings were to a large extent answered by the later contribution of Dr. Tabor. Both those bearings depend on the formation of a thin lubricating film of metal on the surface of the harder material. The aluminium–tin bearings are, I believe, duplex; the tin is distributed in pools in the aluminium or aluminium alloy and can flow to the surface and form a very thin film there. Thus the resistance to motion by shear is characteristic of the tin or the lead, while the area of contact is small, because of the harder metal underneath; therefore, the value of boundary friction is low.

To continue with Dr. Tabor's contribution, I have attempted to correlate my results with those of McKee only qualitatively. McKee showed that there was a marked difference between bronze, copper–lead, and tin-base and lead-base bearings in the position of the ZN/P minimum, and we put the same alloys in the same order, but as regards actual values of friction, we have no direct correlation.

I have not so far been able to obtain any evidence of the effect of fatty acids in the formation of a fluid film, but the experiments to that end have only been very cursory so far, and we may yet find such an effect. Dr. Tabor also made the point that many bearing alloys have one property in common, a low-melting-point constituent; and, as his work and that of Dr. Bowden shows, this is a very valuable property of the bearing metal.

It is not claimed that there is any direct correlation between wear and friction. Fig. 10 is only intended to illustrate the fact that the effect of small differences in friction–velocity curves is likely to be greater than is immediately apparent.

Dr. Clayton points out that bearings normally run under fluid-film conditions, though he would probably agree that there is evidence that occasional touches do occur in almost all bearings during service conditions. It is, of course, at the times when that fluid friction does not operate that damage is done to the surface, and it is that damage rather than the power loss which is important. I should like to be able to quote definite boundary values for various combinations of materials, but we cannot do it yet, for the reasons explained in the paper. We can quote values for harder alloys, but when fluid-film formation occurs under conditions where every effort is made to suppress it we can only give an estimate of boundary friction.

In reply to Mr. Craig Macdonald, I would say definitely that undue importance should not be given from a practical point of view to friction tests of this type. This is fundamental work which may help in interpreting bearing tests, but the real answer, as he says, is in the engine. The way in which we do hope that this work will be useful is as a guide when it is necessary to change the old bearing alloys or develop new ones. We feel that every effort should be made to see that the good properties are not lost in developing new ones—that we do not, for example, lose the advantages of low-hardness and low-melting-point constituents in order to increase the fatigue strength.

Mr. Craig Macdonald refers to the use of very thin linings. It must be quite an engineering achievement to get a standard 0·004-in. lining. Such a lining will not only have high fatigue strength but may also to some extent operate in the same way as the thin lead film of a copper–lead bearing. There will probably be even lower friction with his thin Babbitt than with a thicker one.

The copper–lead used in the investigation was cast on to steel and consisted largely of isolated pools of lead in the copper.

I think that all concerned with bearings would agree with Mr. Greer in his plea for close control of quality, especially where failure may have disastrous consequences.

CORRESPONDENCE.

Dr. J. R. Bristow [*] : With reference to the type of motion to be expected from a system acted upon by frictional forces at its point of contact with a moving surface, it should be noted that relaxation oscillations occur when friction decreases as velocity increases, only if the system is elastically restrained. That relaxation oscillations in an elastic system may be damped to allow kinetic boundary-friction determinations to be made has been shown by the writer,[†] but it seems doubtful if damping a non-elastic system, to produce stability, is fundamentally sound.

So far as can be judged from the paper, in the production of mono-molecular films by rubbing, only one surface, the lower, was treated. It is usually supposed that under conditions of boundary lubrication *both* surfaces are covered with a mono-molecular layer. Under the conditions used in the paper, therefore, it would appear that insufficient lubricant was available to satisfy the surface fields of force of both surfaces. Hence the conditions of lubrication were not boundary but something between boundary and " dry ". May not this explain why, in general, friction values are higher for " rubbed film " measurements than for " excess lubricant " measurements ?

That the larger the contact area the greater the tendency to formation of a fluid film cannot be doubted, but that a friction–velocity curve falling as velocity increases is due, in general, to fluid-film formation is not supported by known facts. Although the falling friction–velocity curve is probably the more common type, a large number of combinations of surfaces and lubricants give *rising* friction with *increasing* velocity, at very low speeds. Indeed so far as mineral oils are concerned, it is the heavy " residues " which tend to give curves of friction rising with velocity, and the " light fractions " to give curves showing a fall of friction with increasing velocity. Also, not all lubricants give increasing friction with rise of temperature; some give a decrease. In fact, the type of friction–velocity curve depends on the lubricant, the surfaces, and the temperature [†] in such ways that the view that fluid-film formation is the general explanation for friction decreasing as velocity increases cannot be entertained. It is, therefore, doubtful if it can be deduced from the results given in this paper that " the chief differences between the four alloys are to be found in the extent of fluid friction present under a given set of conditions ", and hence the statements " that there are no important differences between the four alloys as regards boundary friction " and " that differences in relative performance of the alloys cannot be attributed to differences in boundary frictional properties " may in fact not be correct.

The Author (*in reply*) : In reply to Dr. Bristow, a dead-weight balancing system was used in order to avoid the calibration difficulties and errors due to zero creep which arise with an elastic measuring system. It is not clear to me how the damping system can introduce any error, when measurements are made with the specimen holder stationary, as was the case in all the

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[†] *Proc. Roy. Soc.*, 1947, [A], **189**, 88.

experiments described. When the specimen holder is stationary, the damping medium exerts no force in either direction.

This paper does not claim that all changes in friction with velocity are due to fluid-film formation. It does, however, put forward evidence that the changes observed with these particular materials are at least partly due to this cause. With all four alloys, the friction with a rubbed film varies little over a considerable velocity range (Figs. 2, 3, and 4), whereas in most cases, friction with excess of lubricant decreases sharply over the same velocity range.

This decrease in friction with excess of lubricant is associated with increasingly intermittent electrical contact. It can, therefore, hardly be doubted that the reduction in friction with increase of velocity over the range in question is due to fluid-film formation. As noted in the paper, the evidence obtained is insufficient to indicate whether or not fluid-film formation is responsible for reduction of friction at low velocities with the materials examined. During experiments with other materials, I have myself observed changes in friction with velocity which cannot be attributed to fluid-film formation and have advanced a tentative hypothesis to account for such changes.*

Dr. Bristow suggests that insufficient lubricant was present in rubbed-film experiments to give complete boundary lubrication. This suggestion appears to be ruled out by the fact that the friction at the lowest velocity is in no case appreciably higher with a rubbed film than with excess. In some cases, the rubbed-film friction is lower.

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* *Proc. Roy. Soc.*, 1946, [A], 187, 439.

CORRESPONDENCE ON DR. MARIE L. V. GAYLER AND MR. W. E. CARRINGTON'S PAPER: "METALLOGRAPHIC STUDY OF THE PRECIPITATION OF COPPER FROM A SILVER-RICH SILVER–COPPER ALLOY."

(*J. Inst. Metals,* this volume, p. 625.)

Professor Hugh O'Neill,* D.Sc., M.Met. (Member of Council): The new photomicrographs of the earliest beginnings of precipitation in standard silver are very welcome. On p. 625 the authors state that Norbury was the first to study the physical properties of this heat-treated alloy, but they have overlooked a previous paper by W. Fraenkel † in which hardness, structure, and time of reheating were examined. Reference might also be made to another forgotten paper,‡ presented to the Institute, which touched upon some of the points raised in the present work. Thus, on p. 635 the authors remark that their etching reagent attacked the precipitated copper-rich constituent very readily and probably produced a fictitious particle size. The writer and his colleagues showed that etching and polishing could seriously disturb some of the X-ray diffraction results, especially on the quenched standard silver after heating at 300° C. for 30 min. There was a tendency to obtain on certain polished and etched specimens a ring at 4·075 Å, which was believed to be spurious in some cases. The precipitation process for a fixed time at increasing reheating temperatures was finally found to be progressive, as shown by the values in Table A.

Table A.

Treatment.	Lattice Spacing, Å.	Ball Hardness Values.	
		P_u, kg./mm.^{2}	Meyer "n".
Quenched from 750° C.	4·038	86	2·58
Afterwards:			
Heated at 200° C. for 30 min.	4·042	100	2·47
Heated at 300° C. for 30 min.	4·049	149	2·26
Heated at 500° C. for 30 min.	4·064	127	2·30
Heated at 750° C. for 30 min.	4·061	108	2·34
As received	4·072	109	...

The observed fall in the Meyer n value constituted the original evidence that a precipitation effect up to a certain stage is consistent with a strain-hardening effect, and this view has recently been put forward by Dr. Gayler. §

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* University College, Swansea.

† *Z. anorg. Chem.*, 1926, **154**, 386.

‡ H. O'Neill, G. S. Farnham, and J. F. B. Jackson, *J. Inst. Metals*, 1933, **52**, 75.

§ *J. Inst. Metals*, 1947, **73**, (11), 688.

The writer has previously criticized the work of Ageew, Hansen, and Sachs, referred to by Dr. Gayler and Mr. Carrington on the grounds that their precipitation was found to occur suddenly to the final stable lattice dimensions without any progressive lattice changes as the process continued. Results of the two investigations cannot be compared exactly, but those in Table B indicate the point.

TABLE B.

Treatment.	6·3% Copper, Ageew, Hansen, and Sachs.		7·25% Copper, O'Neill, Jackson, and Farnham.	
	Brinell No.	X-Ray Spectrum.	Brinell No.	X-Ray Spectrum.
Quenched from 700° C.	48	Supersaturated, 4·03 Å.	51	Supersaturated, 4·038 Å.
Afterwards heated at :				
300° C. for 10 min.	55	Precipitation lattice and trace of supersaturated lattice.	...	...
,, ,, 20 min.	70	Precipitation lattice only, 4·075 Å.	...	...
,, ,, 30 min.	...	...	110	Precipitated, 4·049 Å (spurious, 4·072 Å).
,, ,, 360 min.	95	Precipitation lattice only, 4·075 Å.	...	...

Ageew, Hansen, and Sachs recorded that after 20 min. at 300° C., or 40 min. at 250° C., all the original lattice had broken down to the final stable precipitate lattice, without any transitional change of size. This is contrary to the results in Table A; if Table A is right, then surface preparation might have adversely affected the specimens of Ageew, Hansen, and Sachs.

DR. F. A. FOX * (Member) : I would like to direct attention to the similarity in the types of precipitation reported in this interesting paper and those occurring in the binary magnesium–aluminium alloys. In a paper by E. Lardner and myself † we reported the precipitation behaviour of magnesium alloys containing 4–12% aluminium, and four general types of precipitate were found. These types are almost identical with those shown in some of the photomicrographs presented in the present paper and with the types described on p. 631. This similarity provides support for some of the generalizations made by Dr. Gayler in her 1947 Medal Address,‡ and which are based, in part, on the behaviour of the silver–copper alloys.

The AUTHORS (*in reply*) : We thank Professor O'Neill for pointing out two papers which we had unfortunately overlooked.

Professor O'Neill refers to the effect of the condition of the surface of "standard" silver specimens on X-ray parameter results and suggests that surface preparation might be the cause of the difference between the results

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† *J. Inst. Metals*, 1943, **69**, 373.

‡ *J. Inst. Metals*, 1947, **73**, (11), 681.

of X-ray analyses made by him, Farnham, and Jackson and those recorded by Ageew, Hansen, and Sachs. We think that the results of the X-ray analyses carried out by Cox and Sykes support the results given by Professor O'Neill in Table A.

The similarity between the microstructures observed in magnesium alloys containing 4–12% aluminium by Dr. Fox and Mr. E. Lardner and those of standard silver is very striking, and it is interesting that such types of precipitation are now to be found in a number of published photomicrographs of alloys which age-harden, though most of the times of ageing are insufficient to show all types of precipitation.

DISCUSSION ON MR. IVOR JENKINS'S PAPER: "SURFACE EFFECTS DURING THE ANNEALING OF 70 : 30 BRASS." *

(*J. Inst. Metals*, this volume, p. 641.)

Dr. C. E. Ransley,† M.Sc. (Member) (contribution read by Dr. F. A. Champion): I wish to comment on Section IX of the paper, which deals with the diffusion of zinc in α-brass, and in particular to call attention to the uncertainty of diffusion data derived from measurements of the type described by the author. There are several objections to the use of the evaporation technique for this purpose, which have been pointed out before, for example by Rhines and Mehl.‡ These are:

(*a*) The possibility of surface films of oxide, which would hinder the free evaporation of zinc atoms and lead to low values for the rate of loss of zinc.

(*b*) The fact that the diffusivity constant of zinc in copper is very dependent on zinc concentration, and probably increases tenfold between 0 and 30% zinc.

(*c*) The density of α-brass is about 8·3, and of pure copper about 8·9, so that the evaporation of the zinc results in a considerable contraction of the lattice. The metal, therefore, tends to open up at the grain boundaries, and preferential loss of zinc occurs in localized regions of the surface.

The author points out the effect of oxide contamination, and ascribes Dunn's results, which are probably too low, to this cause. I should like to return to this point in a moment. So far as the other objections to the evaporation technique are concerned, the statement on p. 661 that condition (*d*) is fulfilled is not valid; the author's measurements will, at best, only yield a mean value for D, the diffusivity constant, over the concentration range 0–30% zinc.

One assumes that similar specimens were used for the gas-content determinations as for the diffusivity measurements. On the assumption that this is so, I have made a rough calculation of the contribution of the evolution of surface gases to the total loss of weight of the specimen. It would be more useful if the gas evolution were expressed as c.c./cm.^{2} instead of c.c./c.c. of metal, but, unless I have made an error, the loss in ½ hr. at about 400° C. due to surface gases is 0·02 mg., whereas the total loss amounts to only 0·033 mg. No correction appears to have been made for this, so that the value of the diffusivity constant D at 405° C. is probably in error to the extent of considerably more than 50%.

If an approximate correction is made for gas evolution, the author's plot of the logarithm of the diffusivity constant against the reciprocal of the absolute temperature on p. 663 is no longer reasonably linear. As far as I can see, the points fall more nearly on two straight lines intersecting at about 500° C. The high-temperature portion is closely parallel to that through the data of Kirkendall, and indicates an activation energy of rather less than 40,000 cal./g. atom; the lower-temperature line has a much higher slope.

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* Discussion at the Annual Autumn Meeting, Glasgow, 24 September 1947.

† Research Laboratories, The British Aluminium Company, Ltd., Chalfont Park, Bucks.

‡ F. N. Rhines and R. Mehl, *Trans. Amer. Inst. Min. Met. Eng.*, 1938, **128**, 185.

The author's diffusion experiments were carried out at a residual gas pressure of 3 mm. of mercury, but he mentions on p. 655 that incipient oxidation occurred when the pressure was greater than 6–8 mm. The margin of safety is therefore not large, and I would suggest that the low-temperature line represents zinc loss through a slightly contaminated surface, which requires a higher energy of activation than is necessary above 500° C., where the contamination is either unimportant or does not take place.

Dr. A. G. Quarrell * (Member): The author deserves our thanks and congratulations for the paper which he has presented, and which is of interest to most of us. Those who are concerned with the practical problem of annealing brass will be particularly interested in the suggestion that the work may lead to a satisfactory, if somewhat revolutionary, method of bright annealing. On the other hand, as we have seen from Dr. Ransley's contribution, the paper includes work which is of considerable interest to those who are more academically minded.

The bright annealing of brass is made difficult by the relatively high vapour pressure of zinc at the normal annealing temperatures, and, because of this, a static atmosphere and a minimum of idle furnace space are necessary if the losses are to be reduced sufficiently for practical purposes. If a static atmosphere is used, the annealing pot must be adequately sealed from the atmosphere, and therefore can easily be made suitable for vacuum work. Some of us may have misgivings at the suggestion that vacuum conditions should be used in the early stages of bright annealing, but considerable strides have been made in vacuum technique in recent years, and the production of vacua of the order of 4 mm. of mercury at a temperature of about 500° C. should present little difficulty, at least in the case of batch furnaces.

On p. 642, the author refers to saturation of the annealing atmosphere with an equilibrium concentration of zinc vapour. As he indicates, one would expect considerable difficulty in obtaining such conditions, and it would be interesting to know whether he has ever tried this method, and, if so, with what success.

One of the most interesting features of the paper is the light which it throws on the effects which rolling lubricants may have during subsequent annealing. It has been realized for a long time that rolling lubricants remaining on the metal may affect the nature of the scale subsequently formed, but this is the first time, so far as I am aware, that anyone has reported work which indicates that it is not possible to eliminate such effects by an adequate degreasing process. It seems likely that the surface gas content of the brass strip will vary with the nature of the rolling lubricant, and therefore that some progress should be possible by paying attention to the nature of this lubricant. Can the pick-up of harmful impurities be avoided by the use, for example, of silicone oils? They are not an economic proposition at the moment, but the information would be interesting. It might also be of interest to try to develop a rolling lubricant which on decomposition would produce a suitable vapour to act as a heavy annealing atmosphere and so reduce the loss of zinc.

There is considerable divergence of view on what constitutes a good rolling lubricant from the mechanical point of view, and I suggest that the time has come for the metallurgist and the oil technologist to rationalize the position. In doing so, they might well pay attention to some of the points raised in this paper.

If the surface gas content referred to by the author is due to impurities being rolled in, the effect should apply in the case of other copper-base alloys;

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* Research Manager, British Non-Ferrous Metals Research Association, London.

yet as far as I know there is no difficulty in the bright annealing of tin bronzes, for example. Is this due to the fact that there is no reaction between carbon dioxide and the tin bronze, which seems unlikely, or is it because the oxidation product in this case is a transparent continuous film? Incidentally, has the author considered the possibility of obtaining selective oxidation under the reduced pressure which he advocates, by the use of suitable addition elements to his brass? This might prevent the evaporation of zinc without the formation of a discoloured film.

On p. 657, the author states that the expansion of his coils of strip on heating caused the adjacent turns to move closer together. It is difficult to see how this could be so unless the coil were strapped with material of a lower coefficient of expansion.

Mr. R. Chadwick,* M.A. (Member): I found this paper extremely interesting, and full of ideas. Those of us who are interested in the possibilities of bright annealing brasses commercially would, however, be more interested in a process using cracked and burnt ammonia than in one using simply cracked ammonia, because of the lower cost. It is quite feasible now to produce commercially cracked and burnt ammonia of more than 90% nitrogen content, and, by suitable auxiliary equipment, to free it completely from oxygen and reduce water vapour to a very small amount.

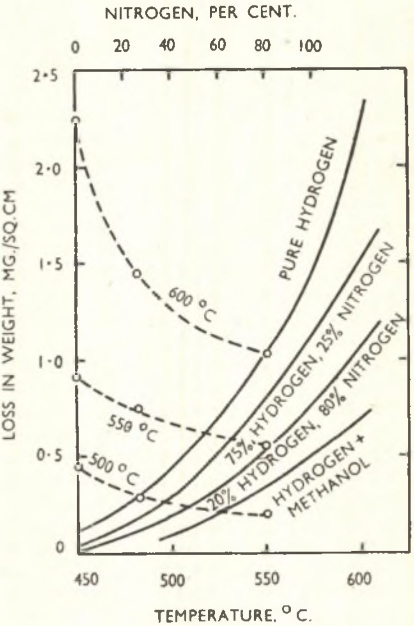

Fig. A.—Effect of Atmosphere Composition on Loss of Zinc from 70 : 30 Brass.

Fig. A is a reproduction of Fig. 10, and, by plotting the loss of zinc against the nitrogen content of the hydrogen at various temperatures, a series of curves shown by the dotted lines is obtained, the shape of which seems to indicate that there would be little advantage in completely eliminating hydrogen. It would be interesting to see whether adding a little methanol to an atmosphere consisting mainly of nitrogen, with a small amount of residual hydrogen, might not reduce staining even further. The remarks of Dr. Quarrell raised other thoughts in my mind as to the possibilities with regard to the surface films of contaminants. The author says nothing about the nature of the rolling oil. Possibly he obtained commercially rolled brass, with an oil film already

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present, but if in fact he and his co-workers rolled the brass themselves, they may know something about the oil, and information on its composition would be of value. It would, of course, be quite feasible commercially to roll using a sulphur-free lubricant, and it would be interesting to know whether this effects an improvement. Another possibility, again arising out of Dr. Quarrell's suggestions, is that the rolling oil could be suitably doped, and from the author's work one might suggest the use of an aldehyde, or some other organic substance giving off a reducing vapour on heating. Polymerized aldehydes are suggested as possibilities in this connection.

Mr. D. C. G. Lees,* M.A. (Member): The emphasis of Mr. Jenkins's paper is, of course, on the bright annealing of rolled brass strip, but it contains some results of interest from the point of view of casting. The author gives gas-extraction figures for brass strip, and for brass strip from which the outer layers have been removed. Even after removal of the outer layers, there remains a certain amount of oxides of carbon, and also a very considerable amount of hydrogen. Has the author examined any pieces of cast 70 : 30 brass? It is generally asserted that brasses do not suffer from hydrogen porosity, because the considerable vapour pressure of zinc over the molten metal precludes the possibility of hydrogen retention. Yet the gases extracted contain a very large proportion of hydrogen—something of the order of 80%—in the case of those samples from which the outer layers were removed. Also, in all cases a considerable amount of oxides of carbon is included. The author implies that the presence of this is due very largely to the residues from rolling oils, but I should like to enquire whether such figures have been found for cast brasses. The work of Bever in the U.S.A. about two years ago, established that there is a slight solubility of carbon in liquid copper, and it would be interesting to know whether the author sees any relationship between the carbon oxides removed and the solubility of carbon in molten copper.

Dr. L. B. Pfeil,† O.B.E., A.R.S.M. (Member of Council): This paper represents work of very high quality, and the Institute is to be congratulated on receiving it for publication. The author has provided information which is of interest not only to those concerned with brass, but to a much wider field. I have read it with the greatest interest in connection with the problem of the bright annealing of nickel silver. We have here a very difficult case—not merely a matter of prevention of scaling during annealing, but also the problem of staining and the etching effect and colour changing, associated with the zinc impoverishment of the surface of the metal.

I interpret the author's results as indicating that in due course the practical man will anneal strip, not in coil but continuously, at higher annealing temperatures and for extremely short times, using a furnace with a very small volume, so that extremely low initial zinc losses from the strip will suffice to stop subsequent loss of zinc. Alternatively, as suggested earlier, Robiette's proposals might be developed, to allow the use of an atmosphere in which the partial pressure of zinc is raised, so that there is no loss of zinc from the strip going through the furnace.

I hope that the author and his colleagues at the G.E.C. research establish-

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ment at Wembley will go on working on this subject, and will give us in due course the benefit of their further work. This subject is very important indeed nowadays. If the strip which is produced in this country does not have a good surface finish, additional polishing will be required for many articles produced from strip, and there is no doubt that labour for the polishing of metal articles is in short supply. It is, apparently, an unpleasant, unpopular job. The metallurgist will therefore be called on to provide semi-finished material, such as strip and sheet, with better and better surface finish, so as to reduce the amount of labour required for polishing.

MR. W. A. BAKER,* B.Sc. (Member): On p. 659, the author, when discussing the effect of various annealing atmospheres, states that an atmosphere containing methanol, either alone or admixed with another neutral atmosphere, "has the effect of reducing oxidation to negligible proportions". The condition of the brass strip is not clear from the description given, but that bare statement rather suggests that the use of the methanol alone is a remedy for the problem.

In discussing this effect, the author suggests that possibly the dissociation of methanol and the liberation of nascent hydrogen may cause reduction of the zinc oxide. I find it difficult to follow this argument, because it seems to me that, even if nascent hydrogen is liberated, when zinc oxide is reduced and steam is liberated, the pressure of steam so formed will rapidly reach the equilibrium value and the reduction will cease. I fail to see the significance of nascent hydrogen in this connection.

Table I gives the gas contents obtained by extraction from the surfaces of brass specimens, and figures are reported in terms of the oxides of carbon, and hydrogen. These gases were extracted in a system maintained at 10^{-6} mm. of mercury, and it would seem that if the brass strip contained zinc oxide and carbon rolled into the surface, the two could interact to yield the oxides of carbon. I do not suggest there is any serious error in the data reported, but it does seem that the amount of carbon oxides obtained by that technique might be substantially greater than the amount which would be evolved when the material was heated under higher pressures, of the order involved in vacuum annealing.

MR. H. H. SYMONDS † (Member): I should like to congratulate the author on the excellence of this paper. With regard to the source of the gases in the brass, in view of the major effect of hydrogen content, the elimination of this at an earlier stage in manufacture would be advantageous, at least when the strip is intended for subsequent cold rolling. Possibly the use of vacuum and cracked-ammonia techniques for the first anneal after initial breaking down might produce strip which would respond much more satisfactorily to annealing at thinner gauges.

Can this gas extraction be applied to material of greater thickness, in view of the very short times for degassing the 0·022-in. material referred to in the paper. Furthermore, has the author any information on the response of 0·022-in. strip to a controlled anneal when the strip ingot has been degassed in this way?

The increased percentage of hydrogen obtained from levels further below

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* Senior Metallurgist, British Non-Ferrous Metals Research Association, London.

† Scientist-in-Charge, Midland Laboratory Guild, Ltd., Birmingham.

the surface seems to be significant, since it appears that reduction of the surface oxides by this hydrogen permits the evaporation of zinc at a more rapid rate. In this connection, apparently a slightly oxidizing atmosphere would be more desirable. The effect of these absorbed gases adds emphasis to the desirability of their elimination at an early stage in the strip manufacture.

The question of surface colour is also important. In the case of brass strip intended for use in articles which are to be subsequently finished by plating or by chemically colouring the surface and lacquering, the surface colour would not appear to be detrimental. I should also like to have the author's views with regard to the lessened tendency to stress-corrosion cracking of brass strip with surface layers of reduced zinc content.

MR. J. W. JONES,* M.Sc. (Member): Most of the members who present papers to the Institute tend to be scientists and academic, and the smaller number, unfortunately, industrialists. The balance of interest in the Institute is in the reverse direction; the industrial element is more numerous, and comes to these meetings to profit by the papers. I sometimes wonder whether the service given by the Institute would not be improved if, to many of the papers, there were an addendum presenting and discussing the particular industrial interest and application of the more scientific data contained in the paper itself.

I should have been happier if the present author had provided at this meeting some samples to illustrate the degree of staining and the degree of success of the various processes. My mind goes back fifteen or twenty years to a discussion on bright annealing in the Birmingham Local Section. One contributor advertised very strongly his particular efforts in bright annealing some brass strip, and showed samples, but a second contributor picked up the brass strip of the first and put his own alongside it. The difference between the two was remarkable; in fact, the second contributor alleged that the first was dull-annealing the material, not bright-annealing it. If we could have had some samples to show the degree of bright annealing obtained, it would have helped us at this stage.

It has already been suggested in this discussion that an ultra-bright anneal is not an absolute necessity for some processes, and it is, of course, an added expense. Is the vacuum annealing really necessary? Would not an atmosphere of an absolutely inert gas, free from carbon monoxide and these other gases, meet the case, and avoid all the practical complications of a vacuum atmosphere?

On p. 658 the author says: " The specimen treated in nitrogen was lightly oxidized, probably because of incomplete purification of the gas ". I cannot help feeling that in doing this work, in exploring very fine effects in ultra-bright annealing, such a thing as probable incomplete purification of the gas ought not to be allowed to remain so indefinite. I am wondering whether, instead of the complicated vacuum process, a really pure nitrogen gas (which, from some limited experience, I do not feel should be so difficult to obtain) would not have given the author effects quite as good as those of his complicated vacuum and double treatment.

The AUTHOR (*in reply*): I should like to thank all those who have contributed to the discussion. I must reply in writing to the points raised by Dr.

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* Senior Lecturer in Materials and Metallurgy, College of Aeronautics, Cranfield.

Ransley in the contribution which was read by Dr. Champion, since they involve some mathematics; but I can say at once that I was perfectly aware of the limitations of the method used in determining diffusivity by this technique, and the data were submitted merely as an indication of the freedom of the brass surface from oxidation during the vacuum experiments.

With regard to Dr. Quarrell's various points, the production of a vacuum on an industrial scale in a bright-annealing plant is not at all difficult. We have actually carried out some tests on an industrial scale; we did so some years ago at Wembley on an annealing container taking a charge-weight of about 30 cwt. of brass strip, and to attain a vacuum of the order of 1 mm. of mercury was not at all difficult. We also, in our preliminary experiments, looked into the question of the saturation of the annealing atmosphere with zinc vapour. We found that the control necessary was very critical. If the partial pressure of zinc in the brass is exceeded, zinc is deposited on the brass; if the atmosphere is under-charged with zinc, zinc evaporation occurs. The process does present difficulties. They are not insuperable, but with the apparatus at present available the technique is certainly very critical.

I heartily endorse Dr. Quarrell's remarks with regard to lubricants. In our work at Wembley on atmospheres generally, we have been very conscious of the harmful effects introduced by lubricants on materials submitted for bright annealing, in both the ferrous and the non-ferrous fields. We have attempted to co-operate with oil technologists on this problem, but so far have not found them very helpful; we obtained some brass supposedly rolled with a sulphur-free lubricant, only to find later that the lubricant did contain sulphur. I strongly endorse Dr. Quarrell's plea that metallurgists and oil technologists should collaborate on this problem, since it is of very great practical importance.

On the question of selective oxidation, it may be of interest to mention that we are engaged at the present time in installing equipment abroad for the bright annealing of brass tubes, and we have recommended that the brass used in this particular case should contain sufficient aluminium to give a protective film of alumina under selective-oxidation conditions. That work has been carried out at Wembley with very encouraging results. The alumina film certainly inhibits zinc volatilization. There appears to be very great promise in the selection of material of that kind.

Dr. Quarrell made a point with regard to the closing-up of coil turns. I regret that I omitted to mention that the coils were bound up with chromium alloy wire of low thermal expansion.

In reply to Mr. Chadwick, we have used burnt ammonia. Our main difficulty has been to obtain burnt ammonia with a sufficiently low dew point to give us satisfactory stain-free annealing. Much has been said in the literature of the advantages of the dehydration of controlled atmospheres. I am not sure that such atmospheres are as good as they are claimed to be, and in the case of materials such as brass and stainless steel one hesitates to use an atmosphere which has to be dried when there is an atmosphere available such as cracked ammonia, which has probably a far lower dew point than could be obtained by ordinary dehydrating methods.

Mr. Lees referred to cast brass. We have not done any work at all on cast brass, and I can offer very little comment on the points which he raised, other than that I do not think that the carbon dioxide evolved during the degassing is associated with carbon in solution in the alloy. The surface gas comes off far too rapidly for one to assume that that can be the case. If the carbon is in solution, then it has to diffuse to the surface and reduce the zinc oxide layer before there can be a reasonable evolution of gas. The time factor involved is such that I think that in this case the gas is actually occluded in the form of impurities rolled into the surface at an earlier stage.

I should like to thank Dr. Pfeil for his remarks, and to mention that in continuous annealing we have carried out some rather interesting experiments, which we hope to submit to the Institute at a later date, on the flash annealing of brass wire, in which we have been attempting to correlate the time necessary to produce full annealing with the time necessary to produce visible etching of the surface of the wire. At the moment, the indications are that the time necessary for full annealing may be greater than that which gives rise to loss of zinc and etching; in other words, one cannot hope, with a normal annealing process, to bright flash-anneal without having a degree of zinc loss which affects the final colour.

Mr. Baker referred to the effect of methyl alcohol and the production of nascent hydrogen. I think that perhaps he has missed the point there. Nascent hydrogen, if it does reduce zinc oxide, will only reduce sufficient to set up the equilibrium concentration of water vapour, so that the water vapour will not lead to re-oxidation. The degree of reduction will not proceed to the extent that water vapour will be formed in sufficient quantity to re-oxidize.

My remarks on cast brass apply largely to the point raised by Mr. Symonds. We have not investigated the degassing of cast brass. I am not sure that degassing at an earlier stage would be an advantage; if we accept the view that the bulk of the gas evolved by the strip is introduced by impurities rolled into the surface, degassing at an earlier stage would probably not materially affect the ultimate surface gas content.

Mr. Jones asks whether vacuum annealing is really necessary. I think that the paper indicates that it is; we find it necessary in order to remove the gases evolved by the brass, which lead to oxidation of the surface. I fail to understand why Mr. Jones should consider that vacuum annealing presents practical difficulties; it does not in fact do so. If one has a suitably designed annealing container which can be effectively sealed, all that one requires is a two-way tap connected to the vacuum pump in one line and to a cracked-ammonia or other atmosphere generator in the other. I see no practical difficulties whatever; and, as I indicated earlier in replying to Dr. Quarrell, we have produced a high order of vacuum in an annealing container with a charge-weight of 30 cwt.

On the question of the oxidation of brass in a nitrogen atmosphere "probably" being due to impurities in the nitrogen, I deliberately said "probably", because the work reported in the paper prior to that statement had indicated that gases in the brass contributed to oxide formation, and we are not sure whether, in the nitrogen experiment, the oxidizing gases arose from the original nitrogen atmosphere or from the gases evolved from the brass itself.

CORRESPONDENCE.

Mr. H. H. Symonds: I should like to ask the author what change in basic composition on the surface of the brass is to be anticipated, and to what depth the loss of zinc is sustained?

Can we accept the theory that most of the gas contained in the surface layers is derived from "rolled-in impurities"? The presence of the greater percentages of hydrogen at lower depths raises the question of the amount of hydrogen at still greater distances from the surface. The whole point suggests the absorption of hydrogen during melting and casting, and the short time necessary for degassing the surface layers of thin strip suggests the possibility of degassing thicker material.

The AUTHOR (*in further, written, reply to the discussion and in reply to correspondence*): Dr. Ransley has queried the accuracy of the diffusivity data reported in the paper. He is correct in assuming that no allowance had been made for the contribution of the evolution of surface gases to the total loss in weight of specimens treated *in vacuo*, but the order of correction is not as great as he has calculated. Thus, at 405° C. the weight of gases evolved after $\frac{1}{2}$ hr. *in vacuo* is 0·01 mg./cm.^{2} on a total loss of 0·033 mg./cm.^{2}, while at 600° C. the respective values are 0·018 mg./cm.^{2} on 1·41 mg./cm.^{2} The contribution of the evolved gases to the total loss in weight at temperatures above 450° C. is a very small percentage of the whole, and the correction necessary in the values of the diffusivity constants quoted in Table V of the paper for the temperature range 476°–600° C. can be neglected. At 450° and 405° C., however, the quoted values are subject to correction, and the following values are submitted after allowance has been made for the weight of gases evolved.

405° C.	$D = 4{\cdot}1 \times 10^{-14}$ g./cm.^{2}/sec.
450° C.	$D = 5{\cdot}4 \times 10^{-13}$ g./cm.^{2}/sec.
476° C.	$D = 2{\cdot}05 \times 10^{-12}$ g./cm.^{2}/sec.

The net result of the correction is to change slightly the slope of the log D–$1/T$ plot given in Fig. 11.

There does not appear to be any published data on gas-extraction tests on tin bronzes, referred to by Dr. Quarrell, but his suggestion that reaction between tin bronze and carbon dioxide may lead to a transparent, protective film of oxide would seem to be very probable.

Further to the point made by Mr. Baker regarding the reduction of zinc oxide by nascent hydrogen formed by the dissociation of methanol vapour, it should be pointed out that, under the conditions of the particular experiments reported in the paper, the brass was treated in a flow of gas, so that equilibrium conditions in the vapour phase were not maintained. It is not suggested at this stage that the use of methanol is the solution to the problem of the bright annealing of brass, but its use following a vacuum treatment appears to reduce appreciably the volatilization of zinc.

With regard to the further communication from Mr. Symonds, as reported on p. 655 of the paper the overall loss in weight due to zinc volatilization after the complete cycle of annealing is of the order of 0·1%. During the later stages of the treatment, further zinc loss is restricted, and by diffusion the brass again becomes homogeneous. During the vacuum treatment, the exposed surfaces only of a coil are free to evaporate, and at the surface the zinc content is virtually zero. The depth affected, however, is very small, and in the experiments described in the paper the concentration gradient never extended below about 0·002 in.

It is not doubted that the bulk of the hydrogen in the alloy originates at a much earlier stage in manufacture, probably during melting and casting. However, as the gas-extraction data indicate, almost all the carbon oxides are concentrated near the surface, and it seems logical to conclude that they can be associated only with "rolled-in" impurities.

OBITUARY.

EDWARD ARTHUR ARLISS.

One who taught him at Cambridge writes: Arthur Arliss came into residence at Pembroke College, Cambridge, in October 1942 and spent two years there before serving in the Army. He showed himself a steady and reliable member of the College and was deservedly popular with his acquaintances. He took a keen and intelligent interest in all scientific matters, and also played in the College Rugby Football side. He gave every promise of rendering useful service in the post-war world, and his untimely death is deeply regretted by all those who knew him.

JAMES WILLIAM DONALDSON.

James W. Donaldson, D.Sc., died suddenly at his home in Gourock on 12 January 1947.

Dr. Donaldson started his career at the Carron Iron Works, Falkirk, in 1902. Subsequently, he studied at the University of Edinburgh and graduated B.Sc., in chemistry. From 1912 to 1914 he was chief assistant chemist at David Colville and Sons, Motherwell. He then obtained a Carnegie Research Scholarship, and a year later was placed in charge of the experimental and research laboratory at Wm. Beardmore and Company, Parkhead. In 1918 he was appointed chief metallurgist and chemist in Scotts' Shipbuilding and Engineering Co., Ltd., Greenock, a post which he held until the time of his death.

Dr. Donaldson made a number of valuable contributions, mainly on the properties of cast irons, to the Institute of British Foundrymen, the Iron and Steel Institute, the Institute of Metals, and the Institute of Mechanical Engineers, and, in so doing, gained several awards, notable among them being the Oliver Stubbs Gold Medal in 1938. In that year also, as a result of his work on cast iron, he was awarded the D.Sc. degree of the University of Edinburgh. He was a frequent contributor of articles to various technical papers and journals.

Dr. Donaldson had a variety of interests; he was a member of the Royal Gourock Yacht Club, and was a keen philatelist. Those who have been closely associated with him experienced his unfailing courtesy and charm of manner—attributes which gained him many friends and which engendered a profound personal regard for him in all who met him.

He was a member of the Institute of British Foundrymen and a joint member of the Institute of Metals and the Iron and Steel Institute. He was a member of the Committee of the Scottish Local Section of the Institute of Metals from 1929 to 1931, and was Chairman of the Section and ex-officio Member of the Council of the Institute from 1934 to 1936. He also served as a Member of Council from 1938 to 1941.

E. A. Fowler.

ARTHUR F. HAAS.

Mr. Arthur F. Haas died at Burlington, Wisconsin, U.S.A., on 19 March 1947, at the age of 61.

He spent his early life in Burlington and received his education there. In 1906 he joined the American Brass Company and remained with that Company until 1921 when, together with four other men, he organized the Chicago Extruded Metal Company. Mr. Haas served as vice-president of this Company until 1941, when he retired. In the last six years he made frequent trips to Chicago to act as consultant for the Company.

Mr. Haas was elected a Member of the Institute in 1929.

JOZEPH HAMBURGER.

Mr. J. Hamburger, J. Azn., Honorary Corresponding Member to the Council for Holland, died suddenly at his home in Utrecht on 10 February 1946, at the age of 60.

Born in Utrecht in 1886, he studied economics and, after finishing, entered the works of the Royal Dutch Lead and Zinc Mills. After having worked in all the departments, he was elected manager and director of the Company, and it was under his superior leadership that the Company extended its many international relations all over the world and developed immensely. The construction of a complete new rolling mill was executed under his direction. He introduced many new working principles and methods, and the whole plant was completely modernized.

His great interest in metallurgical and technical subjects brought him into contact with the Institute of Metals, as an ordinary member first and from 1932 as Honorary Corresponding Member to the Council for Holland. Except for the years of German occupation, he held this post until his death.

He was widely known in the non-ferrous metals world, not only in Holland.

During the war he made, with great courage, well thought-out plans for the reconstruction of the plant, which was being ruined by the Occupiers. These plans are a great inspiration to those who now have the responsibility of carrying on.

Max Hamburger.

THEODORE ALBERT EDWARD HOLDENGARDE.

Theodore Albert Edward Holdengarde, O.B.E., F.R.S.A., F.R.E.S., died at Bulawayo on 4 August 1947.

He was born in 1878 in the Albany district of the Union of South Africa, and was educated at Cathedral Grammar School, Grahamstown, and University College, Durham University. He went to Rhodesia in 1910 and founded the business of Hogarths Metal Works, Limited, of which concern he was the Managing Director until the re-organization of the Company in 1946 as Hogarths, Limited, when he became Chairman of Directors.

From 1937 to 1940 he was Mayor of Bulawayo, and among his many activities he was President of the Bulawayo Agricultural Society, Chairman of the People's Mutual Benefit Building Society, Chairman of the Society of Jews and Gentiles, and Member of the Bulawayo and District Publicity Association, Chamber of Industries, Milton School Council, &c. He was a joint member of the Institute of Metals and the Iron and Steel Institute.

He was greatly interested in archæology, architecture, and arboriculture, and The Castle, Hillside, his hobby and residence, is a permanent memorial to his energy and activity.

He leaves a widow, two sons, and a daughter.

GILBERT A. DEAN.

ALEXANDER ARCHIE JUDE.

Mr. A. A. Jude died at the Queen Elizabeth Hospital, Birmingham, on 8 March 1947.

Mr. Jude, who was for many years chief turbine designer to Messrs. Belliss and Morcom, Ltd., Birmingham, was born at Norwich on 29 June 1875 and was educated at the King Edward VI School, Norwich. He then received a technical education in engineering subjects generally, and was awarded a Whitworth Exhibition in 1893. He served his apprenticeship, between the years 1890–1896, in marine engineering, with Earle's Shipbuilding and Engineering Company, Ltd., Hull, and was employed by them for 5 years subsequently as a draughtsman. He joined Belliss and Morcom, Ltd., in 1901, and was employed as a leading draughtsman in the design and development of their larger triple-expansion steam engines. Concurrently, he undertook research into the design of the steam turbine, producing the firm's first experimental turbine in 1904.

The development of this type of prime mover became Mr. Jude's life's work, and he ranks with Parsons, Rateau, Curtis, and DeLaval as a creator of an entirely successful and original turbine. From then on he took complete charge of design and development of Messrs. Belliss and Morcom's steam turbines. He was a man of great originality and inventive ability. Among his many achievements in turbine construction was the design of the first 3000-r.p.m., 10,000-kW. turbine built in this country, supplied to the West Ham Corporation. In 1906 he published a treatise on the theory of the steam turbine, which embodied much of his early experimental work and experience, and to-day his treatise is still regarded as being an outstanding work on this subject.

He was a man of wide culture and interests : gardening was his particular hobby; he was also a keen musician and no mean painter in water colours. These pursuits absorbed most of his leisure time for many years.

He was elected a Member of the Institution of Mechanical Engineers in 1911, was for many years a Member of the Birmingham Metallurgical Society, and was an Original Member of the Institute of Metals.

E. L. MORCOM.

LOUIS WALTER KEMPF.

Louis Walter Kempf, assistant director of research of Aluminum Research Laboratories, died in Cleveland, Ohio, U.S.A., on 14 June 1947, after an extended illness.

Mr. Kempf had achieved international recognition as a scientist, author, and inventor during the 23 years he was associated with the Aluminum Company of America. He was a member of the American Society for Metals, the American Society for Testing Materials, the American Foundrymen's Association, and the American Institute of Mining and Metallurgical Engineers.

Mr. Kempf was elected in 1946 to the Chairmanship of the A.I.M.M.E.'s Institute of Metals Division. He became a member of the Institute of Metals in 1936.

Born in Luther, Mich., on 22 March 1898, Mr. Kempf obtained his early education in Michigan public schools. After graduating from high school, he acquired industrial experience with Continental Motors, Studebaker Corporation, and the Dodge Motor Company. With America's entry into World War I, Mr. Kempf enlisted in the U.S. Army Air Corps, serving overseas with the 8th Aero Squadron. Upon his discharge in May 1919, he entered the University of Michigan, where he gained both the B.S. and M.S. degrees.

In 1924, Mr. Kempf became associated with the Aluminum Company of America as a research metallurgist. Six years later, he was placed in charge of the Cleveland Metallurgical Division of Aluminum Research Laboratories. His exemplary work brought him promotion in 1943 to the managership of the Cleveland branch of Aluminum Research Laboratories, a post he held until his appointment in 1945 as assistant director of research for Aluminum Research Laboratories. Mr. Kempf was inventor or co-inventor of numerous Alcoa aluminium alloys. A learned and prolific writer, he was the author of many technical papers and metallurgical treatises now regarded as "standard references" in the aluminium industry.

The versatility of his tastes and interests extended from reading English literature, a field in which he was something of an authority, to amateur photography and classical music. He made a hobby of producing his own photographs of northern Ohio rural scenes, and possessed an excellent collection.

Mr. Kempf leaves a widow and son.

GORDON C. MEEK.

ERNEST MILLER.

As one who had a very warm friendship with Ernest Miller extending over something like forty years, I greatly appreciate the opportunity to contribute a short note on his personality and his experiences.

I think it was in 1907, when I was chief of the test room at the Cambridge Scientific Instrument Company, Ltd., that Ernest Miller came to me as an assistant, and even at that early date I was struck by a certain gaiety with which he viewed life and attacked difficulties and which did not in any way interfere with his acute technical appreciation of a problem. When I went to the States in 1907 I lost touch with him, but contact was renewed during the early part of World War I when I learnt that he was engaged on what had been his "first love"—instrument design and construction.

I saw him and heard from him often, with increasing warmth of our friendly feelings and appreciation of his qualifications until, in the business he had established in Birmingham, he became the representative of our Company. In that work, he combined the factors associated with pyrometry and heat insulation and established for himself quite a reputation as an authority on the practical application of these two processes. In this work and capacity Ernest Miller continued until his death on 25 November 1946.

I am sure that I was no exception among his many friends in finding, when meeting him for discussion of technical and business matters, that his gaiety of spirit persisted to the last. He entered into a problem with a feeling that enthused us all, making us feel that it was not only interesting technically but a good game and rather an adventure, and his conversation was enlivened by a fund of anecdotes and original humorous remarks which in themselves were an entertainment.

The technical industries associated with the use and measurement of heat have suffered a great loss in his departure from us, but I am happy to note that the ideals which inspired his own approach to work and business have persisted among us and form a model of how man should live and enjoy life.

He was elected a member of the Institute of Metals in 1922.

Charles E. Foster.

SAMUEL MOORE.

Mr. Samuel Moore died on 7 February 1947, after only a short period of retirement from active service with the firm he had joined in November 1915, Messrs. Aiton and Company, Ltd., Derby.

He originally hailed from the Black Country, and was for many years at Aiton's as welding shop foreman, playing a large part in the development of welding technique. In this he was a recognized authority, not only locally, but also on various national committees on which he served. In July 1937 he relinquished his position as foreman and inaugurated the firm's research laboratory, now an indispensable part of the Company's organization.

He became a member of the Institute of Metals in 1944.

GILBERT CHARLES PITCAIRN.

The death occurred on 17 October 1947, at Hillside Nursing Home, Cardiff, of Mr. G. C. Pitcairn, Sales Manager of Metallisation, Ltd., Dudley. Born at Bristol in 1896, Mr. Pitcairn attended schools at Bristol and Glasgow, but then joined the training ship H.M.S. *Conway*, where he distinguished himself as a student of navigation and as an all-round sportsman. In the First World War he served in the Royal Navy as a lieutenant, and at the close of hostilities took his first mate's ticket in the Clan Line. He married Miss Mary Doris Belliam at Liverpool and, after a short term on tankers, left the sea and took up the study of the manufacture of pottery and earthenware. This resulted in his being appointed general manager to China and Earthenware, Ltd., Seville in 1926, and he remained in this position until the events of the Spanish Revolution made it impossible for him to continue. On his return to this country, he joined the staff of Metallisation, Ltd., and was soon after appointed sales manager, which position he filled until his death.

He was a very jovial and versatile personality and was very popular wherever he went. He was a very active member of Rotary; and undoubtedly he did a good deal in his last years of life to increase the use of metal spraying in this country and abroad. He leaves a widow and one married daughter who is living in Buenos Aires.

He was elected a member of the Institute of Metals in 1943.

W. E. Ballard.

JOHN STEWART GLEN PRIMROSE.

John S. G. Primrose, A.R.T.C., C.I.Mech.E., A.I.M.M., passed away at his home in Birmingham on the afternoon of 2 October 1947, in his 69th year, after an illness of nearly twelve months' duration. His passing will be a personal loss to his many friends, for his helpful outlook, coupled with a wealth of knowledge and experience, endeared him to all who came into close contact with him.

Primrose was a native of Glasgow and commenced his education at Allen Glen's school in that city. His business training was carried out at Messrs.

Nobel's, followed by his becoming a student at the Royal Technical College and University, Glasgow. For a period of nine years he was on the staff of the Royal Technical College, being assistant to Professor A. H. Sexton from 1905 and Lecturer in Metallurgy from 1909. During this period, Primrose furthered his knowledge by a Summer Research Course at Freiberg Academy, Saxony, in 1907.

In 1913 Primrose left full-time academic work to become metallurgist at the Diesel Engine Works, Ipswich, and later, in 1915, joined Ransomes and Rapier. During his connection with the latter organization, he was associated with Sir Wilfred Stokes, K.B.E., when the Stokes Mortar was developed, and took a great interest in the East Anglian Munitions Committee.

In 1923 he joined Messrs. Richard Johnson and Nephew of Manchester, and subsequently, in 1927, Whitecross (Wire) Company, Warrington, then finally, in 1935, The Rover Company, Ltd., at their works in Birmingham. During this period, Primrose was an active member of many technical societies, including the Institute of Metals and the Institute of British Foundrymen, being elected President of the Lancashire Branch of the latter Institute in 1927. In addition, he returned to his academic activity as part-time Lecturer in Metallurgy, notably at Manchester Technical College. Throughout his life, Primrose made many contributions to various technical bodies as author of numerous papers and author and part-author of several books on metallurgy and non-ferrous foundry practice, for example : " The Practical Metallography of Iron and Steel ", by J. S. G. Primrose; "Metallurgy of Iron and Steel ", by A. Humboldt Sexton and J. S. G. Primrose; and " Gun-Metal and Brass Founding ", by H. S. and J. S. G. Primrose.

Generally an obituary consists essentially of a summary of the professional attainments of an individual, but Primrose will be remembered also for the unusually high regard in which he was held by many friends, in this and other countries, to whom he gave unstintingly of his time. He was at his best during technical discussions and although kindly, was forceful and to the point. Among his collection of awards were medals for such diverse activities as technical discussions in learned societies, and markmanship while a member of the 3rd Lanarkshire Rifle Volunteers before the first World War.

Primrose will be long remembered by his friends and colleagues on account of his friendliness, his courtesy, and, under all conditions, his cheerfulness. On all occasions, and to the labourer and manager alike, he gave consideration and thought, and his opinion and decisions always merited the most careful attention.

S. HESLOP.

HENRY LeROY RANDALL.

Mr. Henry LeRoy Randall, President of The Riverside Metal Company, Riverside, New Jersey, U.S.A., died in Zurbrugg Memorial Hospital, Riverside, on 18 February 1947. He was born in New Milford, Connecticut, on 13 October 1891, and was educated in the New Milford High School, Phillips Academy, Andover, Massachusetts, and Yale Sheffield Scientific School, Yale University.

Immediately after his graduation from Yale in 1914, Mr. Randall became associated with the American Brass Company of Waterbury, Connecticut, and remained with that organization until 1916, during which time he was affiliated with the Torrington, Connecticut, and Kenosha, Wisconsin, branches of the Company. His innate executive ability, his fine mind and educational background, combined with his valuable experience with the American Brass Company laid the foundation for his outstanding success in the field of metallurgy in his later life.

As assistant works manager, Mr. Randall came to The Riverside Metal Company in 1916 and advanced rapidly until he was elected President of the Company in November 1920 at the age of 29. This position he held until 1942 when, by merger of The Riverside Metal Company and its Associate, the present Keystone Watch Case Division, he became President of the combined Companies.

During World War II he served as a member of the Brass Mill Advisory Committee of the War Production Board, and by his sane and balanced opinions contributed valuable service, not only to his own Company, but to the brass industry as a whole. He was also a member of the Army Ordnance Association and the Copper and Brass Research Association.

Mr. Randall's career was not unlike that of many others, in that practically his entire business life was devoted to one Company, in his case The Riverside Metal Company, the advancement and welfare of which filled his waking hours.

He became a member of the Institute of Metals in 1929.

John F. Hackett.

PATRICK WILLIAM ROLLESTON.

At the time of his death, at the early age of 44, on 9 September 1947, Mr. Patrick Rolleston was a Director and Vice-President of Aluminium Laboratories, Ltd., and was in charge of the organization of that Company in England.

He graduated from Oxford University, obtaining his B.A. with first-class honours in mathematics and Engineering, in 1924.

He was Vice-President of the Aluminium Development Association and Vice-Chairman of the Executive Committee of that Association, served on the Council of the British Non-Ferrous Metals Research Association, and was a member of the Institute of Metals since 1932, the American Society for Metals, and the American Society for Testing Materials.

Before joining the Aluminium Limited group of companies, of which Aluminium Laboratories, Ltd., is a member, he was with the British Thomson–Houston Company, Ltd., England. In September 1930 he joined the Aluminum Company of Canada, Ltd., and spent three years in charge of technical control at their Shawinigan Falls plant and one year at their Toronto plant. He came to England in 1935 and for two years worked as sales engineer with the Northern Aluminium Company, Ltd.

In 1937 he joined Aluminium Laboratories, Ltd., and was put in charge of their patent and legal department in Montreal. In 1941 his services were loaned to the British Air Commission, New York, where he worked as chief of the Light Metals Section, and in 1943 he was appointed Director of Materials Supply. During the war he visited England on several occasions for consultations with the Ministry of Aircraft Production.

He was particularly interested in international relations, as was evidenced by his membership of the Royal Institute of International Affairs and the Canadian Institute of International Affairs.

In 1944, Mr. Rolleston was appointed Vice-President and Director of Aluminium Laboratories, Ltd., returning to England in 1945 to re-open the Research and Development Laboratories at Southam Road, Banbury.

H. C. Thomas.

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