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ALS AND NAMES OF CONTRIBUTORS IN VOLUME XI WITH THE ARTICLES WRITTEN BY THEM.

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Author of *Portugal for the Portuguese*; etc. } Manuel de Mello
Francisco (*in part*)
- ALBERT CALMÈS. }
Professor, University of Frankfurt, Germany Conducted an enquiry into the economic and financial situation of Albania for the League of Nations. } Luxembourg.
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English Poet Author of *Poems and Ballads*, *Age of Shakespeare*, etc See the biographical article: SWINBURNE, A C } (*part*),
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- A. D. IMMS, M.A., D.Sc. }
Chief Entomologist, Rothamsted Experimental Station, Harpenden, Hertfordshire, England Formerly Forest Zoologist to the Government of India and Professor of Biology, University of Allahabad Author of *A General Textbook of Entomology*, etc } Locust.
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University Lecturer in Biblical Studies, Oxford, since 1927. Sometime Student and Tutor of Christ Church, Oxford. Author of *The Gospel According to St. Mark*, in the Westminster Commentaries } Mark, Gospel of.
- ADA E. LEVETT, M.A. }
Reader in Economic History, King's College, London Late Vice-Principal and Tutor in Modern History, St. Hilda's Hall, Oxford Author of *English Economic History*, *The Black Death on the Estates of the Bishop of Winchester*, etc } Manor (*in part*).
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Secretary of the British Museum Editor of *The Library Association Record*. Lecturer in Bibliography, University of London School of Librarianship Sandars Reader in Bibliography, University of Cambridge, 1926-7 Author of *A List of English Tales and Prose Romances*, *The Sources of English Literature*, etc } Libraries (*in part*).
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Professor of Anthropology, University of California, Berkeley, Calif Author of *Zuni Kin and Clan*, *Anthropology*, etc. } Mandan.
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President of Harvard University Trustee of the Lowell Institute of Boston Corresponding Fellow of the British Academy } Lowell Institute.
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Economic and Financial Section, League of Nations, Geneva } Lithuania (*in part*)
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Of Messrs Pommery and Greno, Ltd Author of *The Blood of the Grape*, *Wine and the Wine Trade* } Madeira Wines.
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INITIALS AND NAMES OF CONTRIBUTORS

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Editor of the *Journal of the Institute of Brewing* Lecturer on brewing and malting } Malt.
at the Sir John Cass Institute, London. Vice-President of the Society of Chemical
Industries.
- A. SCOTT
On the staff of Lloyd's Register of Shipping, London } Lloyd's Register of
Shipping.
- ARTHUR SHERNELL
Member of Parliament for Huddersfield, 1906-18 Thirty years' research work and } Licensed Victualler.
study of social and industrial questions Author of *Life in West London*; *Taxation*
of the Liquor Trade, *Public Control of the Liquor Trade* *State Prohibition and Local*
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English poet and critic Author of *Days and Nights* *Studies in Two Literatures*, } Mallarmé, Stephane
Charles Baudelaire, etc See the biographical article: SYMONS, ARTHUR
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Official of Life Saving Service, United States Coast Guard, Treasury Department, } Life-Boat and Life-Saving
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Formerly Rector of Bow Church, Cneapside. Author of *Life of Cardinal Newman*, } Manning, Henry Edward
Life of Cardinal Manning; etc } (in part).
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Late Professor of Greek Edinburgh University Lecturer, Aberdeen University, } Livy;
1898-9, Edinburgh University, 1899-1903 Classical Examiner to London Uni- } Lucan, Marcus Annaeus
versity, 1919-23. Author of *Hesiod*, *Introduction*, *Translation and Appendices*, } Lucian; Lucretius, Martia
Callimachus, etc
- ABRAHAM WOLF, M.A., D.LITT
Professor of Logic and Scientific Method in the University of London Sometime } Logic;
Fellow of St John's College, Cambridge Fellow of University College, London } Logic, History of (in part)
Author of *The Oldest Biography of Spinoza*, *Textbook of Logic* Editor of the Philo-
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1901-5, Ceylon, 1905-15. Chief Justice, 1914, etc Author of *Law and Practice of*
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Under-Librarian, University Library, Cambridge. } M.
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Military Historian and Critic Military Correspondent to the *Daily Telegraph*, } Mantinea;
London Editor of the Military section, 14th Edition, *Encyclopaedia Britannica* } Marne, Second Battle of
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Professor of Anthropology in the University of London. } Marriage.
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Scholar of Trinity College, Cambridge. H.B.M. Acting Consul for Austria, 1921-6 } Ludendorff, Erich (in part)
Passport Control Officer for Austria, 1922-5 Intelligence Officer, League of Nations }
Union 1926 Author of *The Social Revolution in Austria*, *Survey of International*
Affairs for 1925, part II, (in part), etc
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Sometime Associate of Bedford College, London } Marie Antoinette.
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Superintendent, Kew Observatory, 1893-1925 Awarded James Watt Medal, Insti- } Magnetograph,
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INITIALS AND NAMES OF CONTRIBUTORS

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Provost and Sterling Professor of History, Yale University Author of *Electoral Reform in England and Wales, The Diplomatic Background of the War, The Intimate Papers of Colonel House, etc.* } Lodge, Henry Cabot.
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Of Messrs Henry Head and Co Ltd., Brokers, London Author of *A History of Lloyd's* } Lloyd's.
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Lecturer in Economics in the University of Cambridge. Formerly Fellow of St John's College, Cambridge Served as the Secretary of the Supreme Economic Council, Paris, 1919-20 } Luxury;
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Jodrell Professor of Zoology and Comparative Anatomy, University College, London Author of many papers on Vertebrate Palaeontology and connected subjects in *Proceedings of the Zoological Society, Journal of Anatomy, etc* } Mammoth.
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Brigadier General, United States Marine Corps, Washington Author of *Naval Reconnaissance, etc* } Marines (in part)
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 Reader in Physics at the University of Leeds. Research Fellow, Emmanuel College, Cambridge. Author of *Magnetism and Atomic Structure* } **Magnetism.**
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 Senior Biochemist, Bureau of Chemistry and Soils, United States Department of Agriculture, Washington. Author of *The Principles of the Liming of Soils*, etc. } **Liming (in part).**
- EDWIN DELLEP, LL.D.**
 Academic Registrar, University of London, and University Extension Lecturer } **London University.**
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 Director, School of Oriental Studies, London, and Professor of Persian in the University of London. } **Manchu Language.**
- E. E. LONG, C.B.E.**
 Formerly Director of Eastern Propaganda, Foreign Office, as Officer-in-Charge, Eastern Section, News Department, 1918-27. *The Times* (London) Correspondent in Northern India. Formerly Editor of *The Indian Daily Telegraph*, *The Rangoon Times*, etc. } **Lombok;
 Macassar,
 Madura;
 Malay Archipelago (in part).**
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 Associate Editor, *The Iron Age*, New York. Author of *Elementary Metallurgy* } **Manganese Steel.**
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 Professor of Geography at Bedford College, London, 1882-3. Sometime in Topographical (now Intelligence) Department of the War Office. Author of *The Russians in the Amur*, *A Systematic Atlas*, etc. } **Map (in part).**
- E. IBBETSON JAMES, O.B.E., M.A.**
 Sometime British Consul Officer, Allied Supreme Economic Council. Later, Member of Secretariat of League of Nations and International Labour Office, Geneva. Member of the Editorial Staff, London, 14th Edition, *Encyclopædia Britannica*. } **Lloyd, Marie.**
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 Editor of *Theatre Arts Monthly*, New York, and *Theatre*. } **Little Theatre Movement (in part).**
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 Translator, *Vedic Hymns*. Author of *The Life of Buddha as Legend and History*. } **Lumbini;
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 Maitreya.**
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 Professor of Portuguese Language, Literature and History in the University of London. Comendador, Portuguese Order of S. Thiago. Corresponding Member of Lisbon Academy of Sciences, Lisbon Geographical Society, etc. Editor of *Letters of Manuel de Mello* in Hispanic Society's Portuguese series, etc. } **Lopes, Fernão (in part)
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 Hon. Fellow of New College, Oxford. Lecturer on Hellenistic History and Literature at King's College, London. } **Lysimachus.**
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 Analyst and Technical Consulting Chemist. Past Vice-President of the Institute of Chemistry of Great Britain and Ireland. Managing Director, Technical Research Works Ltd., and Director of Loders and Nucolize, Ltd. Joint-Author of *Oils, Fats, Waxes and Resins*. } **Margarine (in part).**
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 Author of *Life of Mary Wallstoncraft*, *Feasts of Antiochus*. Co-Author of *Lithography and Lithographers*. } **Lithography (in part).**
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 Editor of *United Empire*, Journal of the Royal Empire Society. Formerly on the staff of *The Saturday Review*. Author of *Life of General Wolfe*, etc. } **Malay Archipelago (in part).**
- ETHEL TRUMAN**
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 Humorist in verse and prose. On the Staff of *Punch*. Author of *Parodies Regained*, etc. } **Limericks.**
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 Late Librarian of the Bodleian Library, Oxford. Principal Librarian and Superintendent of the London Institution, 1873-82. Author of *Kellic Researches* } **Mandeville Jehan de part.**

INITIALS AND NAMES OF CONTRIBUTORS

- CAPTAIN F A M WEBSTER
Joint Editor of *The Blue Magazine* London and writes on athletics. } Marathon Race.
- FLORIAN CAJORI PH D., LL.D., Sc.D.
Professor of History of Mathematics, University of California, Berkeley, California
Late President Mathematical Association of America. Author of *A History of Mathematics, History of Mathematical Notations*, etc } Logarithms.
- FRANCIS CRAWFORD BURKITT, F B A., D D., D THEOL
Notitian Professor of Divinity in the University of Cambridge, and Fellow of Trinity College } Mandaeans.
- FREDERICK GEORGE MEESON BECK, M A
Formerly Fellow and Lecturer in Classics, Clare College, Cambridge } Lombards (*in part*),
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Professor of Anatomy, University of London President, Anatomical Society of Great Britain and Ireland Lecturer on Anatomy at St Thomas's Hospital and the London School of Medicine for Women } Liver, Anatomy of;
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Consulting Engineer. Contributor to *The Times Engineering Supplement, Engineering Machinery*. } Machine Tools (*in part*)
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Editor, *American Machinist*, New York. Member, American Society of Mechanical Engineers Author of *American Machinist's Handbook; Aircraft Handbook Machine Shop Operations, The Working of Steel* } Machine Tools (*in part*)
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Past President, Institute of Mining and Metallurgy Adviser on Metalliferous Mining to the Mines Department Author of *The Mineral Resources of Natal* (Report to Natal Government), *The Iron and Steel Industry of the U. K. under War Conditions, The Past, Present and Future of the Gold Mining Industry of the Witwatersrand Transvaal* } Limonite.
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Director of Heavy Traction, Westinghouse Electric and Manufacturing Company, New York } Locomotive (*in part*)
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Author of *Marine Engineering Practice, Coal and Oil Fired Boilers Marine Engineering Repairs*. } Marine Engineering.
- FRANK J G DUCK, B S., CH E
Of the Worthington Pump and Machinery Corporation, New Jersey Member, American Institute of Chemical Engineers Co-Author of original edition of *Coal Miner's Handbook* } Lithophone.
- FRITZ KLEIN, PH D.
Member of the staff of the *Deutsche Allgemeine Zeitung* } Luther, Hans.
- F. M. STENTON.
Professor of History, University of Reading Editor of the History (Mediaeval) section, 14th Edition, *Encyclopaedia Britannica* } Mark System
- FRANK RICHARDSON CANA, F R G S
Editorial Staff, *Encyclopaedia Britannica*, 1903-11 and 1914-5 Staff of *The Times*, London, since 1916. Author of *South Africa from the Great Trek to the Union*, etc } Madagascar (*in part*)
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Major, Judge Advocate General's Department, United States Army, Washington } Martial Law (*in part*).
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Curator and Librarian of the Museum of Practical Geology, London, 1879-1902 } Marble (*in part*)
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Captain, Corps of Engineers, United States Army, War Department, Washington } Light Railways, Military
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Printer for many etchers and lithographers in America, including George Bellows and Albert Sterner } Lithography (*in part*).
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University Reader in Economics, Oxford Author of *The World of Labour; Self Government in Industry, Guild Socialism Restated, Social Theory* etc. } Marx, Karl Heinrich
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- GEORGE EARLE BUCKLE, M A., LL D
Editor of *The Times*, London, 1884-1912 Editor of *Letters of Queen Victoria*. Author of *The Life of Disraeli* } McKenna, Reginald.
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Secretary of the Royal National Life Boat Institution } Life-Boat and Life-Save
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Consulting Engineer and Joint-Editor of *Engineering and Industrial Management* } Locomotive Coaling (*in part*).
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Author and Publicist Author of *The Minoans Ronald Burrows. a Memoir*; etc. } Locarno, Pact of.
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Lecturer on Naval History, University College, London Formerly Professor of Fortification at the Royal Naval College, Greenwich Editor of *The Study of War* } Lithuania (*in part*),
Malay States (*in part*).
- GEORGE GREGORY SMITH, M.A., LL D
Professor of English Literature at Queen's University, Belfast. } Lyndsay, Sir David.
- GEORGE R PUTNAM, M S., D SC
First Commissioner of Lighthouses, United States Lighthouse Service, Washington Author of *Lighthouses and Lightships of the United States*, etc. } Lighthouses (*in part*).

INITIALS AND NAMES OF CONTRIBUTORS

- GEORGE SEMES LALARD.**
 Barrister-at-Law, Inner Temple Author of *Charles Keene Shirley Brooks*, etc. }
- CLARET T. MURPHY, C.B.E. D.Sc., F.I.C. F.R.S.**
 Director, Chemical Research Laboratory, Department of Scientific and Industrial Research, London Formerly Mason Professor of Chemistry, University of Birmingham and Professor of the Faculty of Applied Chemistry, Royal College of Science for Ireland, Professor of Applied Chemistry, Technical College, Firsbury. Author of *Organic Chemistry of Irons and Alloys* Contributor to Thorpe's *Dictionary of Applied Chemistry*. Editor of the Chemistry section, 14th Edition, *Encyclopaedia Britannica*. }
- GEOFFREY WHITTON.**
 Founder of the British Drama League Art Editor to Messrs Chatto and Windus, 1903-27. Publications include many articles on the theatre in various periodicals; also *The Art of Mimicry*, etc. }
- SIR HERBERT ATKINSON BARBER**
 Specialist in Manipulative Surgery }
- HENRY BEALE HUGH, B.Lit.**
 Publisher, *Playart Gazette*, Martha's Vineyard Mass. }
- REVEREND HORACE CAPTER HONEY, A.M. D.D.**
 Fellow of the American Association for the Advancement of Science, Geological Society of America, National Geographic Society and Société de Spéléologie (France). Author of *Geological America*, *Handbook of Mammoth Cave of Kentucky*, etc. }
- SIR HUGH CLIFFORD G.C.M.G., G.B.E., F.R.G.S.**
 Governor of the Straits Settlements High Commissioner for the Malay States and British Agent for Borneo, since 1927 Governor of Ceylon, 1925-7. Author of *Further India* and many other works Joint-Author with Sir Frank Swettenham of a *Dictionary of the Malay Language*. }
- H. C. LONG, B.Sc.**
 Ministry of Agriculture and Fisheries, London Editor of *Journal of Ministry of Agriculture and Fisheries*. Author of *Common Weeds of the Farm and Garden*, *Plants Poisonous to Livestock*, *Poisonous Plants on the Farm*. }
- HUGH F. AGNEW, A.B., M.P.**
 Chairman of the Department of Marketing, New York University School of Commerce Accounts and Finance Author of *Co-Operative Advertising by Competitors*, etc. }
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 Mathematical Puzzle Expert. Author of *The Canterbury Puzzles*, *Amusements in Mathematics*; etc. }
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 Late Editor of *The Atlantic Monthly* Author of *Life of James Russell Lowell*, *History of the United States*; etc. }
- HENRI FRANZ.**
 Art Critic, *Gazette des Beaux Arts*, Paris. }
- HELEN HADMAN JOSEPH, B.A.**
 Director of Helen Maun Joseph Marionettes Author of *Book of Marionettes*. }
- HUGH HALE LEIGH BELLOI, M.A., D.C.L.**
 Late Associé de l'Institut de Droit International; Honorary Secretary, International Law Association and Grotius Society; Acting Professor of Constitutional Law, University of London, and Secretary, Breaches of the Law of War Committee. Author of *Commerce in War*, *The Pharmacy Acts*, *Permanent Court of International Justice* etc. }
- H. J. CADBURY.**
 Professor of Biblical Literature, Bryn Mawr College, Bryn Mawr, Pa. }
- HERBERT JENNINGS ROSE, M.A.**
 Professor of Greek, University of St. Andrews, Fife. Fellow and Lecturer of Exeter College, Oxford, 1907-11 Associate Professor of Classics, McGill University, 1911-5 Professor of Latin, University College of Wales, Aberystwyth, 1919-27 Author of *The Roman Questions of Plutarch: Primitive Culture in Greece, Primitive Culture in Italy*, *A Handbook of Greek Mythology*; and articles in Hastings' *Encyclopaedia of Religion and Ethics*; etc. }
- H. M. LYDENBERG, A.B.**
 Assistant Director of the New York Public Library Author of *The New York Public Library: Life of John Shaw Billings*. Editor of *Diaries and Drawings of Archibald Robertson in America, 1762, 1776-1780*. }
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 Governor, Porto Rico. }
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 Textile Technologist and Consultant. Author of *Grammar of Textile Design*. }
- MRS. HILDA ORMSBY, B.Sc.**
 Lecturer in Economic Geography London School of Economics. }

INITIALS AND NAMES OF CONTRIBUTORS

- SIR HUMPHRY DAVY ROLLESTON K C B M A M D H O D Sc LL D
Physician Ordinary to the King Regius Professor of Physic, University of Cambridge Consulting Physician to the Royal Navy Examiner in the Universities of Oxford Cambridge, London, etc Formerly President of the Royal College of Physicians Author of *Chemical Lectures*, etc., and Joint-Editor (with Sir Clifford Allbutt), of 2nd Edition of *A System of Medicine*. } Longevity.
- E HAROLD SPENDER, LL.D
Formerly on the Staff of *The Pall Mall Gazette*, *The Westminster Gazette*, *The Daily Chronicle*, *The Manchester Guardian* and *The Daily News* Author of *A Britain in America*, *The Cauldron of Europe* and biographies of David Lloyd George Herbert Henry Asquith, etc } Lloyd George, David (part)
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Author of "The Commentary on Acts" in the *Westminster New Testament, Handbook on the Apocryphal Book* in the "Century Bible" } Logia (in part).
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Student, Tutor and Librarian, Christ Church, Oxford Formerly Fellow of All Souls, Oxford. } Logic, History of (in part)
- HENRY WILLIAM CARLESS DAVIS, C.B.E., M A
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- H W FLOREY
Huddersfield Lecturer in Special Pathology, University of Cambridge } Lymph.
- H. W PARKER, B A
Assistant, Department of Zoology, Natural History Museum, South Kensington, London } Lizard.
- REV HENRY WHEELER ROBINSON, M A., D D.
Principal, Regent's Park College, London, since 1920 Formerly Professor of Church History and the Philosophy of Religion, Rawdon College, Leeds Author of *Hebrew Psychology in Relation to Pauline Anthropology* (in Mansfield College Essays), *The Religious Ideas of the Old Testament* } Malachi.
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British Orientalist Author of *Cashy and the Way Thither*, *Book of Ser Marco Polo* } Mandeville, Jehan de (part).
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Artist and Writer. } Lorenzetti;
Luni, Bernardino;
Mantegna, Andrea.
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Chief Engineer, Splitdorf-Bethlehem Electric Company, Newark, N. J. Author of } Magneto, High Tension
Theory of A.C. Circuits
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Professor of Oceanography, University of Liverpool Author of *Conditions of Life at Sea*, *British Fisheries*. } Marine Biology
- JAMES ALEXANDER ROBERTSON, PH B., L H D
Professor of American History, John B Stetson University, Deland, Fla. Managing Editor, *Hispanic-American History Review*, Baltimore, Md Translator and Co-Editor of *The Philippine Islands*. } Manila.
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Author of *Renaissance in Italy*, *Studies of the Greek Poets* } Machiavelli, Niccolò.
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Regius Professor of Natural History in the University of Aberdeen Gifford Lecturer St Andrews, 1915 Terry Lecturer, Yale University, 1924 Author of *The Study of Animal Life*, *Outlines of Zoology*, *Heredity*, *Darwinism and Human Life*, *What is Man?*, *Concerning Evolution* Joint-Author (with Professor Patrick Geddes) of *Evolution, Sex, Biology*. } Life; Locomotion of Animals.
- JAMES B. SHAW
Professor of Mathematics, University of Illinois, Urbana, Ill } Linear Algebras.
- BRIGADIER-GENERAL SIR J E EDMONDS, C.B., C.M.G., F.R.G.S
Officer in Charge of Military Branch, Historical Section, Criminal Investigation Department, London Served in South African and European Wars Author of } Loos, The Battle of;
Marne, The First Battle.
Official History of the War, etc.
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Consulting-Engineer Author of *Locomotives of Great Power*; *New Era for Steam Locomotives* etc } Locomotive Coaling (in part),
Locomotive (in part).
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Military Assistant to the Chief of the Imperial General Staff. Chief General Staff Officer, Tank Corps, 1917-8 Formerly Chief Instructor, Camberley Author of } Macedonian Army;
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Tanks in the Great War, *The Reformation of War*; *Sir John Moore's System of Training*.
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Late Gilmour Professor of Spanish Language and Literature, University of Liverpool. Author of *A History of Spanish Literature* } Lull, Ramon.
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English Historian and sometime Assistant Keeper of the Public Records Editor of the *Paston Letters*, *Letters and Papers Illustrative of the Reigns of Richard III, Henry VII, and Henry VIII* Author of *The Houses of Lancaster and York*, etc. } Mary I.
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Chemist, Messrs Walter Carson & Sons, Battersea, London. } Luminous Paint.

INITIALS AND NAMES OF CONTRIBU

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 Director of the Dock and Warehouse Committee of the Port of London Authority, 1924-29. President of the Institute of Transport 1923-4. Author of *History of the Port of London*
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 Miss. Professor of Finance and Dean, Faculty of Commerce, University of Birmingham. Member of the Warwickshire Agricultural Wages Committee. Author of *Trade and Public Money*, etc.
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 Department of Banking and Finance, New York University School of Commerce, Accounts and Finance. Author of *Elements of Business Finance*
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 Director of Ethnology, Assam. Deputy Commissioner, Naga Hills. Author of *The Naga Nagas*, *The Sewa Nagas*
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 Professor of Constitutional Law, University of London. Reader in Constitutional Law to the Inns of Court. Brigadier-General, Late Deputy Adjutant-General. Editor of the Law section, 11th Edition, *Encyclopaedia Britannica*
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 Late Historical Adviser to the Crown. President, Essex Archaeological Society, 1916-21. Author of *Fossil England*, *Peerage and Pedigree*
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 Lecturer in Geology, University College of Wales, Aberystwyth.
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 President of the University of Florida, Gainesville, Fla. United States Commissioner of Education. Author of *Philosophy of the World War*, Monographs in educational and scientific subjects
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 Professor of English and formerly Dean of the Graduate School of Arts and Sciences, Harvard University. Author of *Convention and Revolt in Poetry*
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 Author of *Ariovian Romances*
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 Late Lecturer in Law, Columbia Law School, New York.
- JAMES MACKENNON, M.A., PH.D., D.D., F.R.S.E.
 Professor of Ecclesiastical History, University of Edinburgh. Author of *Luther and the Reformation*.
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 Professor of Legislation, Harvard Law School. Author of *The Business of the Supreme Court of the United States*
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 Engineer-in-Chief, Trinity House, London.
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 Assistant Commissioner, Makokehng, Assam. Author of *The Lhota Nagas*
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 Agricultural Organiser for Derbysire. Contributor to the *Journal of the Ministry of Agriculture*
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 Chairman and President of the Executive, London Midland and Scottish Railway. Director of the Bank of England. Member of the British Royal Commission on Income Tax, 1919, of the Committee on Taxation and National Debt, 1927. British Representative on the Reparation Commission's (Dawes) Committee on German Currency and Finance, 1924, and Member of the Committee of Experts, Paris, 1929. Author of *Worth and Income of the Chief Powers*, *Wealth and Taxable Capacity*.
- SIR JOHN SMITH FLETT, K.B.E., M.A., D.Sc., LL.D., F.R.S.
 Director, Geological Survey of Great Britain and Museum of Practical Geology. Formerly Lecturer on Petrology in Edinburgh University.
- REV. JAMES SIBREE, D.D., F.R.G.S.
 Retired Missionary of London Missionary Society, after 51½ years' service in Madagascar. Author of *Madagascar and Its People*, etc.
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 Late Secretary, Royal Geographical Society, and Editor of *Statesman's Year Book* and *The Geographical Journal*
- JOHN SPENCER THOMPSON, M.A.
 Vice-President and Mathematician, Mutual Life Insurance Company. Author of various papers on Transactions of Actuarial Society.
- JOSEPH SWIRE, F.R.G.S.
 Member of the Royal Institute of International Affairs and a Member of the Balkan Co. etc.

INITIALS AND NAMES OF CONTRIBUTORS

- JAMES THOMAS SHOTWELL, PH.D., LL.D.
Director Division of Economics and History, Carnegie Endowment for International Peace, New York, and Professor of History in Columbia University. } Louis IX. (*in part*).
- JAMES VERNON BARILETT, M.A., D.D.
Professor Emeritus of Church History, Mansfield College, Oxford. Author of *The Apostolic Age*. } Luke;
Mark, St.
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Assistant Professor of English, Harvard University. Author of *Increase Mather*, etc. } Longfellow, Henry
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President of Bowdoin College, Brunswick, Maine. } Maine.
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Sometime Scholar of Wadham College, Oxford. Matthew Arnold Prizeman, 1907; Author of *Vasco da Gama and His Successors*. } Malay Archipelago (*in part*).
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Consulting Engineer. Hon. Secretary of the Lightning Research Committee. Author of *Modern Lightning Conductors*, etc. } Lightning Conductor.
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Professor of Missions, Yale University. Formerly Professor of History, Denison University, Granville, Ohio. Author of *The Development of China; History of Early Relations between United States and China*. } Manchuria (*in part*).
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Author and Journalist. Member of the War Trade Advisory Committee, 1915-8. Parliamentary Secretary to the Ministry of Shipping, 1916-8. Chairman of the Tonnage Priority Committee, 1917-8. Editor of the Economics, Engineering and Industries section, 14th Edition, *Encyclopædia Britannica*. } Lloyds Bank Limited;
London General Omnibus Co., Ltd.;
Marconi's Wireless Telegraph Co., Ltd.
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French Scholar and Ecclesiastic. Late Lecturer at the Ecole Pratique des Hautes Etudes, and Director of the French School of Archaeology at Rome. See the biographical article DUCHESNE, LOUIS MARIE OLIVIER. } Lucius (*in part*).
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Director of the Department of Applied Physiology, National Institute of Medical Research, London. Formerly Professor of Physiology, London Hospital. Fellow of University College, London. } Light and Radiation in
Relation to Health.
- LAWRENCE R. DICKSEE, M.COM., F.C.A.
Head of Sellers, Dicksee & Co. Sir Ernest Cassel Professor of Accountancy and Business Organization in the University of London, 1919-26. Dean of the Faculty of Economics in the University of London, 1925-6. } Liquidation (*in part*).
- L. RODWELL JONES, B.Sc., PH.D.
Professor in Geography in the University of London. } Manitoba.
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Reader in Philosophy in the University of London. } Logistic.
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Commander of Legion of Honour, 1917. Governor-General of Nigeria, 1914-9. British Member of Permanent Mandates Commission, League of Nations, since 1922. } Mandate.
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M.P. for Blackburn. Member of the Balfour Committee on British Trade and Industry. Member of the Staff of *The Economist*, London, etc. Under the pen name of "Iconoclast," wrote *The Man of Tomorrow*, J. Ramsay MacDonald, etc. } MacDonald, James
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Author of *Robert Elsmere*, etc. and contributor to *Dictionary of Christian Biography*. See the biographical article. WARD, MARY AUGUSTA. } Lyly, (Lilly or Lyhe),
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Reader in Ancient History in the University of London. Secretary to the Classical Association, 1911-4. } Macedonian Empire;
Manuel I., Comnenus.
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Architect to the Dean and Chapter of St. Paul's Cathedral. Editor of the *Architectural Review*, 1906-20. Co-Author of *Later Renaissance Architecture in England*. } London (*in part*).
- M. GUILLAUME
Managing Director of *Le Petit Journal*, Paris. } Lyautey, Louis H. G.;
Mangin, Charles Emile.
- MARCELLE M. BRESSON
A Librarian of Conservatoire Des Arts et Metiers, Paris. Formerly Assistant in Geography, Sorbonne and Member of the Staff of *Annales de Géographie*. } Madagascar (*in part*).
- MARCUS NIEBUHR TODD, M.A.
Reader in Greek Epigraphy, University of Oxford. Joint Author of *Catalogue of the Sparta Museum*. } Lysander.
- REV. MARK PATTISON, LL.D.
Late Rector of Lincoln College, Oxford. See biographical article. PATTISON, MARK. } Macaulay, Thomas B.
(*in part*).
- MILlicENT TODD BINGHAM, M.A., PH.D.
Corresponding Member, Sociedad Geográfica de Lima. Author of *Peru, Land of Contrasts, Geographical Contrasts in Peru*. } Lima;
Loreto (Peru).

INITIALS AND NAMES OF CONTRIBUTORS

- MAGNUS W. ALEXANDER, M.S.
Press Dept., National Industrial Conference Board. Author of *Safety in the Foundry*
(*Transactions of the Foundry*) etc.
- MILES WILLIAM TRAVERS, D.Sc., F.I.C., F.R.S.
Fellow of University College, London. Honorary Professor (formerly Professor) and
Fellow in Applied Physical Chemistry in the University of Bristol. Director, Indian
Institute of Science, 1906-14. Author of *The Liberation of Hydrogen*, *The Experi-*
ments in Study of Gases etc.
- NICHOLAS G. GEORGE O.B.E., B.Sc., M.Inst.C.E.
Consulting Civil Engineer. Formerly Chief Engineer, Tyne Improvement Com-
missioner, served B.E.F. Lieut. Colonel (late R.E.). Acting Director, Civil Engineer
in-Chief's Department, Admiralty. Chief Civil Engineer for Docks, Harbours, and
Inland Waterways, Ministry of Transport.
- NEWMAN MILES PENZER, M.A., F.R.G.S., F.G.S.
Author of *Climate in British West Africa*, *The Tin Resources of the British Empire*, *The*
Local Resources of Burma, *Non-Ferrous Metals and other Minerals* etc.
- NATHANIEL W. STEPHENSON, A.B., Litt.D., LL.D.
Professor of History and Biography in Scripps College and in the Graduate School
of Claremont College, Claremont, Calif. Author of *An American History*, *The Day*
of the Conference, *Abraham Lincoln and the Union*.
- O. C. STINE, Ph.D.
Bureau of Agricultural Economics, United States Department of Agriculture, Wash-
ington. Editor of *Journal of Farm Economics*, *Agricultural History*.
- OSBERT JOHN RADCLIFFE HOWARTH, O.B.E., M.A.
Secretary of the British Association for the Advancement of Science. Scholar in
Geography, Christ Church, Oxford, 1911. Member of the Geographical Section,
Naval Intelligence Department, London, 1915-9.
- OLIVIA ROSSETTI AGRISTI
Writer, Lecturer and Interpreter to the Assemblies of the League of Nations and the
International Economic Conference. Connected with the Founding of the Inter-
national Institute of Agriculture in Rome. Lecturer in the U.S. on Italian Economic
Conditions, 1919, 1930, 1923. Author of *Giovanni Costa, His Life and Times*. On the
Editing Staff of the General Fascist Confederation in Industries, Rome.
- OTIS SKINNER, A.M.
Actor. Author of *Foothlights and Spotlights*, *Mad-folk of the Theatre*.
- PERCY GARDNER, Litt.D., LL.D., F.S.A., F.B.A.
Professor of Classical Archaeology, Oxford University, 1887-1925. Professor Emeritus
since 1925. See the biographical article GARDNER, PERCY.
- PETER GORDON BROWN, M.A.
Fellow of the Institute of Actuaries. Assistant Actuary, Government Actuary's
Department, London.
- P. G. H. BOSWELL, O.B.E., D.Sc.
George Herdman Professor of Geology in the University of Liverpool.
- PAUL HENRY NYSTROM, Ph.D.
Professor of Marketing, Columbia University School of Business, New York. Author
of *Economics of Fashion*, *Economics of Retailing*, etc.
- PAUL MARTIN PEARSON, A.M., Litt.D.
Founder and President, Swarthmore Chautauqua Association, Swarthmore, Pa.
Former President, The International Lyceum Chautauqua Association. Author of
Intercollegiate Debates, *Extemporaneous Speaking*.
- P. M. ROXBY, M.A.
Professor of Geography in Liverpool University.
- PAUL PHILIPPE CRET
Professor of Architectural Design, University of Pennsylvania, Philadelphia. Fellow,
American Institute of Architecture. Architect of Pan-American Union, Washing-
ton, Valley Forge Memorial Arch, Philadelphia.
- SIR PAUL VINOGRADOFF, D.C.L., LL.D.
Late Corpus Professor of Jurisprudence in the University of Oxford. Formerly
Honorary Professor of History in the University of Moscow. Author of *Villainage in*
England, *English Society in the 11th Century*; etc.
- MAJOR-GENERAL SIR PERCY Z. COX, G.C.M.G., G.C.I.E., K.C.S.I.
Acting British Minister to Persia, 1918-20. High Commissioner in Mesopotamia,
1920-3. Secretary, Foreign Department, Government of India, 1914.
- R. A. LONG
Chairman of the Board of Long-Bell Lumber Company, Kansas City, Missouri.
- ROBERT ANCHEL
Archivist, National Archives, Paris.
- SIR RICHARD CLAVERHOUSE JEBB, O.M., LL.D., D.C.L.
Public Orator, Cambridge University, 1869-75, and Professor of Greek, 1889-1905.
Author of *Translations into Greek and Latin, Homer, an Introduction to the Iliad and*
Odyssey, etc. See the biographical article: JEBB, SIR R. C.
- R. D. CARMICHAEL
Professor of Mathematics at University of Illinois, Urbana, Ill.
- ROBERT E. WOOD
President, Sears, Roebuck and Company, Chicago. Brigadier-General and Acting
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- R. FIRTH, M.A., Ph.D.
Member of the Polynesian Society. Author of *Primitive F-- of the New*

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- RUSSELL G PELLY, F.I.C.
Joint-Author of *Oils, Fats, Waxes and Resins.* } Margarine (*in part*)
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Archdeacon of Westminster Formerly Fellow of Merton College and Grimfield }
Lecturer and Lecturer in Biblical Studies, Oxford. Professor of Biblical Greek at } Manasses, Prayer (part)
Trinity College, Dublin, 1888-1906.
- R. H. GABRIEL, M.A., PH.D.
Professor of History, Yale University Author of *The Evolution of Long Island* }
Editor, *Christianity and Modern Thought* } Long Island (*in part*)
- SIR HENRY REW, K.C.B.
Board of Agriculture and Fisheries, 1898 Assistant Secretary, 1906-18 President, }
Royal Statistical Society, 1920-2. Secretary to the Ministry of Food, 1916-7. } Liming (*in part*).
Chairman, Inter-Departmental Committee on Unemployment Insurance in Agri-
culture, 1925-6 Author of *A Primer of Agricultural Economics, The Economic Re-*
sources of Canada, etc
- ROBERT HERON RASTALL, Sc.D., F.G.S.
University Lecturer in Economic Geology and Fellow of Christ's College, Cambridge }
Member of Council of the Geological Society, 1915, and Mineralogical Society, 1918 } Malachite.
Attached to War Office, 1915-9 Author of *Geology of the Metalliferous Deposits*.
Editor of the Geology section, 14th Edition, *Encyclopædia Britannica*.
- COLONEL RICHARD LIONEL HIPPISELY, C.B., F.R.A.S., F.R.S.
Employed in the Trigonometrical Survey of Cyprus. Deputy Director, Army Signals, }
Central Force, 1914-6. } Linkages.
- RODERICK MACKENZIE, M.A.
Fereday, Fellow of St John's College, Oxford, and Assistant Editor of the 9th Edition }
of Liddell and Scott's *Greek-English Lexicon* } Lithuanian Language
- ROBERT NISBET BAIN
Assistant Librarian, British Museum 1883-1909 Author of *Scandinavia: the Po-* }
litical History of Denmark, Norway and Sweden, 1513-1900, The First Romanovs, } Margaret (1353-14
1613 to 1725; Slavonic Europe: The Political History of Poland and Russia from
1469 to 1796, etc
- SIR RONALD ROSS, K.C.B., K.C.M.G., M.D., D.Sc., F.R.S.
Director in Chief, Ross Institute and Hospital for Tropical Diseases, London. Con- }
sultant in Malaria, British Ministry of Pensions, London. Formerly Consultant } Malaria (*in part*).
in Malaria, War Office Nobel Prizeman for Medicine, 1902. Author of *The Pre-*
vention of Malaria.
- RENÉ POUPARDIN, D-ÈS-L.
Secretary of the Ecole des Chartes. Honorary Librarian of the Bibliothèque Natio- }
nale, Paris } Lorraine.
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Member of Institute of Mining and Metallurgy (past President). Hon. Member }
Surveyors' Institute H.M. Chief Inspector of Mines, 1905-20. Author of *The* } Lignite;
British Coal Industry. } Low-Temperature
Carbonization.
- ROBERT RANULPH MARETT, M.A., D.Sc., F.R.A.I.
Rector of Exeter College, Oxford. University Reader in Social Anthropology, }
Author of *Anthropology; Psychology and Folklore; etc.* Editor of *Anthropology and* } Mana.
the Classics.
- R. S. RAIT, C.B.E.
Historiographer-Royal for Scotland, since 1910 Professor of Scottish History and }
Literature in the University of Glasgow } Mary Queen of S
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Late Dean of St Paul's, Author of *The Oxford Movement. Life of St Anselm etc* }
See the biographical article. CHURCH, RICHARD WILLIAM. } Lombards (*in part*).
- S DE JASTRZEBSKI, F.S.S.
Member, American Academy of Social and Political Science Formerly Assistant }
Registrar-General, Great Britain } Marriage-Rate.
- REV STEWART DINGWELL FORDYCE SALMON, M.A. D.D.
Professor of Systematic Theology and Exegesis of the Epistles, United Free Church }
College, Aberdeen, 1876-1905. Author of *The Parables of Our Lord; etc.* Editor of } Logos (*in part*).
The International Library of Theology, etc.
- STEPHEN HERBERT LANGDON, M.A., B.D., PH.D.
Professor of Assyriology, Oxford, since 1919 Curator in the University Museum, }
Babylonian Section, Philadelphia, 1916-8 Director of the Weid-Blundell and Field } Marduk.
Museum Expedition to Mesopotamia, since 1922.
- SAMUEL McCUNE LINDSAY, PH.D., LL.D.
Professor of Social Legislation, Columbia University, New York. President Academy }
of Political Science, New York. Author of *Social Aspects of Philadelphia Relief Work;* } Liquor Laws and I
Railway Labor in the United States; Child Labor Legislation. } Control.
- GERALD STRICKLAND, 1ST BARON STRICKLAND, G.C.M.G.
Head of the Ministry and Minister of Justice, Malta, since 1927. Member of the }
Malta Legislative Assembly. } Malta (*in part*).
- THOMAS ASHBY, D.LITT., F.B.A., F.S.A., HON.A.R.I.B.A.
Formerly Director of the British School at Rome. Author of *Turner's Visions of* }
Rome; The Roman Campagna in Classical Times; Roman Architecture. Revised and } Loreto; Lucania;
completed for press a *Topographical Dictionary of Ancient Rome* (by the late J. B. } Lucca; Lucera;
Plattner). Author of numerous archaeological articles. } Magna Graecia.
- T. D. KENDRICK, M.A.
Of the Department of British and Mediaeval Antiquities, British Museum. } Malta (*in part*).

INITIALS AND NAMES OF CONTRIBUTORS

- THOMAS F. HAMLIN, B.A. B.Arch**
 Secretary of the History of Architecture, Columbia University, New York. Chairman of City Plan Committee of the Merchants' Association, New York. Author of *The English Architectural Literature, The American Spirit in Architecture*
- Rev. THOMAS MARTIN LINDSAY, LL.D., D.D.**
 Late Principal of the United Free Church College, Glasgow. Formerly Assistant to the Professor of Logic and Metaphysics in the University of Edinburgh. Author of *History of the Reformation in the Isle of Lewis*, etc.
- THOMAS P. MARTIN, A.M. Ph.D.**
 Library of Congress, Washington. Formerly Associate Professor of History, Boston University.
- THOMAS SPOONER, M.A.**
 Vice-Chancellor of Balliol College, Oxford, and Lecturer in History, East London and Birkbeck Colleges University of London. Stanhope Prizeman Oxford 1887. Assistant Editor of *Dictionary of National Biography, 1891-1901*. Author of *The Age of Johnson*, etc.
- THOMAS SWAYNE ADAMS, A.B. Ph.D.**
 Professor of Political Economy, Yale University. Author of *Taxation in Maryland* and *Elements of Economics*.
- THOMAS WOODHOUSE**
 Head of Weaving and Textile Designing Department, Technical College, Dundee.
- VIRGE SVYDER**
 Professor of Mathematics, Cornell University, Ithaca, N. Y. President, American Mathematical Society.
- Rev. WILLIAM AUGUSTUS BREVOORT COLIDGE, M.A., F.R.G.S., Hon. Ph.D.**
 Fellow of Magdalen College, Oxford. Editor of the *Alpine Journal*, 1880-9, etc.
- W. ALISTON PHILLIPS, M.A.**
 Lecky Professor of Modern History, Dublin University. Contributor to the *Cambridge Modern History*, etc.
- W. BRADSTON MOORE, M.D., M.R.C.S., L.R.C.P.**
 Director of the Central Laboratory, Ministry of Pensions, London.
- WILLIAM BELMONT PAPER, A.B.**
 Editor of *South American of Today*.
- WILLIAM DRAPER LEWIS, LL.B., Ph.D., S.S.D.**
 Dean of the Law School, University of Pennsylvania. Editor of *Great American Law*, etc.
- WILLIAM D. MATTHEW, A.M. Ph.D. F.R.S.**
 Professor of Palaeontology and Director, Museum of Palaeontology, University of California, Berkeley, California. Author of various scientific treatises and magazine articles on fossil vertebrates.
- W. D. MCCLELL**
 Editorial Staff London, 11th Edition, *Encyclopaedia Britannica*.
- WILLIAM EDMUND ARMYTAGE AXON, LL.D.**
 Senior Deputy Chief Librarian of the Manchester Free Libraries. On Literary Staff of *Manchester Guardian*, 1874-1905. Author of *Annals of Manchester*, etc.
- WAFREN E. COX**
 Art Editor, 14th Edition, *Encyclopaedia Britannica*.
- W. ELMER EASLEY, A.M. Ph.D.**
 Clark University, Worcester, Mass. Assistant Editor, *Economic Geography*. Specialized in resources—agricultural geography and arctic geography.
- Rev. WILLIAM FAIRBATHES, M.A., D.D.**
 Minister of Dunfermline, United Free Church, Kirkcaldy, N.B. Author of *Maccabees* (Cambridge Bible for Schools), *The Background of the Gospels*, etc.
- WILLIAM FERGUSSON IRVINE, Hon. M.A.**
 Hon. Secretary and General Editor of Historical Society of Lancashire and Cheshire, 1898-1909. Local Secretary for Cheshire for the Society of Antiquaries, 1909. Author of *Liverpool in the Reign of Charles II*; *Old Halls of Wirral*, etc.
- LIEUT.-COLONEL WULFGANG FOERSTER**
 Late General Staff, German Army. Keeper of Public Records, Potsdam. Formerly Member of the Historical section of the General Staff. Chief of the General Staff of the XI. Corps, 1915. Author of *Prinz Friedrich Karl von Preussen, Graf Schlieffen und der Weltkrieg*.
- WILLIAM F. PARISH**
 Consulting and Lubricating Engineer, New York. Member, American Society of Mechanical Engineers.
- WALTER GEORGE BELL, F.S.A., F.R.A.S.**
 Editorial Staff, *Daily Telegraph*, London. Author of *The Great Fire of London in 1666*, *The Great Plague in London in 1665*, *Unholy London*, etc.
- WILLIAM HAMMOND WRIGHT**
 Astronomer in the Lick Observatory, University of California. In charge of the Lick Observatory's Expedition to the Southern Hemisphere, 1903-6.
- WILLIAM KING GREGORY, A.M. Ph.D.**
 Curator of the Departments of Comparative Anatomy and Ichthyology, American Museum of Natural History. Professor of Vertebrate Palaeontology, Columbia University. Author of *Orders of Mammals*.
- Lotus (*in part*);
 Louis Styles;
 Manor House.
- Lollards (*in part*);
 Lutherans (*in part*)
- McDuffie, George
- Marlowe, Christopher
part
- Luxury Taxes (*in part*)
- Linen and Linen Manu-
 facture,
 Manila Hemp.
- Line Geometry.
- Lugano, Lake of.
- London, Conferences of
 Louis Philippe I;
 Magyars,
 Mahmud II (*in part*).
- Malaria (*in part*)
- López, Francisco Solano
- Marshall, John.
- Machaerodus.
- Mac; Local Government
- Manchester (*in part*)
- Lighting and Artificial
 Illumination (*in part*)
- Mammoth Cave.
- Maccabees;
 Maccabees, Books of.
- Liverpool (*in part*)
- Ludendorff, Erich (*in part*)
- Lubricants;
 Lubrication.
- London (*in part*)
- Mars.
- Mammalia;
 Marsupialia.

INITIALS AND NAMES OF CONTRIBUTORS

XVII

- W L B WILLIAM LEWIS BLENNERHASSETT DSO OBE
Formerly Acting British Vice Consul at Kovno Lithuania Member of the London Stock Exchange } Lusatia.
Lithuania (*in part*).
- W L F WALTER LYNWOOD FLEMING, A.M., PH.D.
Dean, College of Arts and Sciences, Vanderbilt University, Nashville, Tenn. Author of *Documentary History of Reconstruction*. } Lynch Law.
- W. L. G. WILLIAM LAWSON GRANT, M.A., LL.D.
Principal of Upper Canada College, Toronto Professor of Colonial History at Queen's University, Kingston, Canada, 1910-5 Formerly Best Lecturer in Colonial History at Oxford University } Mackenzie, William Lyon.
- W. L. W. REV. W. L. WARDLE, M.A., D.D.
Lecturer in Biblical Criticism and Exegesis of the Old Testament, Manchester University. Principal of Hartley College, Manchester } Manasseh (King of Judah);
Manasseh (Tribe of Israel).
- W. M. Sk. WARNER M. SKIFF, B.S.
Manager, Engineering Department, National Lamp Works of General Electric Company. } Lighting and Artificial
Illumination (*in part*).
- W. N. D. WILLIAM N. DAVEY.
Adjusting Department, Johnson and Higgins, Insurance Brokers, New York. } Marine Insurance (*in part*).
- W. O. E. O. REV. W. O. E. OESTERLEY, M.A., D.D.
Professor, Hebrew and Old Testament Exegesis, King's College, London University Author of *The Books of the Apocrypha Their Origin Contents and Teaching*, etc } Manasses, Prayer of (*in part*).
- W. R. C. WHITEFOORD R. COLE, B.A.
President of the Louisville and Nashville Railroad Company, Louisville, Ky } Louisville and Nashville
Railroad Company.
- W. S. L.-B. WALTER SYDNEY LAZARUS-BARLOW, B.A., M.D., F.R.C.P.
Member of the Cancer Committee, Ministry of Health Formerly Professor of Experimental Pathology Middlesex Hospital Medical School, London University Author of *A Manual of General Pathology Elements of Pathological Anatomy and Histology for Students* Editor for Medical Science, 14th Edition, *Encyclopaedia Britannica* } Mammary Gland, Diseases
of.
- W. Sto. MAJOR W. STORMONT.
Manager, Compagnia Italiana Turismo (Italian State Railways), Official Agency and Steamship Lines } Lloyd Triestino Line.
- W. T. C. WILLIAM THOMAS CALMAN D.Sc., F.R.S.
Keeper of the Department of Zoology, British Museum (Natural History) Author of "Crustacea" in Lankester's *Treatise on Zoology* } Lobster;
Malacostraca.
- W. W. F. W. WARD FOWLER, M.A.
Late Fellow of Lincoln College, Oxford Sub-Rector, 1881-1904 Gifford Lecturer, Edinburgh University, 1908 Author of *The City State of the Greeks and Romans*, *The Roman Festivals of the Republican Period*, etc } Mars.
- W. W. P. W. WYATT PAINE, J.P., F.S.A.
Stipendiary Magistrate, East Ham, London, since 1925. Author and editor of numerous legal textbooks. } Lien (*in part*).
- W. Y. S. WILLIAM YOUNG SELLAR, LL.D.
Late Professor of Humanity, Edinburgh University Author of *The Roman Poets of the Republic*. } Lucilius, Gaius (*in part*).
- Y. K. YOUNGHILL KANG, ED.M., B.S.
Instructor, Comparative Literature, New York University. Lecturer on Chinese Poetry at Labor Temple School, New York. } Li Po or Li Tai Po.
- X. Initial used for anonymous contributors.



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LIBIDO TO MARY QUEEN OF SCOTS

LIBIDO (li-bîd'ô), defined by Freud as "the energy of those instincts which have to do with all that may be comprised under the word 'Love'." Jung enlarged the concept so that for him it describes the energy resident in all instincts. Libido is usually considered to be synonymous with other such vague concepts as *élan vital* and psycho-physiological energy. It is claimed intellectual processes is measured by intelligence and speed, but the measurement of a "wish" is more difficult, because the considered to be the inner feeling of need sets appropriate to its appeasement, may on its measurable overt conduct on account of (unconscious) and suppressive (conscious)

an goddess of funerals. She had a sanctuary (perhaps on the Esquiline), where, by an act of Tullus, a piece of money was deposited in a certain place. Here the undertakers (*libitinarii*), who arranged funeral arrangements by contract, had their shop necessary was kept for sale or hire; here registers for statistical purposes. By antiquaries sometimes identified with Persephone, but usually or completely) with Venus Libentina or Libitina may, however, have been a goddess connected with luxuriant nature and life (cf. *lib-er, lib-ido*), then, all such deities in the underworld, she also became the goddess of the underworld, she also became the goddess of the underworld, she also became the goddess of the side of her character predominated in the

Roscher's *Lexikon der Mythologie*, s v
an architect, born at Elis, who was employed by the temple of Zeus at Olympia (q v) about 460 B.C.

town of south-western France, capital of an ancient department of Gironde, at the confluence of the Dordogne, 22 m. E.N.E. of Bordeaux on the Garonne. Pop. (1926) 14,184. The river is tidal, and can reach the town at the highest tides. It is an ancient site. Under the Romans *Condate* (south of the present Libourne, it was destroyed in the 15th century. Resuscitated by Charlemagne, it was

rebuilt in 1269 under its present name and on the site and plan it still retains, by Roger de Leybourne (of Leybourne in Kent), seneschal of Guienne, acting under the authority of King Edward I of England. It suffered considerably in the struggles of the French and English in the 14th century. The church of St. Jean, restored 15th-century Gothic, has a stone spire 232 ft. high. On the quay a 14th-century clock-tower survives from the old ramparts, and the hôtel-de-ville is a quaint relic of the 16th century. Libourne is the seat of a sub-prefecture and of tribunals of first instance and of commerce. Trade is in local wines and brandies. Printing and cooperage are carried on.

LIBRA (The Balance), in astronomy, the 7th sign of the zodiac, denoted by the symbol ♎ , resembling a pair of scales, probably in allusion to the fact that when the sun enters this part of the ecliptic, at the autumnal equinox, the days and nights are equal.

LIBRARIES. A library (from Lat. *liber*, book) is a collection of printed or written literature. The earliest libraries of the world were probably temples. The earliest collections of which we know anything were collections of archives.

ANCIENT LIBRARIES

Assyria.—In the course of his excavations at Nineveh in 1850, Layard came upon tablets of clay, covered with cuneiform characters. These varied in size from 1 to 12 in square. It is estimated that this library consisted of some 10,000 distinct works and documents. The tablets appear to have been methodically arranged and catalogued, and the library seems to have been public. (See BABYLONIA and NINEVEH.)

Ancient Egyptian Libraries.—At an early date Heliopolis was a literary centre of great importance, with culture akin to the Babylonian. Attached to every temple were professional scribes. We possess a record relating to "the land of the collected works (library) of Khufu," a monarch of the 4th dynasty, and a similar inscription relating to the library of Khafra, the builder of the second pyramid. At Edfu the library was a small chamber in the temple, on the wall of which is a list of books (Brugsch, *History of Egypt*, 1881, 1 240). The exact position of Ikhnaton's library (or archives) of clay tablets is known. A library of charred books has been found at Mendes (Egypt Expl. Fund., *Two Hieroglyphic Papyri*), and we have references to temple libraries in the Sileh "Nile" stelae and, perhaps, in the Harris papyrus. The most famous of the Egyptian libraries is that of King Osymandyas (Rameses II., 1300-1235 B.C.) described by Dio-

the Roman Western
 According to Eustathius
 At the Persian invasion
 by the conquerors

Greece.—Amongst known collectors of books were Pisistratus, Hecaterus of Samos, Euclid the Athenian, Nicocrates of Cyprus, Euripides and Aristotle (Athenæus i. 11). At Cnidus there was a special collection of works upon medicine. Dioscorides is reported to have been the first of the Greeks who collected books on a large scale. Plato is known to have been a collector and Xenophon tells us of the library of Euryclides. The library of Aristotle was bequeathed by him to his school. The poems and by Theophrastus to Neleus, who carried them to Sicily, where it is said to have been concealed underground to avoid the literary cupidity of the kings of Pergamum. It is certain that the libraries of Alexandria were the most important, as they were the most celebrated of the ancient world.

Alexandria.—Ptolemy Soter had, it seems, already begun to collect books, but it was in the reign of Ptolemy Philadelphus that the libraries were properly established in separate buildings. There were two libraries at Alexandria; the larger in the Bruchean quarter was in connection with the museum, a sort of academy, while the smaller was in the Serapeum. The number of volumes was very large, although it is difficult to attain any certainty amongst varying accounts, such as those of Tzetzes (42,800 in the Serapeum and 400,000 in the Bruchean), Julius Gelius (700,000) and Sertius (1,000,000). It should be observed that, as the ancient roll or volume usually contained less matter than a modern book, these numbers must be discounted for comparison with modern collections. The first five librarians appear to have been Zetodotus, Callimachus, Eratosthenes, Apollonius and Aristophanes; they cover about a century. Some of the first experiments in bibliography were the catalogues of the Alexandrian libraries. Amongst other lists, two were prepared by order of Ptolemy Philadelphus, one of tragedies, the other of comedies. The *Synagoge* of Callimachus formed a catalogue of all the principal books arranged in 120 classes. After the time of Aurelian, the Serapeum became the principal library. The usual statement is that the libraries continued to flourish until they were destroyed in A.D. 390 and hardly be supported.

The Pergamum.—German researches in the acropolis of Pergamum (1878-85) revealed four library rooms (Al Conze, *Die Pergamen. Bibliothek*, 1884). Despite the embargo placed by the Romans upon the export of papyrus the library, when it was transported to Egypt numbered 300,000 volumes. We learn from Suidas that in 221 B.C. Antiochus the Great summoned the poet and grammarian, Euphron of Chalcis, to be his librarian.

Rome.—It is not until the last century of the republic that we hear of libraries in Rome, with the exception of the writings of Mago upon agriculture. The first considerable collections of which we hear in Rome were brought there as the spoils of war. The library of Perseus was all that Aemilius Paulus reserved from the prizes of victory (167 B.C.) for himself and his sons. Next came the library of Apollonius the Teian, brought from Athens by Sulla (86 B.C.). The zeal of Cicero and Atticus in adding to their collections is well known. Tyrannion is said to have had 20,000 vols. of his own, and Cicero wrote to M. Terentius Varro, "Si bonum in bibliotheca habes, nihil deerit." The honour of being the first actually to dedicate a library to the public is said by Pliny and Ovid to have fallen to G. Asinius Pollio, who erected a library in the Atrium Libertatis on Mount Aventine. Augustus erected two libraries, the Octavian and the Palatine. The former was founded (33 B.C.) in honour of his sister, the charge of the books being committed to C. Melissus. The Octavian and Palatine libraries perished by fire; the story that the Palatine was destroyed by order of Pope Gregory the Great in the 6th century is now generally rejected. Tiberius, the immediate successor of Augustus, established on the Palatine what Gelius refers to as the 'Tiberian library'. Vespasian established a library in the Temple of Peace erected after the burning of the city under

Neo Domitian restored the libraries then destroyed, and he, or Hadrian, founded the Capitoline library. The most famous and important of the imperial libraries was that created by Ulpian Trajanus, known as the Ulpian library, afterwards removed to the baths of Diocletian. The library of Domitian, which had been destroyed by fire in the reign of Commodus, was restored by Gordian, who added to it the 62,000 books bequeathed to him by Serenus Sammonicus. In the 4th century there are said to have been 28 public libraries in Rome.

Roman Provincial Libraries.—The library which the younger Pliny gave to Comum cost a million sesterces, Hadrian established one at Athens, described by Pausanias, and recently identified with the Stoa of Hadrian. At Ephesus and at Timgad in Algeria, the structural plan of the library buildings is clear (R. Cagnat, *Les Bibliothèques municipales dans l'Empire Romain*, 1906 *Mém. de l'Acad. des Ins.*, tom xxxviii pt 1). A private library discovered at Herculaneum contained 1,756 rolls on shelves round the room, to a height of about 6 ft., with a central press. The Christian libraries closely followed the classical prototypes.

The names of several librarians (generally slaves or freedmen) are preserved to us in inscriptions, including that of C. Hymenæus physician and librarian to Augustus.

Constantinople.—When the seat of empire was removed by Constantine to his new capital upon the Bosphorus, the emperor established a collection there. Constantine's library, which contained 6,000 vols., was perhaps mainly intended as a repository of Christian literature, it was greatly enlarged by Julian and Theodosius, at whose death it is said to have increased to 100,000 volumes. Julian not only augmented the library at Constantinople but founded others.

As Christian literature grew, libraries became part of the ecclesiastical organization, and it became the rule to attach one to every church. The largest of these libraries, that founded by Pamphilus (d. A.D. 309) at Caesarea, and said to have been increased by Eusebius to 30,000 vols., is frequently mentioned by St. Jerome. St. Augustine bequeathed his collection to the library of the church at Hippo, which was fortunate enough to escape destruction at the hands of the Vandals. Even the hermit communities of the Egyptian deserts, out of which developed the later monastic orders, accumulated books.

With the removal of the capital to Byzantium the libraries of Rome ceased to collect the writings of the Greeks, while the Greek libraries had never cared much to collect Latin literature. The church became increasingly hostile to pagan letters. The repeated irruptions of the barbarians soon swept the old learning and libraries alike from the soil of Italy. With the close of the Western empire in 476 the ancient history of libraries may be said to cease.

MEDIÆVAL PERIOD

Gaul.—During the first few centuries after the fall of the Western empire in the West, as in the East, few cared for learning. Sidonius Apollinaris tells us of the libraries of several private collectors in Gaul.

During the 6th and 7th centuries in the Irish monasteries there appear to have been many books. The library of York, which was founded by Archbishop Egbert, was almost more famous than that of Canterbury, and was described in verse by Alcuin. The inroads of the Northmen in the 9th and 10th centuries had been fatal to monastic libraries. The correspondence of Lupus Servatus, a pupil of Hrabanus Maurus at Fulda, and afterwards abbot of Ferrières, illustrates the paucity and dearness of books, the declining care for learning, and the increasing troubles of the time. Charlemagne collected a number of choice books for his private use. Although these collections were dispersed at his death, his son, Louis, formed a library which continued to exist under Charles the Bald. But the greatest private collector of the middle ages was doubtless Gerbert, Pope Sylvester II.

St. Benedict.—For the next four or five centuries the collecting and multiplication of books were almost entirely confined to the monasteries. In each newly founded monastery there was to

be a library *et velut cura q aedam illustra n auctorum* hats of el gous wr ters Mon e Cass no became the start ng point of a long trad ton Of the reformed Benedictine orders the Carthusians and the Cistercians were those most devoted to literary pursuits The abbey of Fleury, of Melk and of St Gall were remarkable for the splendour of their libraries The Augustinians and the Dominicans rank next to the Benedictines The libraries of Ste Geneviève and St Victor, belonging to the former order were amongst the largest of the monastic collections Richard of Bury praises them for their diligence in collecting books. Sir Richard Whittington built a large library for the Grey Friars in London, and they possessed considerable libraries at Oxford

Monastic Libraries.—In Italy, the earliest and most famous was Monte Cassino, which fell a prey to the Saracens and to fire in the 9th century The library of Bobbio was famous for its palimpsests, the collection was mainly transferred to the Ambrosian library at Milan.

Of the monastic libraries of France the principal were those of Fleury, of Cluny, of St Riquier and of Corbie. The library of St Riquier, in the time of Louis the Pious, contained 356 mss, with over 500 works Of the collection at Corbie in Picardy we have also catalogues dating from the 12th and from the 17th centuries In 1638, 400 of its choicest manuscripts were removed to St Germain-des-Prés. The remainder were removed after 1794, partly to the national library at Paris, partly to the town library of Amiens

The chief monastic libraries of Germany were at Fulda, Corvey, Reichenau and Sponheim The library of Corvey on the Weser, after being despoiled in the Reformation was presented to the University of Marburg in 1811 The library of Reichenau fell a prey to the Thirty Years' War The library at St Gall, formed as early as 816 by its second abbot, still exists

England.—In England the principal collections were those of Canterbury York Wearmouth, Jarrow, Whitby, Glastonbury, Crowland Peterborough and Durham The library of Christchurch, Canterbury, originally founded by Augustine and Theodore, contained, in the 13th or 14th century, about 5,000 works It was destroyed by the Danes about 867. Of Whitby there is a catalogue of the 12th century. The catalogue of Glastonbury has been printed by Hearne in his edition of John of Glastonbury The library of Crowland perished by fire in 1091, Peterborough was rich, from a catalogue of about the end of the 14th century, it had 344 vols, with nearly 1,700 titles The catalogues of Durham have been printed by the Surtees Society (The oldest catalogue of a Western library is that of the monastery of Fontanelle in Normandy [8th century]) Many catalogues may be found in the collections of D'Achery, Martene and Durand, and Pez, in the bibliographical periodicals of Naumann and Petzholdt and the *Zentralblatt f. Bibliothekswesen* The Rev Joseph Hunter has collected some particulars as to the contents of the English monastic libraries; E. Edwards has printed a list of the catalogues (*Libraries and Founders of Libraries*, 1865, pp 448-454 See also G. Becker, *Catalogi Bibliothecarum Antiqu.* [1885]) In the 14th century the Franciscans compiled a general catalogue of the mss in 160 English libraries, and about 1400, John Boston, a Benedictine monk of Bury, catalogued the libraries of 195 religious houses in England and part of Scotland (Tanner, *Bibl Brit Hibern.*, 1748) Leland's list of the books he found during his visitation of the houses in 1539-45 is printed in his *Collectanea*. The identification of the early provenance of mediaeval mss has been greatly advanced of late years, especially by the works of M R James, both by catalogues of existing collections and publications of surviving monastic catalogues e.g., those of Canterbury and Dover (1909). (See, generally, J W Clark, *The Care of Books* [1909], and E. A. Savage, *Old English Libraries*, 1911.) These catalogues, with many others, afford abundant evidence of the limited size and character of the monkish collections

The Development of Library Arrangements.—Modern library methods began with the rule of St. Benedict early in the 6th century In the 48th chapter the monks were ordered to

borrow a book apiece and to read it straight through In many houses the treasury or spendment contained two classes of books—one for the monks generally one more closely guarded A press near the infirmary contained books used by the reader in the refectory. By the end of the 15th century the larger monasteries found the necessity of a separate library apartment Libraries were specially built at Canterbury, Durham, Cîteaux, Clairvaux and elsewhere, and there grew up increased liberality in the use of books. By the 15th century, collegiate and monastic libraries were on the same plan the books being laid on desks or lecterns, and chained to a horizontal bar As the books increased the accommodation was augmented by one or two shelves erected above the desks The library at Cesana is still in its original condition The Laurentian library at Florence was designed by Michelangelo on the monastic model There were no chains in the library of the Escorial, erected in 1584, which showed, for the first time, book-cases placed against the walls Chains continued to be used in England in church libraries down to the early part of the 18th century, as at Wimbome. Triple desks and revolving lecterns, raised by a wooden screw, formed part of the library furniture The English cathedral libraries were fashioned after the same principle By the end of the 17th century the type of the public library developed from collegiate and monastic prototypes became fixed throughout Europe The library of St John's college, Cambridge (16th century) and the Bodleian at Oxford are slightly developed from the mediaeval type In that of Trinity college, Cambridge, the walls are covered with books and the windows are raised (H R. Tedder 'Evolution of the Public Library,' in *Trans of 2nd Int Library Conference*, 1897, 1898.)

Arabians.—Greek manuscripts were eagerly sought for and translated into Arabic, and colleges and libraries everywhere arose, notably at Baghdad, Cordova, Cairo and Tripoli The royal library of the Fatimites in Africa, and that collected by the Omayyads of Spain are reported, perhaps with exaggeration, to have contained 100,000 and 600,000 mss It is said that there were no less than 70 libraries opened in the cities of Andalusia.

Renaissance.—In the 9th century, under Leo the Philosopher and Constantine Porphyrogenitus the libraries of Constantinople awoke into renewed life. Meanwhile, in the West we find arising outside the monasteries a taste for collecting books Charles V. of France formed a considerable library of 920 vols, including much newer literature, and had a catalogue of them prepared in 1373 Guy, earl of Warwick, formed a collection of French romances, which he bequeathed to Bordesley abbey in 1315 Richard of Bury, the doubtful author of the *Philobiblon*, amassed a noble collection The taste for secular literature and for the classics gave a fresh direction to collectors, and a disposition to encourage literature began to show itself Cosimo de' Medici formed a library at Venice while living there in exile in 1433, and on his return to Florence laid the foundation of the great Medicean library Niccolò Niccoli had already, in 1436, left his library of over 800 volumes for the use of the public Frederick, duke of Urbino, and Poggio Bracciolini, were among the chief collectors of the Latin mss buried in monastic libraries Beyond the Alps, Matthias Corvinus, king of Hungary, amassed a great collection of splendid manuscripts With printing the modern history of libraries may be said to begin.

MODERN BRITISH LIBRARIES

State Libraries, British Museum.—The British Museum ranks in importance before all the great libraries of the world, except the National Library of France, and excels in the arrangement and accessibility of its contents. The library consists of about 3,200,000 printed vols and 56,000 mss; the shelves measure about 55 miles This extraordinary opulence is principally due to the enlightened energy of Sir Anthony Panizzi (q.v.).

The foundation of the British Museum dates from 1753, when effect was given to the bequest (in exchange for £20,000 to be paid to his executors) by Sir Hans Sloane, of his books, manuscripts, curiosities, etc., to be held by trustees for the use of the nation. A bill was passed through parliament for the purchase of the Sloane collections and of the Harleian mss costing

the privilege of obtaining a copy of every publication entered at Stationers' Hall. A library having been established to defray the expenses of purchases, a library for providing suitable accommodation, the museum and library were established in Montagu House and opened to the public Jan. 25, 1759. In 1763 George III presented to the Trustees a collection (in 240 vols.) of Civil War and Commonwealth tracts. The Rev. C. M. Cracherode bequeathed his collection of choice books in 1779, and Sir Joseph Banks his library of 600 vols. of natural history and travels in 1800. Of other libraries which have been incorporated in the museum, the most valuable are George III's collection, 15,000 volumes of tracts and 10,000 vols. of printed books, which was transferred (for a pecuniary consideration) by George IV in 1803, and that of the Right Hon. Thomas Grenville (30,000 vols. of rare books bequeathed in 1824). The Cracherode-Banksian, King's and Grenville libraries are still preserved as separate collections.

The collections of newspapers starting with those in the Treasury and Buryay collections are unique; provincial newspapers have since 1905 been stored at a repository at Hendon. Of newspapers published in the United Kingdom 3,226 are annually sent and bound. The department of mss. is equal in importance to that of the printed books. The collection of *European* mss. contains 54,000 vols., over 30,000 vols. a rich series of charters, etc., and a vast number of papers, ranging from the 3rd century B.C. down to our own times, and includes the *Codex Alexandrinus* of the Bible, the old historical chronicles of England, the charters of the Anglo-Saxon kings, the Arthurian romances, and also unprinted works by English writers. The famous collections of mss. made by Sir Robert Cotton and Robert Harley, earl of Oxford, have already been mentioned and from these and other sources the museum has become rich in early Anglo-Saxon and Latin codices, such as Beza's, the charter of King Edgar and Henry I to Hyde abbey, which are written in gold letters, or the Lindisfarne Gospels A.D. 700, containing the earliest extant Anglo-Saxon version of the Latin gospels. The museum can boast of an early copy of the *Iliad*, and one of the earliest known codices of the *Odyssey*. Among the unrivalled collection of Greek papyri are the unique mss. of several works of ancient literature, such as Aristotle, *On the Constitution of Athens*, the *Mimes* of Herodas, and the *Odes* of Bacchylides. Irish, French and Italian mss. are well represented. For illuminated mss. special reference may be made to the Lindisfarne Gospels, the Bedford Hours, the Sforza Book of Hours and Queen Mary's Psalter. The collections of local and family history, of maps and of music are very rich. Oriental printed books (12,500) and mss. (16,200) form, since 1892, a separate department. The collection includes the library formed by Mr. Rich (consul at Baghdad in the early part of the 19th century); the Chambers collection of Sanskrit mss., and a library of Hebrew mss., including that of the great scholar, Mirkisius and codices of great age, brought from Yemen. The collection of Syriac mss. is important.

The building in which the library is housed was opened in 1857. The reading room is surrounded by book stores placed in iron stacks, the origin of the more modern steel stacks, in these are fitted hanging and rolling auxiliary bookcases. The presses made in the reading-room contain upwards of 60,000 vols.: to those on the ground floor (20,000), readers have direct access. The Natural History Museum, South Kensington, a department of the British Museum under separate management, has a library of books on the natural sciences numbering over 100,000 volumes.

Patent Office and other State Libraries.—The finest technical library in the country is that of the Patent Office in Southampton Buildings, London. The library contains 220,000 volumes. Another special library is the National Art Library, transferred to South Kensington in 1856. It contains about 150,000 vols. and 250,000 photographs. For science there is the library of the Science Museum, South Kensington, which was founded in 1857 (170,000 vols.). It is devoted to pure and applied science;

its main aim is to provide its own subject catalogue and index to scientific books and periodicals.

The only other State libraries which are open to the public are those of the Board of Education (50,000 vols.), the Ministry of Agriculture, the Imperial Institute and the Imperial War Museum.

Among the other State libraries in London may be briefly noted as follows—Admiralty (1700) 100,000 vols., House of Commons (1818), c. 60,000 vols., House of Lords (1834) 80,000 vols.; India Office (1800) 130,000 printed books and 15,000 mss. and xylographs, Kew Royal Botanic Gardens (1853), 40,000 volumes.

Outside London the most important State libraries are the national libraries of Scotland, Wales and Ireland. Sir George Mackenzie, of Rosehaugh, may be regarded as the founder of the National Library of Scotland. In 1684 the first librarian was appointed, and in 1686 the books and furniture were valued at upwards of £11,000, exclusive of donations. The library retains the copyright privilege conferred upon it in 1709. Of the special collections the most important are the Astorga (Spanish), purchased in 1824, the Thorkekin collection, relating chiefly to the history and antiquities of the northern nations; the Dietrich collection of German pamphlets and dissertations, and the Barnboughle Scottish collection presented in 1928 by Lord Rosebery.

Manuscripts number well over 3,000. There are 13 monastic chartularies which escaped the destruction of the religious houses to which they belonged. The mss. relating to Scottish church history include the collections of Spottiswoode, Wodrow and Calderwood. Sir James Balfour's collection and the Balcarres papers consist largely of original State papers of James V, Queen Mary and James VI. The Sibbald papers are largely topographical. The Riddell notebooks illustrate Scottish genealogy. The Magnusson Icelandic mss., purchased in 1825, and some Persian and Sanskrit, with a few classical, manuscripts may be noted. The most important mss. of old poetry are the Bannatyne mss., written by George Bannatyne in 1568, and the Auchinleck mss.

In 1922, the Faculty finding the maintenance of the general library increasingly onerous, offered it to the Government as a national library of Scotland. The Government accepted the offer in 1923, when an institution towards which movements had been made in Scotland since 1870 received a gift of £100,000 from Sir Alexander Grant, and the necessary act was passed and the library transferred in 1925. The library now contains over 750,000 volumes. The advocates retain the law section.

The National Library of Wales at Aberystwyth, founded in 1907, was opened in 1915. It enjoys the copyright privilege, and now contains nearly 500,000 volumes, classified by the Library of Congress scheme. It is very rich in Welsh manuscripts, including the collection of Sir John Williams and Wynn of the Gwydyr, Penarth, Crosswood and Carregiwyd papers. Francis Bourdillon's Romances, and C. Thomas-Stanford's *Euclids* are among special collections of printed books. The National Library of Ireland, Dublin, was founded in 1877, and incorporates the library of the Royal Dublin Society. It contains about 300,000 volumes classified on the decimal system, and catalogued in various forms.

University and Collegiate Libraries.—The earliest library of the University of Oxford was in existence in 1337, the second was founded by Humphrey, duke of Gloucester (d. 1447); these perished, and the Bodleian library was founded in 1598 and endowed in 1611 by Sir Thomas Bodley (qv). He opened the library in 1603 with upwards of 2,000 volumes. In 1610 he obtained a grant from the Stationers' company of a copy of every work printed in the country, a privilege still enjoyed under the Copyright Acts. Other chief benefactors have been Archbishop Laud, John Selden, Richard Gough, Francis Douce, Lord Sunderland (brother of Edmund Malone) and Richard Rawlinson. The library now contains almost 1,250,000 printed volumes, and about 40,000 manuscripts (other than charters, rolls, etc.). In oriental manuscripts it is, perhaps, superior to any other European library and it is exceedingly rich in other manuscripts especially in English literary and local history and in early printing.

The Radcliffe library of natural science, founded by Dr. John Radcliffe (d. 1714) and opened, in 1749, in the domed building known as the "Radcliffe Camera," was transferred to the new University museum and laboratories in 1860, when the trustees offered the use of the Camera to the curators of the Bodleian, the building was transferred absolutely in 1927. In the Camera are the modern books, and it also serves as a reading-room, especially for undergraduates and in the evening. Departmental libraries forming part of the Bodleian are the Indian Institute, the Law library, Maitland library (social and legal history), and Rhodes house (Colonial history).

The Bodleian library is open by right to all graduate members of the university, and to other recommended students. The ordinary expenditure is about £10,000. A large repository has been arranged for book storage underground. Controversy as to extension or new building was acute in 1927-28, but was left undecided by Convocation.

The Taylor Institution for modern languages is due to the benefaction of Sir Robert Taylor, an architect (d. 1783). The Finch collection (bequeathed in 1830), is kept with it.

The libraries of the several colleges vary considerably. That of All Souls was established in 1443 by Archbishop Chichele, and possesses 40,000 printed volumes and 300 mss., and is rich in law. The library of Christ Church is rich in divinity and topography. Corpus possesses a fine collection of Aldines, with about 400 mss. Exeter college has classical dissertations and English theological and political tracts. Jesus college has the bequest of Sir Leoline Jenkins and also Welsh mss. Keble college has the mss. of many of Keble's works. Magdalen college has about 22,500 volumes and 250 mss. with scientific and topographical collections. The old library of Merton college (*see above*) now specializes in modern foreign history and philosophy. New college has about 17,000 printed volumes and about 350 mss., including several presented by its founder, William of Wykeham. Oriel college has a special collection on comparative philology and mythology. Queen's college is strong in theology, in modern history, and in English county histories. St. John's college library is largely composed of theology and law before 1750, and medical books of the 16th and 17th centuries. Wadham college has the botanical books bequeathed by Richard Warner (1775) and Benjamin Wiffen's collection on the Spanish Reformers. Worcester college has of late specially devoted itself to classical archaeology. It is also rich in old English drama and poetry, and drawings by Inigo Jones.

The University library at Cambridge dates from the earlier part of the 15th century. Two early catalogues are preserved, the first embracing 52 vols. and dating from about 1425, the second a shelf-list, apparently of 330 vols., made in 1473. The library, which contains about 1,000,000 vols. and 19 miles of shelves, has the copyright privilege. It includes a fine series of *editiones principes* of the classics and of the early productions of English and Netherlandish presses. The mss. number over 70,000, in which are included a considerable number of *adversaria* or printed books with *ms. notes*, which form a leading feature in the collection. The most famous of the mss. is the *Codex Bezae* of the four gospels and the Acts, which was presented to the university by Beza himself.

There is a library attached to the Fitzwilliam museum, bequeathed to the university in 1816. It contains printed and *ms.* music, and a collection of illuminated mss., chiefly French and Flemish. Catalogues and reprints have been published.

Trinity College Library.—The library of Trinity college has over 100,000 printed and nearly 2,000 *ms.* volumes. Amongst special collections are the Capell collection of early dramatic and especially Shakespearean literature, German theology and philosophy, and the Grylls bequest in 1863 of 9,600 vols., including many early printed books. There are printed catalogues of the Sanskrit and other oriental mss. by Aufrecht and Palmer, of the incunabula by Robert Sinker, and of the Capell collection by W. W. Greg, 1903.

Clare college library includes George Ruggle's early Italian and Spanish plays. The library of Corpus Christi college is famous for

the bequest made by Archbishop Parker in 1575. The printed books are less than 5,000 in number; the ancient mss. attract scholars from all parts of Europe. Gonville and Caius college library is of early foundation. The printed books of King's college include the bequest by Jacob Bryant (1804). The mss. are almost wholly oriental. Magdalene college is remarkable for popular literature and for naval mss. the greater portion of which is in the Pepysian library (*See PEPYS, SAMUEL.*) The library of Peterhouse, the oldest in Cambridge, possesses a catalogue of some 600 or 700 books dating from 1418. It has a unique collection of *ms. music*. Queen's college library contains about 30,000 vols., and is rich in Semitic literature. The library of St. John's college is rich in early printed books and English history.

The library of the University of London, founded in 1837, now at South Kensington, has over 300,000 vols., and includes the Goldsmiths' Economic (60,000 vols.), and a musical library. Other collections are De Morgan's collection of mathematical books, Grote's classical library, etc.

University college library, Gower street, established in 1829, has 286,000 vols., including Jeremy Bentham's library, Morrison's Chinese library, Barlow's Dante library, collections of law, medicine (including medical history), mathematical, Icelandic, theological, art, oriental and other books.

King's college library, founded in 1828, has over 70,000 volumes. In close association with the University of London is the London School of Economics and Political Science (1896) in which is housed the British Library of Political Science, with 250,000 books and 500,000 pamphlets and official reports. The School of Oriental Studies was established in 1916 in the building of the London institution. The library of Sion college (1635) is rich in liturgies, Port-Royal authors, etc., and contains about 200,000 vols. classified on a modification of the decimal system. The copyright privilege was commuted in 1833.

English Provinces.—The Rothamsted Experimental Station has an agricultural library of 20,000 volumes. The other English universities and colleges have libraries; the chief are: Manchester (205,000 vols.), Birmingham (120,000 vols.), Liverpool (100,000 vols.), Leeds (98,000 vols.), Sheffield (83,000 vols.), Bristol (70,000 vols.), absorbing in 1924 the library of the Bristol Medical Chirurgical Society (1831), Durham (39,000 vols.) has many incunabula. That of Exeter is combined with the City library. The Association of University Teachers established in 1925, at Birmingham, an enquiry bureau for the University libraries, to act as a centre for mutual lending; this it is intended to transfer when possible to the central library for students. The University libraries share in the grants made by the Government's Universities Grants committee. A few of the libraries of theological colleges and public schools are important and have historical collections, incunabula, etc., such as Oscott college (1838), 36,000 vols., Stonyhurst college (1794), c. 40,000 vols.; Shrewsbury school, 7,000 vols., etc.

Scotland.—The University library of Edinburgh originated in a bequest of books made to the town in 1580 by Clement Little, advocate. In 1831 the books were removed to the present building. Modern accessions have been the Halliwell-Phillips (Shakespeare), the Laing (Scottish mss.), the Baille (oriental mss.) and the Hodgson (political economy). The library now consists of about 350,000 vols. of printed books, with over 8,000 mss.

All schools and colleges in Scotland are well equipped with libraries. The oldest University Library, St. Andrews (1456) contains well over a quarter of a million volumes. Glasgow (15th Cent.) has 255,000 volumes, Aberdeen (1500) 260,000 volumes. Among others are New College, Edinburgh (1843), 50,000 volumes, and Royal Technical College, Glasgow, 16,000 volumes.

Ireland.—In 1601 the English army, to commemorate their victory at Kinsale, subscribed £1,800 to establish a library in the University of Dublin. Later bequests and gifts have been Sir Jerome Alexander's (law books and mss.), 1674; Palliser, 1726; Gilbert, 1736; and Quin (classical and Italian), 1805. In 1802 the collection of 20,000 vols. formed by the pensionary Fagel, was acquired. The library enjoys the copyright privilege. After the recognition of the Irish Free State the right was confirmed. The

Queens College Belfast (1829) has about 100,000 vols., Queen's College Cork (1829) 100,000, University College Dublin (1827) 100,000 and St. Patrick's College Maynooth (1795) about 100,000. See L. Newcombe *The University and College Libraries of Great Britain and Ireland*, 1907.

Cathedral and Church Libraries.—With one or two exceptions libraries are attached to the cathedrals. Intended for the use of the cathedral clergy they are in most cases open to the public, and are well stocked. Many have valuable mss., but most were damaged in the Civil War and the printed collections are the work of an earlier generation of the 18th century. That of St. Paul's cathedral was founded in very early times, and now numbers some 20,000 vols. and pamphlets with a good collection of early Bibles and Testaments, Paul's Cross sermons, and works connected with the cathedral (catalogue 1893).

For the library of Christ Church, Oxford which belongs alike to the college and the cathedral see above. That of Durham, 10,000 vols., dates from monastic times and possesses many of the books which belonged to the monastery. The collection is largely general, and is kept up to date. It is especially rich in very early mss., written at Durham. The library at York is open to the public, has many valuable mss. and early printed books. It includes Edward Hailestone's topographical library (catalogue of 1785, 1835). The foundation of the library at Canterbury dates probably from the time of Augustine, but nothing of the pre-Conquest library survives. Many of the mss. originally here were transferred by Archbishop Parker to Corpus Christi college, Cambridge (catalogue 1743 and 1802, of mss. 1911). The present building was erected in 1867. The Lincoln cathedral library (catalogue 1879, of incunabula 1925 of mss. 1927) was re-founded by Dean Honeywood, at the Restoration in a building by Wren. Chichester dates from the Restoration only. Ely is rich in the non-roman. Exeter possesses many Saxon mss., including the 'Exeter Book' of Old English poetry, the gift of Leofric, the first bishop. At Lichfield the existing library is post-Restoration but includes the famous Evangelium of St. Chad. The collection at Norwich is chiefly modern. The earlier library at Peterborough being almost destroyed in the Civil War, Bishop White Kennett re-founded it, but many of his books have been lost. Salisbury is rich in incunabula (catalogue 1880). Winchester cathedral library is mainly the bequest of Bishop Morley (17th century). The library at Bristol was burnt and pillaged in the riots of 1831. At Chester, in 1691, Dean Arderne bequeathed his books and part of his estate 'as the beginning of a public library for the clergy and city.' The library of Hereford (catalogue of mss. 1917) is a good specimen of an old monastic cathedral library, Worcester has fine mss. (catalogue, 1906, and of incunabula 1910). The four Welsh cathedrals were supplied with libraries by a deed of settlement in 1709. All are small, the largest St. Asaph has about 1,750 volumes. That founded by Archbishop Leighton in 1684 in Dunblane cathedral (2,000 vols.), is the only cathedral library in Scotland of any historic interest. The public library established about 1691 in St. Patrick's cathedral, Dublin by Archbishop Marsh, was incorporated in 1707, and endowed by its founder at his death in 1713. The books are chiefly theological and include the libraries of Bishop Sullingfleet and of Elias Boucher-au, the first librarian. In 1849 Beriah Botwell published *Notes on the Cathedral Libraries of England*.

The best Catholic libraries in London are those of Brompton Oratory (1849—55,000 vols., 3,000 pamph.) and Westminster cathedral (22,000 vols. and valuable archives). The archiepiscopal library at Lambeth palace (21,000 printed books and 1,300 mss.) has been enriched by the gifts of Laud, Tenison, Manners Sutton, and others of his successors. It is rich in theology and Church history. Of the illuminated mss. and early printed books, catalogues have been issued by S. R. Maitland (1792—1866). The mss. are described in H. J. Todd's catalogue, 1812, and the older volumes by M. R. James, 1900.

Endowed Libraries.—In London the Bishopsgate institute,

founded out of City charities contains about 50,000 vols. and a fine collection of prints, drawings and maps of London. The Cripplegate institute (1896) in Golden Lane, also founded out of charity moneys, has three branches—St. Bride institute, the Queen Street, Cheapside, branch, and St. Luke's institute. The St. Bride Foundation Technical Reference Library (1895) is a very complete collection of about 30,000 vols. on printing and allied arts. Dr. Williams's library (over 75,000 vols.), founded in 1716 by the will of Dr. Daniel Williams is primarily theological and has been enlarged to include philosophy, history and literature, with collections of theosophy and of the works of Boehme, Law, and other mystics. The mss. include the original minutes of the Westminster Assembly, letters and treatises of Richard Baxter and the journals of Crabbe Robinson.

The most notable of the English provincial endowed libraries are those of Manchester. That founded by Humphrey Chetham in 1653 is still housed in its old collegiate buildings (100,000 vols. and mss.). More important is the John Rylands. In 1928 the John Rylands had 310,000 vols. and 10,000 mss., including the 6,000 Crawford mss. from Haigh Hall, bought in 1901 and 20,000 French Revolution broadsides, etc., presented by the earl of Crawford in 1924. Other considerable endowed libraries are the William Salt, Stafford (20,000 vols. of Staffordshire history) opened 1874, the Solon Ceramic library, Stoke-on-Trent (5,500 vols. and 100 current periodicals), St. Deniol's (1894), Hawarden, founded by W. E. Gladstone, and the Shakespeare Memorial (1879), Stratford-upon-Avon.

The oldest endowed library in Scotland is the Innerpefferay, Perthshire (1680), founded by David Drummond, 3rd Lord Madertie. The most important is the Mitchell in Glasgow, founded by Stephen Mitchell (1874), opened in 1877. It contains valuable collections of Scottish poetry, Burns' works, Glasgow printing, and art. It contains over 250,000 vols., and is the reference library for the Glasgow public library system. Glasgow also has Stirling's and Glasgow Public Library (1791), which was amalgamated with an existing subscription library (60,000 vols.) and Baillie's Institution Free Reference library (24,000 vols.) established under the bequest of George Baillie (1863), but not opened till 1887. The public library of Armagh, Ireland was founded in 1770.

Libraries of Societies and Learned Bodies.—Full particulars of most will be found in R. A. Rye's *Libraries of London: a Guide for Students* (3rd ed., 1927), and a more summary guide, covering the whole country, in the *Aslib Directory*, 1928.

Of the law libraries, that at Lincoln's Inn, London, is the oldest and the largest (72,000 vols.). That of the Middle Temple contains 70,000 vols. The library of the Inner Temple is known to have existed in 1540. Its chief collections are William Petyt's mss., received in 1708, John Adolphus's historical pamphlets, and the Crawford collection on crime. There are about 62,000 vols. Gray's Inn library (30,000 vols.) was established before 1555. The Law Society (1828) has 62,000 volumes. The Royal Institution of Great Britain (1803), possessing a general reference subscription library of about 150,000 vols., was closed in 1916, its oriental section remaining to help found the London University School of Oriental Studies, while its Western books went to the university and college libraries.

The best library of archaeology is the Society of Antiquaries', Burlington House, 60,000 vols., many mss. and early printed books. For natural sciences there are the libraries of the Royal Society (1667) in Burlington House, which contains over 100,000 vols., mainly publications of scientific bodies (the celebrated Arundel bequest, dating from the society's infancy, has been dispersed), Geological Society (1807), 40,000 vols. and maps, the Linnean Society (1788), 50,000 vols.; the Zoological Society (1829), about 35,000 vols. The Royal Society of Medicine (1907), incorporating a number of medical societies, 120,000 vols.; the Royal College of Physicians (1525), 40,000 vols.; the British Medical Association, 20,000 vols.; the Royal College of Surgeons (1800), 60,000 vols.; the Medical Society (1773), largely historical, 20,000 vols., the Chemical Society (1841) over 30,000 vols. Other important London society libraries are the Royal Geographical Society (1830) 80,000 vols. and numerous

maps, open to the public for reference; the Royal Colonial Institute (1868), 184,000 vols of British colonial literature, the Royal United Service Institution, Whitehall (1831), 32,000 vols, belles-lettres, politics and history. The Gladstone library (31,000 vols. and pamph.) of the National Liberal Club may be used occasionally by non-members, the Garrick (a small dramatic collection), and the (Senior) United Service Club (Dugald Stewart's library) may be mentioned. Very few club libraries are supervised by trained librarians. Libraries are owned by the British and Foreign Bible Society (catalogue of Bibles, 1903-11), the Institution of Civil Engineers (53,000 vols.), the Institution of Electrical Engineers (25,000 vols.), the Royal Academy (10,500 valuable vols.), the Royal Institute of British Architects (23,000 vols.), and many others.

The library of the Writers to the Signet (1722), now contains about 150,000 vols., with early prints and other rare books, especially in British topography.

The library of the Royal Irish Academy at Dublin (1785, 50,000 vols. and over 2,000 Irish mss.), is partly supported by a Government grant and is freely open.

Among subscription libraries, the London library (300,000) stands first in order of importance. It was founded in 1841 as a lending library for the use of scholars, largely at the instance of Carlyle. Author and subject catalogues have been printed, the latter of great value.

The first circulating library in Birmingham was opened in 1757, and was followed by Liverpool Lyceum (1758) and Warrington's (1760), both merged in the museum and by Leeds (1768).

Other proprietary libraries have been established at Leicester, Liverpool (Athenaeum, 1798), Manchester, Newcastle, Belfast (the Linen Hall library), Nottingham and elsewhere. In Scotland the first subscription library was started by Allan Ramsay, the poet, at Edinburgh in 1725. Commercial subscription libraries have increased greatly, Mudie's (1841), W. H. Smith's, and *The Times Book Club* being typical modern examples.

Many of the principal clubs possess libraries; that of the Athenaeum (London) is by far the most important. It now numbers about 75,000 vols. of choice books. The pamphlets (of which also there is a complete printed catalogue), include those collected by Gibbon and Mackintosh. Next comes the Reform club, with about 60,000 vols.

Public Libraries.—The first act of parliament authorizing the establishment of public libraries in England was obtained by William Ewart, M.P. in 1850. In 1853 the act of 1850 was extended to Ireland and Scotland.

The Public Libraries Amendment Act of 1919, besides establishing the county as a library unit, removed the rate-limit in England and Wales. The American library in 1928 was spending roughly four to five times as much per head as the average British library.

British Library Legislation.—The main points in British library legislation are as follows:—(a) The acts are permissive and not compulsory. (b) Municipal libraries are managed by committees appointed by the local authorities, who may delegate to them all their powers and duties. Glasgow has contracted them out by a special act. In Ireland, committees are appointed much as in England. (c) Power is given to provide libraries, museums, schools for science, art galleries and schools for art. (d) The regulation and management of public libraries are entrusted to the library authority, which may either be the local authority or a committee with a full or partial delegation of powers.

The London Government Act, 1899, by uniting various vestries or boards, extinguished about 23 library areas. The Metropolitan County of London in 1928 comprised 27 library areas, or, counting also the City, 28.

From 1887 progress has been rapid. An immense stimulus was given from about 1900, when Andrew Carnegie (*qv*) began to present library buildings to towns in England as well as to Scotland and the United States. In 1926, 57 out of 62 counties, 81 out of 82 country boroughs, all metropolitan boroughs, 232 out of 249 municipal boroughs, 732 out of 792 urban districts, and 12,660 out of 12,841 are, by adoption or inclusion, library areas under

the acts. But 49 urban areas, with a population of 580,000, had then no library service, nor in 1925 had half the rural population of the country.

Building Developments and Equipment.—The Carnegie Trust, in 1917, ceased to make grants, and in 1925 decided to consider no further applications. The total sum expended by the trust on public library buildings in 1914-26 was £295,600. In every case "open access" was adopted, and stress was laid upon accommodation for children. Good specimens may be seen at Manchester and Croydon. Great improvements were effected in design. Card catalogue and subject-lists have almost entirely taken the place of printed catalogues. Library policy has, also, become far more liberal than it was before the World War. Of the greatest importance to business men has been the establishment in great city libraries, since 1919, of commercial and technical departments, notably those of Birmingham, Manchester, Liverpool and Glasgow.

There is one important municipal library which is not rate-supported under the Public Libraries Acts. This is the Guildhall reference library of the Corporation of the City of London. A library was established for London by Sir Richard Whittington between 1421-26. But it did not remain without accident, about 1549 the Lord Protector Somerset carried off three cart-loads of books, and during the great fire of 1666 the remainder together with the buildings were destroyed. Nothing was done to repair the loss until 1824, a new library was opened in 1828.

The library (nearly 200,000 printed vols. and nearly 15,000 mss. in 1928) includes a special collection of books, prints and drawings about London, the Solomon Hebrew and rabbinical library, the National Dickens library etc., and the libraries of the Clockmakers' and Gardeners' companies and of the Old Dutch church in Austin Friars.

British Library Administration.—A brief statement of the work and methods of public libraries in the United Kingdom will help to give some idea of the extent of their activities. In 1909 60 million vols. were circulated every year for home-reading, 54% representing fiction, including juvenile literature. The reference libraries issued over 11 million vols., exclusive of books consulted at open shelves, and to the reading-rooms, 85 million visits are made per annum. It is evident, moreover, that a complete revolution in library practice has been effected since 1882. Very little had been accomplished in the way of scientific classification schemes, although the decimal method of Melvil Dewey had been applied in the United States. Dewey's system is now in use in 180 public libraries, J. D. Brown's "subject" classification in 59 the later but important library of Congress system in about five.

A complete catalogue of a general popular library contains no addition to bibliography, is costly and is out of date the moment it is printed. Modern libraries therefore compile complete catalogues only in manuscript form, and issue cheap class-lists, supplemented by lists of recent accessions.

The idea of using separate clips or cards for cataloguing books, in order to obtain complete powers of arrangement and revision, is not new, having been applied during the French revolutionary period. The card system is perhaps the most generally used, but many improvements in the adjustable binders, called by librarians the "sheaf system," already begun to make this latter form a serious rival. The card method consists of a series of cards, each bearing one entry, kept on edge in trays or drawers, to which projecting guides are added in order to facilitate reference. The sheaf method provides for slips of a uniform size being kept in book form in volumes capable of being opened by means of a screw or other fastening, for the purpose of adding or withdrawing slips. Both sides of a slip may be used, while a number of entries may be made on one slip. For great research libraries, however, the catalogue in volumes, though expensive to keep up to date, is the easiest to use.

In the United States, practically every library has its open shelf collection. On the continent of Europe, however, this method is rare. The first "safeguarded" open access municipal lending library was opened at Clerkenwell (now Finsbury), London, in 1893. Every year several municipal systems are reorganized in

...one library having ... The pre- ... of the British part are automatic locking wickers for ... and ... registration of borrowers. The great ... of British and American libraries use cards for "charging ... of ... books lent to borrowers.

Various Activities of Libraries.—Other activities of modern ... which are common to both Britain and America are ... of ... drawing attention to the books in the library, ... work with children provision of books for the ... for foreign residents travelling libraries and the educa- ... In some districts (e.g., Leicester) the ... elementary schools supplied with books, over which the teachers are able to exercise supervision. Under the ... of ... Act 1921, all national documents were placed under the charge of the master of the rolls, who could order their deposit in authorized repositories. Many public li- ... and some of local societies were so designated, and the care of archives received a great stimulus, their study had, since 1919, been included in the curriculum of the School of Librarian- ... and was added in 1927 to that of the Library Association.

Excellent work has been accomplished within recent years by the Library Association and the University of London School of Librarianship in the training of librarians.

The report of the departmental committee on public libraries, 1927 is the best survey of the field since that of 1849. The committee aimed at stimulating backward authorities by showing what is done in more favoured places. They were opposed to putting the libraries under the education authorities. The effect of the report was to outline a re-ordinated national system of public libraries, consisting of the urban libraries and the county libraries, with their village and small town branches, all these working together in regional schemes of co-operation, and beyond them the Central Library for Students acting as a reserve for out-of-the-way books, and acting as the centre for mutual loans between a large circle of special libraries and the public libraries. The report obtained general approval, notably that of the Library Association. In the same year the Scottish Library Association appealed to the secretary of state for Scotland to appoint (and the minister of finance in Northern Ireland appointed) similar committees to make enquiry and report on the library service in those countries.

(X.; A. Es)

COUNTY LIBRARIES

Whilst the library movement made notable headway during the last quarter of the 19th century, largely through the generous financial encouragement of Andrew Carnegie, the 28 years that followed have witnessed a greater and, since 1918, a much more rapid advance. Before this date the service was severely handicapped by two reactions, the one penny rate limit, which, except in the largest cities, precluded anything like adequate expenditure on books and salaries, and the almost total impossibility of applying the Public Libraries Acts in the smaller centres of population. An admirable statistical report, setting forth in detail the anomalies and difficulties of the situation, was prepared by Prof. W. G. S. Adams and published by the Carnegie United Kingdom Trust in 1915. From this it was manifest that the position in the towns could not be remedied without the removal of the rate limit, and the only hope for the rural areas was in some broad scheme of co-operation. The Library Association had persistently agitated for new legislation, with the former object as the most urgent item. Pending action by the Government the Carnegie Trustees now set up a number of circulating systems on a regional basis, as an experiment and an object lesson to show how the rural problem should be solved.

Legislation.—The position of these rural systems was regularized in Scotland by the Education (Scotland) Act of 1918, empowering county education authorities to make book provision for children and young persons attending schools or classes, and for adults. The subject was also dealt with in an interim report

by the adult education committee of the Ministry of Reconstruction, and almost immediately, the Public Libraries Act of 1919 was passed, authorizing county councils to adopt the acts, to levy a rate, and provide a library service through their education committees. Similar powers were granted in Northern Ireland by the Public Libraries Act of 1924, and in the Irish Free State by the Local Government Act of 1925.

Success of the County Library System.—Hitherto, such rural library systems as had been established, were financed by the Carnegie Trustees, who continued to offer to defray the capital expenditure of county councils which were willing to adopt the acts. During the period 1915-27, the grants made by the trustees for this purpose in Great Britain totalled £263,785, with some supplementary grants for the period ending in 1930. Further sums are being allocated to Irish county libraries, and grants are made from time to time for special objects. In their report issued in March 1928, the trustees show that 22 English, three Welsh and six Scottish counties are now independent of their assistance, and will henceforth rely entirely on public funds. Thus it is obvious that the progress of the system has been extremely rapid, only five counties, by the end of 1926, not as yet adopted the Public Libraries Acts, one of these being London where there is no area not already provided for by previous adoption of the acts, and the other Westmorland which has a scheme based on the Kendal public library. The rate of this expansion is indicated by the figures given in the report of the Public Libraries Committee set up by C. P. Trevelyan, then president of the Board of Education in 1924, which completed its proceedings in 1927. In 1911 the population in England and Wales resident in library areas amounted to 62.5% of the total. The percentage rose to 68.8 by 1921, to 90.4 by 1924 and by 1926 to 96.3. Of this last figure, the urban library service accounts for 61.1%, and the county systems for 35.2%. Thus only 3.7% of the population now reside in areas for which there is as yet no provision and none even contemplated. The committee therefore propose that the remaining county councils should be constituted library authorities for their areas, and, further, that those councils which have excluded certain populous areas, covered by towns or urban districts, should be constituted library authorities for the whole. The result would be to bring in a further population of 1,332,000. The report pointed out, however, that a library area does not necessarily imply a library service, and that, so far as they were able to ascertain, in 1925 only about one-half of the 12 millions dwelling in county library areas were actually enjoying a library service.

The system began with the periodical supply of boxes of books to village centres, usually in schools, and the boxes were sent by railway or other carriers. An increasing number of counties now have their own motor-vans, which are fitted with shelves and form small travelling libraries, affording the local volunteer librarian some opportunity of choosing books on the spot. Here and there, local interest or the philanthropy of some well-wisher has resulted in the formation of small stocks of reference books, and even the opening of a village reading-room. Special provision is usually made, so far as resources permit, for adult classes, and special collections are formed for teachers. The problem of the community of 10 to 20 million inhabitants embraced by a county area is gradually being solved by the method of differential rating, small libraries of the municipal type being established in such places. Middlesex is an excellent example of the policy of co-ordinating the municipal library and the rural system. Two other experiments that will be watched with attention are being carried out in Cornwall and Northern Ireland. In Cornwall, seven borough and two urban district libraries have been brought into a co-operative scheme for the whole county. The Belfast library has been encouraged by a liberal grant from the Carnegie Trustees to become the centre of a regional scheme of co-operation for the whole of Northern Ireland. Merely fractional rates as low as one-tenth to one-fourth of a penny were raised by the county authorities in the first instance. In some places these have risen to a half penny or even more. But it is admitted that the county services are sen-

ously under-financed, and that as the public realizes the benefits and opportunities within their scope a much more liberal provision will be demanded.

Post-war Developments.—In both county and town, progress since the act of 1919 would have been far greater but for the general anxiety to keep down the rates. That act abolished the rate limit in England and Wales, and next year the limit in Scotland was raised to threepence, and in Ireland the same, with an extension to sixpence in county boroughs (In Northern Ireland the penny rate limit was re-established in county council areas, with a possible differential rating for urban districts, to a maximum of threepence, with Government consent.) Most of the municipal libraries proceeded to levy rates in proportion to their necessities. But, with the increase in the prices of books, other expenses, and the persistent demand for retrenchment, it has been difficult to maintain efficiency in municipal libraries at the high level desired, and the pay of the assistant is still inconsistent with the idea that he is entering a learned profession. The public libraries committee offer various recommendations for the general improvement of the service, particularly by schemes of co-operation, but they were not of opinion that the urban libraries should be transferred to the education committees, or that the numerous library districts in the metropolis should be united under the London County Council. Only one member pressed for the latter reform.

The Central Library for Students.—Most important among these schemes for general or local co-operation was the plan for developing the Central Library for Students as a national library forming a special department of the British Museum, to be a supplemental supply to the municipal and county libraries throughout England and Wales (Scotland and Ireland being supplied from the depôts at Dunfermline and Dublin), and to undertake such other urgent duties as the preparation of a union catalogue, the organization of an information bureau, and the issue of periodical book-lists. This library was started in 1917, largely to provide books for adult classes; but has grown from a collection of 3,000 books to a collection of 37,560, a large proportion of them costly works, supplying, in 1927, no less than 465 libraries with books they were unable to afford. The Central Library is mainly financed by an annual subsidy of £3,000 from the Carnegie Trustees. By a mutual arrangement with a large number of outlier libraries, comprising various public libraries, and such important research libraries as the Science library at South Kensington, those of the London School of Economics, the Linnaean, Folk-Lore and Royal Asiatic Societies, the Society of Antiquaries, the Royal Colonial and Royal Anthropological Institutes, and the Royal Irish Academy, it is able to satisfy the needs, not only of students but also of advanced research in all parts of the country. The public libraries committee outline a system of co-operation in which public libraries would be grouped round regional centres, usually the great urban libraries, with a federation of special libraries pooling their resources, and a central library acting as centre of the whole system. They recommend that an interim grant of £5,000 a year should be made by the Government to the Central Library to establish it on a sound basis, and that the Science library should have an additional £3,500 a year to enable it to act in co-operation as the central supply for research students in science. The aggregate cost to the national exchequer of their proposals for the development of the Central Library and of the Science library, and of the agency for central cataloguing, would not exceed £12,000 a year, and the benefit to scholarship, research, industry and commerce would be incalculable.

Co-operation with Special Libraries.—The growth in numbers and extent of special libraries of all kinds has been remarkable during the period reviewed. The valuable work of the Association of Special Libraries and Information Bureaux, established in 1925, has been a main factor in promoting this, and the publication of their Directory, "Aslib" (1928), another work financed by the Carnegie Trustees is an immense benefit to librarians and users of libraries, since it is the first systematic survey of the special library resources of the nation. Similarly, the

work of the joint standing committee on (university) library co-operation is doing much to facilitate the mobilization of the resources of university and other learned libraries, and the publication of the *World List of Scientific Periodicals* has materially contributed to the same object.

Librarianship.—The Library Association which for many years had striven to raise the educational status of workers in libraries, and had held lectures, correspondence classes and examinations with that purpose, appealed in 1917 for the establishment of a day school within the University of London, for the regular training of librarians. With the support of the Carnegie Trustees, who undertook to provide £1,500 a year for the first quinquennium, the School of Librarianship was opened at University College, London. A reduced grant was made for the second quinquennium, the balance required being made up by the university senate. According to the latest report, 540 students have been admitted to the school during the nine years covered, including many part-time students engaged in library work in the London area. A large and increasing number of these were already graduates of various universities. Easter and summer schools have been held both at home and abroad, with excellent results. The influence of the school in raising the educational standard of librarianship, improving salaries, and increasing the proportion of women relatively to men, employed in libraries, has been considerable. The recent Government report is emphatic on the need for improved educational qualifications for librarians and urges that the School of Librarianship, which is performing a national service, should be maintained and that it "would appear to have a strong claim on the funds which the university receives from the State." An appeal for a permanent endowment fund has recently been launched. Classes in librarianship have also been started at Manchester, mainly for the benefit of assistants in that neighbourhood and at Dublin for Irish students. Many library authorities now require a sound standard of general education from entrants to the service, and the Library Association specifies the matriculation standard for candidates for its certificates.

Other Library Developments.—The only obstacle to a general advance, after the Government report of 1927, as rapid and epoch-making as that which followed the Government report of 1919, is the present demand for economy. Great events are pending, and will probably, in a few years, be matters of history. The British Museum in spite of the great extensions of a few years back, is still cramped for space; a large part of the interior is about to be reconstructed, and it is proposed to enlarge the Hendon repository and remove all newspapers there. Cambridge has decided to remove the University Library to a new building. Oxford is about to settle the problem of the Bodleian by erecting an additional building across Broad Street and a repository at Jordan Hill for material not in constant request. What is healthiest at the moment is the intense interest aroused by the many-sided problems opened up by the growth of libraries, and by the widening consciousness of the immense part they must play in every department of life. The adoption of a more active policy by the Library Association, coupled with the appointment of a full time paid secretary and the acquisition of permanent headquarters, where they will probably soon be joined by other bodies having cognate interests, should help to a concentration of effort in the right direction. (E. A. BA.)

BRITISH DOMINIONS

The majority of the British Dominions have permissive library laws. The rate limit is not so strict in every case. There is, for example, no rate limit in Tasmania, and South Australia may raise a library rate equivalent to threepence in the £. In Africa, Australia and Canada the Governments make grants to public libraries. The Canadian and Australian libraries are administered more or less on American, and those of South Africa, India, etc., on English lines.

Africa.—There are several important libraries in South Africa. The oldest library is the South African public library at Cape Town, established in 1818, which enjoys the copyright-privilege for the Cape (100,000 vols.). This library contains the collections

the legislatures have enacted, notably the Parliamentary Library, Cape Town. The chief public libraries are those of Port Elizabeth, Kimberley, Durban, Bloemfontein, Bulawayo, Germiston, which has a country circulating system, and Johannesburg, the only really free public library in the Union. At Johannesburg a subscription for borrowing. The Education Department supports school libraries. The University library of Cape Town is being greatly developed. In 1908 that at Pretoria consists of 20,000 vols. A summary of the literature of South African public libraries, by P. Freer, will be found in *The Library Journal*, 1913. In North Africa there are considerable libraries, at Cairo especially the Royal Library (1579) 107,000 vols., 20,000 mss., 500 papyri, and at Algiers, the latter under French control.

Australia.—The various States legislate for libraries independently and maintain libraries. The Commonwealth library at Canberra was founded in 1927. The State public libraries circulate books to institutes, etc. In the country Victoria subsidized local libraries. The local public libraries are those of Victoria at Melbourne 1853 (122,000 vols.), of New South Wales at Sydney 1867 (120,000 vols., including the Mitchell library); this was an old subscription library bought by the Government, of South Australia at Adelaide (135,000 vols.), of Queensland, at Brisbane, 1866 (134,000 vols.) and of West Australia at Perth 1860 (112,000 vols.). The university libraries are Sydney (180,000 vols., including the fine Fisher collection, 1885), Adelaide (70,000 vols.), which assists in control of the public library, Melbourne (50,000 vols.), and Brisbane (50,000 vols.).

Tasmania.—Only Hobart (Tasmanian Public library, 1849) had in 1923 used the large powers given by the act of 1867.

New Zealand.—In New Zealand there are 23 public libraries established under acts dating from 1869 to 1877, which allow a penny rate. At Auckland the Turnbull Free Public library (1880) has Sir George Greys Australasian collection and many rare books (210,000 vols.); Christchurch 1859 (41,000 vols.) and Wellington 1873 are the next largest. Wellington has the General Assembly library. The university library of Otago Dunedin, 1872 is the chief academic library.

India and the East.—The chief library in India is the Imperial library at Calcutta (152,000 vols.). At Calcutta the Sanskrit college has 1,000 printed Sanskrit vols. and 4,000 Sanskrit mss., and many Jain mss.; Madras University library has a new and handsome building. The library of the Asiatic Society of Bengal was founded in 1784 (35,000 vols. and 20,000 mss.). The Geological Survey library has 50,000 vols.

The Bombay branch of the Royal Asiatic Society (1804) has 100,000 printed vols. and 2,000 mss. The Moolle Feroze library (founded 1852) is chiefly of mss. in Arabic and Persian. There are libraries attached to Elphinstone college and the Universities of Alahabad and Lahore (54,000 vols. each), Dacca (45,000 vols.), and Bombay (1864) 35,000 vols., including the Fawcett Economic library. The library of Tippoo Saib, consisting of 2,000 mss., fell into the hands of the British (catalogue 1809).

Pearsons the most remarkable library in India is that of the raja of Tanjore which dates from the end of the 16th or beginning of the 17th century. There are now about 18,000 mss. written in Deserogari, Nandinagari, Telugu, Kannada, Grantha, Malayalam, Bengali, Panjabi, or Kashmiri, and Uriya; 3,000 are on palm leaves. Dr. Burnell's printed catalogue describes 12,375 articles.

The Royal Asiatic Society has branches, with libraries attached, in many of the large cities of India and the Far East. At Rangoon there are several good libraries. The Raffles library at Singapore collects books relating to the Malayan peninsula and archipelago. In Ceylon there is the Museum library at Colombo (1877, with 15,000 vols.). The All-India Public Library Association formed in 1921 to spread the public library movement throughout India, by means of provincial library associations, a quarterly journal, periodical conferences, the issue of pamphlets, and the training of librarians in Baroda, Travancore, Pudukottai, and Mysore the

State helps liberally and the movement has made progress. In British India hardly any Government help is forthcoming, save for libraries under State management in capital cities.

Palestine.—The chief library is the Hebrew National and University library (1923), 130,000 vols., which contains the Goldzieher Hebrew and Klein mathematical collections, and publishes a quarterly review *Kiryath sefer*.

Canada.—The most important public library is that of Toronto (1883), which has over 400,000 vols., and includes a notable children's department in a separate building, and which compiles the annual *Canadian Catalogue* of new books since 1921-22 (published 1923), the central reference building was, in 1928, about to be rebuilt.

There were in 1909, 413 public libraries described as 131 free and 282 not free. The other most important libraries in Ontario are—Queen's university, Kingston (1841), 150,000 vols., rich in Canadian history, Library of Parliament, Ottawa, about 300,000 vols. Legislative Library of Ontario, Toronto (1867), about 150,000 vols.; University of Toronto (1856), 220,000 vols. and 77,000 pamphlets.

In the province of Quebec, there are several large and important libraries, among which may be mentioned the Fraser institute, Montreal (1885), 103,000 vols., McGill university, Montreal (1855), 268,000 vols., comprising many important collections, the Seminary of St Sulpice, Montreal, about 225,000 vols., Laval university, Quebec, 173,000 vols.; and the Library of the Legislature (1792).

In the province of British Columbia, under an act of 1919, a public library commission governs the six public libraries, 23 "public library associations" and 386 travelling libraries, and in 1928 was surveying the system (*Report for 1926-27*).

In Nova Scotia there is a system of circulating books among the school libraries. The Legislative library at Halifax incorporates that of the Nova Scotia Historical Society (1878). The school law of New Brunswick provides for grants to school libraries, in the West Indian islands, the Institute of Jamaica, Kingston (1879) and the Trinidad Public library (1841) should be mentioned.

(X, A. Es.)

LIBRARY SCHOOLS

The first school in the world established solely for the professional training of librarians was started at Columbia college, New York city, in 1887, by Melvil Dewey, then librarian of the college. Dewey's plan for a school for the training of librarians had been presented to the American Library Association as early as 1883, but was opposed by some of the leading librarians. Opposition gradually gave way, however, as the value of formal professional training for library workers was demonstrated, and other schools were established in various parts of the country, beginning with the Pratt Institute School of Library Science in 1890. In 1915 the Association of American Library Schools was organized, with ten charter members, for the purpose of maintaining standards of instruction. By 1921 three additional schools had been admitted to the association. Only five of these schools were conducted under the auspices of a college or university of standard grade, and with some of them the university affiliation was merely nominal. About 1920 a demand for university standards became perceptible, and culminated, in 1924, in the creation by the American Library Association of a board of education for librarianship, one of the principal functions of which was to be the formulation of minimum standards for library schools. Under the standards recommended and adopted by the American Library Association in 1925, the schools were classified as junior undergraduate, senior undergraduate, graduate and advanced graduate. All but one of the 13 schools have been accredited by the board, and, in addition, two others. About 8,500 students have completed at least the first year's work in the accredited schools.

For admission to a junior undergraduate school one year of college study is required, and three years for the senior undergraduate, while a bachelor's degree, in addition to other qualifications, is required by the graduate schools. The junior undergraduate schools grant a certificate on the completion of a one year course. For three years of college study and one year of

library school study a bachelor's degree is usually given by the senior undergraduate schools. Most of the graduate schools give a certificate for the first year's work although two grant a second bachelor's degree for the first year of library school study. Four university schools grant the degree of M.A. or M.S. The curricula are made up of three types of subjects, the bibliographical, technical and administrative. While many other courses are given, from one-half to two-thirds of the student's time is devoted to bibliography and bibliographical method, reference service and book selection. The first year course is largely prescribed, although some of the schools offer elective courses. Specialized courses in library work with children were offered in at least five schools. (C. C. W.)

SPECIAL LIBRARIES

With a view to greater accessibility of special resources, the American Association of Special Libraries was formed in 1909, and has issued a directory (2nd ed. 1925). The formation of a corresponding British Association has already been recorded, and a similar directory was published by this body in 1928.

In Great Britain, during 1910-26 there was a great development of scientific, technical and commercial libraries and bureaux of information. The same movement has developed in America, probably to an even larger extent, though in that country the public library has, until recently, undertaken a larger proportion of this kind of service. Of great importance in this connection are compilations like the *World List of Scientific Periodicals* (1926-27), and the *Subject Index of Periodicals* (1915).

Mercantile Marine.—The British Sailors' Society has attempted this service for more than a century. Since 1920 it has revived and developed its arrangements under the stimulus of a Carnegie Trust subsidy. The Seafarers' Education Service (founded 1920), also with the aid of a trust grant, and contributions from the owners and the men's unions, has succeeded in placing substantial libraries of a more advanced kind upon ships. The Carnegie Corporation of New York has similarly financed the American Merchant Marine Library Association. In Great Britain a system of supply to lighthouses and lightships was initiated by the Carnegie Trust, with the aid of the public authorities concerned.

Libraries for the Blind, etc.—In Great Britain the needs of the blind have been met by the establishment of the National Library for the Blind in London, founded in 1882. It was severely damaged by the Thames flood of 1928. Books in Moon or Braille type are lent freely to public libraries, and individual readers. A sectional library for deaf education was set up in the library of the University of Manchester in 1920. Hospital collections are distributed under the auspices of the Red Cross Society. A collection for the use of nurses and health visitors has been set up by the College of Nursing (1921).

FRANCE

Besides the unrivalled libraries of the capital, France possesses a remarkable number of provincial libraries. In 1857 there were 340 departmental libraries with an aggregate of 3,734,260 printed vols. and 44,436 mss. In 1908 the printed books had increased to over 20 million and are now probably 30 million at least.

Paris.—The Bibliothèque Nationale (formerly Bibliothèque du Roi, Royale, or Impériale), is, perhaps, the finest library in the world. The real foundation of the institution may be said to date from the reign of King John, the Black Prince's captive, who bequeathed his "royal library" to his successor, Charles V. Charles V. removed the library from the Palais de la Cité to the Louvre, where it was arranged on desks in a large hall of three storeys by the first librarian and cataloguer, Claude Mallet, the king's valet-de-chambre. His *Inventaire des Livres du Roy nostre Seigneur estans au chasteau du Louvre* is extant, as well as the inventories made by Jean Blanchet in 1380, and by Jean le Begue in 1411 and 1424. Charles VI added some hundreds of mss. to the library, which, however, was sold to the regent, duke of Bedford, after a valuation had been established by the inventory of 1424, transferred to England, and finally dispersed at

the regent's death in 1435. Charles VII. did little to repair the loss, but under Louis XI. another library was created, the first librarian was Laurent Paulmier, and Jean Fouquet of Tours was named the king's *enlumineur*. Charles VIII. enriched it with many fine mss. executed by his order, and also with most of the library of the kings of Aragon seized by him at Naples. Louis XII. incorporated the Bibliothèque du Roi with the fine Orleans library at Blois, and further enriched it by plunder from Parma and by the purchase of the Gruthuyse collection, it was described at this time as one of the four marvels of France. François I. enlarged and removed it to Fontainebleau in 1534. He set the fashion of fine bindings, which was still more cultivated by Henri II., and which has never died out in France. During the librarianship of Amyot the library was transferred from Fontainebleau to Paris. Henri IV. removed it to the Collège de Clermont but in 1604 another change was made, and in 1622 it was installed in the Rue de la Harpe. Under J. A. de Thou it acquired the library of Catherine de' Medici, and the Bible of Charles the Bald. In 1617 a decree ordered the deposit of two copies of every new publication, but this was not enforced till Louis XIV.'s time. The first catalogue worthy of the name was finished in 1622, describing some 6,000 vols., chiefly mss. Many additions were made during Louis XIII.'s reign, notably that of the Dupuy collection, but a new era dawned under Louis XIV. Colbert, one of the greatest of collectors, so enlarged the library that it became necessary to make another removal. It was therefore, in 1666, installed in the Rue Vivien (now Vivienne). The departments of engravings and medals were now created, and were soon important. Nic. Clément made a catalogue in 1684 according to the arrangement still used (in 23 classes, each designated by a letter of the alphabet), with an alphabetical index. After Colbert's death Louvois employed Mabillon, Thevenot and others to procure books, etc. from all parts of the world. A new catalogue was compiled in 1688 in 8 vols. by several scholars. Towards the end of Louis XIV.'s reign it contained over 70,000 volumes. Under the Abbé Bignon the library was removed to its present home in the Rue Richelieu. Between 1735 and 1739 a catalogue in 11 vols. was printed and duplicates were sold. In Louis XVI.'s reign the La Vallière sale yielded many valuable accessions. A few years before the Revolution the printed books numbered over 300,000 vols. and opuscles. The Revolution increased the library, now called the Bibliothèque Nationale, and the other State libraries, with the forfeited collections of the *émigrés*, as well as of the suppressed religious communities, which by enactments of 1789-92 were gathered into "dépôts littéraires" (See below opening of account of provincial libraries). In the difficulties made by such numerous acquisitions Van Praet showed himself a great administrator. Napoleon increased the Government grant; and by the strict enforcement of the law of deposits, as well as by the acquisition of collections, the library progressed, under him, towards his idea of universality. At the beginning of the century it held 250,000 printed vols., 83,000 mss., and 1,500,000 engravings. After 1815 the mss. which he had taken from conquered capitals had to be returned. After the World War, with the fall in the value of the franc, the library was seriously impoverished. A new administrator, P. Roland-Marcel, mitigated poverty by various means. (1) a "consortium," under a joint council, of the library with the other chief Parisian national libraries, *etc.*, the Mazarine (which became the 5th department of the Nationale), the Sainte-Geneviève, and the Arsenal, and later, the University of Paris, by decrees of Aug. 29, 1923, and Dec. 28, 1925, purchases of books and periodicals being divided between them; (2) the library, and then the group, were by laws of April 28, 1927, and March 5, 1928, given the status of "civil personality," carrying the right to hold funds. (3) the loi du dépôt légal was amended, with the result of greatly enlarging the receipts of current French books; the weekly catalogue of accessions of new French books was amalgamated with the list of new publications issued by the trade ("Bibliographie de la France"), (4) the "salle ovale" or "salle de lecture publique," rendered less important by the development of the public libraries of the arrondissements of Paris, was, in 1928, being converted into a periodical

... exchange for loans ...
 ... established in 1927 (3), an "Office de documentation et de recherches bibliographiques," established by the Society of Friends of the Bibliothèque Nationale. These arrangements greatly increased the library's effectiveness. But the ...
 ... purchases of printed books in 1927, (130,225 ...
 ... purchases of old or rare books

Riches of the Bibliothèque Nationale.—According to the ...
 ... 1926-27 the riches of the Bibliothèque Nationale may be enumerated as follows:—(1) Imprimés more than 5,000,000 vols. a ...
 ... 1921, 13,215 vols. (apart from maps, ...
 ... 500,000 m. 28,000 vols ...
 ... 120,000 mss (3) Estampes, 3,015,000 pieces ...
 ... Médaillons 218,500 pièces

... "salle de travail" is obtained through a card procured from the secretarial office. The ship catalogue ...
 ... from 1880 and gives a list of all accessions since that date. It is divided into two parts: one for the names of authors and the other for subjects. Of the *Catalogue général des livres imprimés* (authors only), 91 vols., A. Lecompte, had appeared in 1920. It is expected to be completed in 11 years. Anonymous periodicals etc. are reserved for later treatment. The preface to vol. 1 by L. Dehse is a valuable historical account of the library. The place of the unpublished volumes was from 1905 supplied by a photographic issue of the mss slips of the ...
 ... catalogue. Other exceptionally important catalogues out of very many are: *Catalogue de l'histoire de France* (1885-89, 21 vols.); *Table des auteurs. Catalogue général des incunables des bibliothèques publiques de France*, by M. Peilacher and L. Poizat (1897-1909); *Livres d'Heures imprimés au XV^e siècle conservés dans les bibliothèques publiques de Paris*, by P. Lacombe (1907); etc. L. Vallée's *Catalogue des cartes et plans révisés à Paris et aux environs de Paris* (1908), *Bibliographie générale des travaux historiques et archéologiques publiés en France*, by R. de Lasteyrie in collaboration with d'E. Lefèvre-Pontalis, S. Bougenot, A. Vidier, t. i-vi (1884-1905); H. Omont's *Catalogue général des manuscrits français* (1895-1915, 13 vols. and index in the press, 1928). For the Greek collection important catalogues have been made by H. Omont, the present keeper of the manuscripts, and for the Latin by Dehse. M. Omont and others. For many oriental languages catalogues have been compiled, and those of manuscripts in modern languages are nearly all completed. The Département des Médailles et des Estampes possess excellent catalogues. The former department includes vases, bronzes and gems: the catalogues of the Greek and Early French series are remarkable. The Département des Estampes has been described in the vicomte H. Delaborde's *Le Département des Estampes à la Bibliothèque Nationale* (1875); it includes drawings. F. Courbier's *Catalogue sommaire des gravures et lithographies composant la Réserve* (1900-01) is supported by many fine special catalogues. A list of works on and of the catalogues of the Bibliothèque Nationale and most other French libraries, may be found in A. Vidier *Annuaire des Bibliothèques et des Archives* 1927, pp. 13-38. The second copy of every new French publication deposited by the printer is allotted by the Council of the National Libraries to one of the other institutions represented upon it.

The Bibliothèque de l' Arsenal was founded by the marquis de Paulmy (Antoine-René d'Argenson) in the 18th century: in 1786 it received 30,000 vols. from the duc de La Vallière's library. It contained, in 1926, about 950,000 vols., 17,462 mss., with the Estienne collection (2,300 portfolios) of which the inventory is complete and 120,000 prints: it is the richest library for the library history of France and has more than 30,000 theatrical pieces, including the Auguste Rondel collection, added in 1922, and, accordingly, it receives belles lettres in the allotment of deposited books.

The Bibliothèque Mazarin owes its origin to the great cardinal

who ... he directed on to Gabriel Nauvé it was open to the public in 1642. Dispersed during the Fronde, it was reconstituted with 40,000 vols. after Mazarin's death, in 1661, and left to the Collège des Quatre-Nations, which, in 1691, made it again public. It is now one of the libraries of the national "consortium," and forms a 5th department of the Nationale, it has 300,000 printed vols., including 1,900 incunabula, and 4,600 mss.

The first library of the Genovefains had nearly disappeared when Cardinal François de la Rochefoucauld, who had charge of the reformation of that order, constituted, in 1642, a new library with his own books. The Bibliothèque Ste-Genève, in 1716 possessed 45,000 vols. It became national property in 1791, and was called the Bibliothèque du Panthéon and added to the Lycée Henri IV under the Empire. In 1926 it contained 510,000 printed vols., 1,225 incunabula, 3,872 mss., 40,000 prints and 4,000 maps and plans. There is a special Scandinavian section under the patronage of the Governments of the four Scandinavian countries, which, in turn, appoint the librarian. The general catalogue of printed books (1891, and suppl. to 1910), of mss (1894-96, and suppl. 1913), and others are printed.

Official.—The Bibliothèque du Ministère des affaires étrangères contains 90,000 vols., 300,000 pamphlets and 500,000 documents. The Bibliothèque du Ministère de la Guerre, formed by Louvois, possesses 180,000 vols. and 861 mss. The École supérieure de la Guerre (70,000 vols.) and other institutions come under this department. The Bibliothèque et Musée de la Guerre, founded after the World War, has 110,000 vols., apart from periodicals, documents, maps, etc. The Bibliothèque du Ministère de la Marine is of old formation (catalogue 1838-43), it contains 60,000 vols. and 376 mss., the catalogue of manuscripts was compiled in 1907. The Service hydrographique has 70,000 vols. and 391 mss. The Bibliothèque de la Chambre des députés (1796) possesses 350,000 printed books and 1,622 mss. (printed catalogue of law and political economy, 1883, and of mss., 1907). The Bibliothèque du Sénat (1818) contains 170,000 vols., and 1,345 mss. There are also the following law libraries: Office de législation étrangère (80,000 vols.), Faculté de droit of the University (172,000 vols.), Cour d'appel, Ordre des avocats (1871), 80,000 vols. (printed catalogue, 1880-82), avocats de la Cour de Cassation, and Cour de Cassation. The City of Paris owns, among other libraries, the Bibliothèque Historique de la Ville de Paris, destroyed in 1871 but restored in 1872 (about half a million vols.), the Forney (industrial art), and those of prefectures, hospitals and schools. The arrondissements have each from three to six popular libraries, the stocks ranging from 2,000 to 17,000 vols. and averaging about 6,000. A few have children's libraries. The Association des Bibliothécaires Français in 1928 urged a development of popular public libraries in France generally.

Educational.—The library of the university is that of the Sorbonne (1762), originally including only arts and theology. In 1800 it was the Bibliothèque du Prytanée, in 1828 des Quatres Lycées, and in 1812 de l'Université de France. The faculty sections now are (1) Sciences et des Lettres à la Sorbonne, (2) Médecine, (3) Droit, (4) Pharmacie. Before the separation of Church and State there was also (5) Protestant Theology. After the Bibliothèque Nationale it is the richest, and above all in the fields of classics, archaeology and literature, philosophy, mathematics and physics. Installed since the year 1807 in the New Sorbonne it is a library of the very first rank. The section of Sciences et Lettres has 700,000 printed books and 1,590 mss. Amongst important bequests are those of Leclerc, Peccot, Lavis, Derembourg and Beljame (the last including an important Shakespearean library).

At the Sorbonne are also to be found the libraries of the laboratories, notably the geological. The section relating to medicine housed since 1891 in the new buildings of the Faculté de Médecine, includes 337,000 vols. and 85 mss. The Bibliothèque de la Faculté de Droit (1772), contains 172,000 vols. The fourth section, Faculté (formerly École supérieure) de Pharmacie, greatly developed since 1882, now contains 61,000 vols. The section of art and archaeology contains 100,000 vols. recently enriched by the gift of the Jacques Doucet library.

The other libraries connected with higher education include that of the *École des Beaux-Arts* (40,000 vols., 100,000 reproductions, 14,000 drawings), *École normale supérieure* (1794), has a portion of Cuvier's library, there are 400,000 vols.; *École des Chartes* (50,000 vols.) The library of the *Museum d'histoire naturelle* (18th century) has 225,000 vols., 2,300 mss., 8,600 original drawings on vellum from 1631. The *Bibliothèque de l'Office et Musée de l'Instruction publique* (formerly *Musée pédagogique*), 1880, has 100,000 volumes. The other principal museums (*Louvre*, *Cluny*, *Guimet*, etc.) have large working libraries for the curators and students. In 1760 was founded the *Bibliothèque de l'Institut de France*, which is very rich; its acquisitions come particularly from gifts and exchanges (600,000 vols., 4369 mss.), especially the modern one, the *Fondation Thiers* (75,000 vols. and 1,000 mss.), is attached to the *Institut*. Among other libraries may be mentioned those of the *Conservatoire National de Musique et de Déclamation* (1775), *Observatoire* (25,000 vols.); *Institut Catholique* (184,000 vols.), *Conservatoire national des arts et métiers* (60,000 vols.); *Poisonaise* (attached to the *Académie polonaise des sciences et lettres*) (containing the *musée Adam Mickiewicz* (120,000 vols., 12,000 mss. and autographs, 30,000 prints), and the *Comédie Française* (30,000 vols. and 1,700 mss.).

Before the Revolution there were, in Paris alone, 1,100 libraries with two million volumes. In 1791 more than 800,000 vols. were seized in Parisian religious houses and transferred to eight "dépôts littéraires," while, in the provinces, six million vols. were seized and transferred to similar local depositories. The organization of the central libraries (decree of 3 Brumaire An IV—Oct. 25, 1795), came to nothing, but the consular edict of Jan. 28, 1803, organized the local depots, and the library system was reconstituted, alike in Paris and the provinces. Many precious books and mss. were burnt, since by the decree of 4 Brumaire An II (Oct. 25, 1793) the Committee of Instruction ordered, on the proposition of its president, the deputy Romme, the destruction or modification of supposedly feudalist books and objects of art.

The books in public provincial libraries, numbered, in 1910, over 9,200,000 vols., 15,540 incunabula and 93,986 mss., and the number of printed books was probably nearly doubled by 1928. The number in the colonies and protected States outside France is uncertain, but in 1910 was over 200,000 vols., to this must be added the 2,428,954 vols. then contained in the university libraries, now, doubtless, more than doubled, even without reckoning that of Strasbourg, transferred from Germany. There are over 300 departmental libraries, and as many belong to learned societies. Nearly all are administered under State control by municipalities. The collections distributed from the depots after 1803 remain State property, and the 42 libraries in which these "fonds d'État" preponderate are "classed" by the Ministry of Public Instruction; the librarians of these have higher qualifications and are less subject to local control than those of the "unclassed." They are organized by a law of 1897, and like the universities, are subject to the inspectorate of the Ministry and its consultative commission, established in 1909. This body controls professional qualifications, and publishes collective catalogues (as of mss. and incunabula) and technical instructions.

Old Municipal Libraries.—In most towns there are, besides the learned and historical "bibliothèque de la ville," popular lending libraries, privately founded, but since 1874 subsidized, supplied with books and inspected by the Ministry. In one or two departments there is the beginning of a rural circulating system. Most municipal libraries date but a short time before the Revolution, but there are exceptions. Thus Angers owes its first collection to Alain de la Rue about 1376, it now contains 92,170 vols., 71 incunabula and 2,120 mss. That of Bourges dates from 1466 (45,900 vols., 325 incunabula, 485 mss.). That of Carpentras was established by Michel Angluc between 1452 and 1474 (83,000 vols., 184 incunabula, 2,154 mss.). Mathieu de la Porte is said to be the founder of the library at Clermont-Ferrand, at the end of the 15th century; it contained rather more than 49,000 vols. at the time of its union with the *Bibliothèque Universitaire*.

Amongst the libraries which date from the 16th century must

be mentioned that at Lyons, founded by François I in 1527, it possesses 600,955 vols., 897 incunabula and 9,730 mss. (many catalogues printed).

In the 17th century were established the following libraries: Abbeville, by Charles Sanson in 1685; Besançon, by Abbé Boisot in 1696, La Rochelle, by the *Consistoire Réforme* in 1604; St. Etienne, by Cardinal de Villeroi.

The principal libraries founded during the 18th century are the following: Aix-en-Provence (1705); Bordeaux (1738), Chambéry (1736), Dijon (1701); Grenoble (1772); Marseilles (1799), Nancy (1750); Nantes (1758), Nice (1786); Nîmes (1778), Niort (1771), Perpignan (1759); Rennes (1733), Toulouse (1782). The World War wrought very great havoc among the libraries of the northern departments. The libraries of Arras, Douai, Peronne, Rethel, Saint-Quentin, Compiègne, Noyon, Verdun, and many other places were wholly or largely destroyed; that of Reims was mainly removed to safety.

Nearly all the other municipal libraries date from the distribution of the *dépôts littéraires* in 1803. Those of Avignon, Montpellier, Caen, Rouen, Tours, and Versailles are specially important; in a second rank come Amiens, Auxerre, Beaune, Brest, Douai, le Havre, le Mans, Orleans, Pau, Poitiers, Toulon.

The Ministry of Public Instruction has published joint catalogues of certain classes, e.g., *Catalogues des mss. des bibliothèques de Paris et des Départements* (1885), and the *Catalogue Général des Incunables des Bibliothèques Publiques de la France*, by Marie Pellechet and M. L. Polain (vols. 1-iii A H). The old university libraries, scattered and thrown into the depots at the Revolution, were re-established by acts of 1875, 1879 and 1882, when Jules Ferry united the faculty libraries in each of the 17 academic districts in one university; civil personality, carrying financial autonomy, followed in 1896. The *Bibliothèque Nationale et Universitaire*, formerly the *Universitäts und Landesbibliothek* of Strasbourg founded in 1871 to replace that burned in the Franco-Prussian war, is the largest provincial university library (1,700,000 vols., 1,900 incunabula, 4,759 mss., 5,000 papyri). Others are Aix, Algiers, Besançon, Bordeaux, Caen, Clermont, Dijon, Grenoble, Lille, Lyons, Marseilles, Montpellier, Poitiers, Rennes, Toulouse. That of Nancy was totally burned ten days before the Armistice of 1919. The library profession is organized by central legislation, starting from a royal ordinance of 1839, which assigned one-third of the higher posts to trained "archivistes-paléographes." Municipal librarians are appointed by the mayors. The prefect of the Seine appoints those of the City of Paris, since 1904 exacting certain technical training. The "classed" libraries are seeking complete nationalization, on the lines of the organization of the archives, and the establishment of a single certificate of training (Ch. Mortet, "The Public Libraries of France" in *Library Assoc. Record*, 1925, pp. 145-159).

The *Association des Bibliothécaires Français* (founded in 1906, its bulletin, 1907, now forming part of the *Revue des Bibliothèques*) actively promotes library reform.

GERMANY (WITH AUSTRIA AND SWITZERLAND)

Germany is emphatically the home of large libraries; there is no law of deposit wider than the individual States and Saxony and some less important parts of the Reich have no law of deposit at all. To supply the lack of a single library, where all German books may be preserved, the national book-trade union, the *Börsenverein der Deutschen Buchhändler*, established one, the *Deutsche Bucherei*, in Leipzig in 1913, this is subsidized by the Reich, the Saxon State, and the city, and the books are deposited freely by a voluntary agreement of the publishers. It had 675,000 vols. in 1928. There is an active professional body, the *Verein deutscher Bibliothekare*, which, since 1902, has published a valuable year book. In 1921 the Austrian association joined the German. The number of German universities has tended to multiply considerable collections; 1,617 libraries were registered by P. Schwenke in 1891. The *Jahrbuch der deutschen Bibliotheken* for 1927, which gives statistics and administrative details of 395 German libraries, makes a total of 41,000,000 vols.; in 1909 W. Erman had reckoned 190 libraries and 23,500,000 volumes.

books are borrowed extensively, especially in Prussia. In 1924 was promulgated the *Leihverkehrsordnung für die deutschen Bibliotheken* which authorized and organized mutual lending between all libraries in the country. Owing to financial exhaustion and the depreciation of the currency under 1923, German libraries were unable to acquire foreign publications and in 1920 there was formed the *Norddeutscher der deutschen Wissenschaft* (emergency union of German learning) to secure files of recent foreign journals for exchange, and to distribute foreign publications among the German libraries. By edict of Jan 5, 1926, a national exchange bureau (*Reichsaustauschstelle*) was formed in the Ministry of the Interior to serve the same purposes as the corresponding institution.

Popular libraries (*Volksbuchereien*) exist in most towns. Karl Preussler formed a plan for setting them up in 1839, and four were founded in Berlin in 1850. After 1890 a number of popular libraries were established, some by municipalities, but many by associations and firms. In 1907 the Berlin City library was founded; it now has 20 districts and 90 branches, with 400,000 books. Hamburg also has a large system.

Most of the States have a consultative office for popular libraries and the *Deutsche Zentralstelle für Volkswirtschaftliches Buchwesen* acts as a centre. The *Verband Deutscher Volksbibliothekare* (founded in 1922 as the *Deutscher Bucherverband*) publishes an annual directory (1926). Very few *Volksbuchereien*, however, attempt the work of the public library of English-speaking countries and the expenditure on them is only a halfpenny per head. In Prussia since 1907 and in Baden since 1928 a council deals with library matters at the Ministry of Public Instruction. Generally the State does not concern itself with the town libraries and the popular libraries but there is much in common between these two classes. Sometimes popular libraries are under the supervision of a scientifically administered town library as in Berlin, Danzig, etc.; elsewhere as at Magdeburg, we see an ancient foundation take up the obligations of a public library. In Prussia from 1893, and in Bavaria, regulations are in force as to the professional education of librarians. This regulation has been in force as regards librarians in Bavaria from 1905. Throughout Germany librarians are divided by qualifications into three grades. There are schools of librarianship at Berlin (1921, founded at Göttingen in 1836), Munich, Leipzig, Freiburg and Bam.

Libraries in Berlin.—Berlin is well supplied with libraries, 200 being recognized by P. Schwenke and A. Hirtzschansky in 1906 (but about five million printed volumes). The largest of them is the State (formerly Royal) library, which was founded and made public by the "Great Elector" Frederick William, in 1661. From 1699 the library became entitled to a copy of every book published within the royal territories, and it has received many valuable accessions by purchase and otherwise. It now includes 2,118,707 printed vols. and 36,810 mss. Current catalogues of accessions since 1892 and of the Prussian University libraries, also since 1893, of academic publications of German universities, etc. are printed. The catalogues of mss. are mostly in print, vols. 1-15, 18-23 (1853-1905). The library is specially rich in oriental mss. The musical mss. are very remarkable and form the richest collection in the world as regards autographs. The building erected about 1780 by Frederick the Great, rebuilt in 1909 and twice added to, houses the University library and the Academy of Sciences. There is a regular system of mutual lending established by ministerial edict of Jan 27, 1893, between the State library and a great number of Prussian libraries. This is the same in Bavaria, Württemberg and Baden; the oldest system is that between Darmstadt and Gießen (dating from 1837).

Conducted by the State library are the *Gesamtkatalog der Preussischen wissenschaftlichen Bibliotheken* (describing the printed books in the Royal library and the Prussian University libraries in one general catalogue upon slips), the *Auskunfts-bureau der Deutschen Bibliotheken* (founded in 1905 to give information

where any particular book may be consulted) and the *Kommision für den Gesamtkatalog der Wiegendrucke* (a complete catalogue of books printed before 1500) of which 3 vols. out of 12 or more, appeared by 1928. For most of these improvements and for many others credit is due to Friedrich Althoff for 15 years Prussian minister for education.

The University library (1831) numbers 381,000 vols., exclusive of dissertations. The library possesses the right to receive a copy of every work published in the province of Brandenburg.

Some of the governmental libraries are important, mostly those of Berlin, especially those of the War Office (353,000 vols.), *Statistisches Landesamt* (260,344 vols.); *Reichstag* (277,500 vols.), and *Patent-Amt* (257,000 vols.).

The Prussian University libraries outside Berlin include Bonn (511,380 printed vols., 2,140 mss.), Breslau (545,305 printed vols., 4,570 mss.), Göttingen, from its foundation, in 1736-37, the best administered library of the 18th century (734,949 vols., 3,234 mss.), Kiel, Königsberg, Marburg, Münster. Largely in consequence of the impoverishment of the years after 1918 the university libraries practise a division of the field of knowledge according to Dr. Balcke. (C. Balcke "The German Library World," in *The Library Association Record*, 1927, pp. 101-121, the only recent general account of German libraries; this section is in part based upon it.) Bonn collects Romance, Göttingen English, Kiel Scandinavian, Breslau Slavonic, Heidelberg art and archaeology, Königsberg philosophy, Leipzig Italian and oriental, Tübingen theology and oriental, Berlin German and foreign, academia, and Griefswald Low German. Under provincial administration are the (formerly) *Königliche und Provinzialbibliothek* at Hanover (232,000 printed vols., 4,083 mss.), and the *Landesbibliothek* at Cassel (230,000 printed vols., 4,400 mss.). Frankfurt a/M., Cologne and other large towns possess excellent municipal libraries.

Munich.—The libraries of Munich include two of great importance. The State (formerly Royal) library was founded by Duke Albrecht V of Bavaria (1550-79), who made numerous purchases from Italy, and incorporated the libraries of the Nuremberg physician and historian Schedel, of Widmannstadt, and of J. J. Fugger. The number of printed vols. is estimated at 1,580,000 and about 50,000 mss. The library has 16,000 incunabula, many from the monastic libraries closed in 1803. The oriental mss. are numerous and valuable, and include the library of Martin Haug. The catalogue of the printed books are in manuscript, printed catalogue of mss. (1853). The University library (850,000 vols., 4,000 incunabula, 4,000 mss., 45,000 vols. on reference shelves) was originally founded at Ingolstadt in 1472 and removed with the university to Munich in 1826. After these two the most noteworthy is the *Bayrische Armee-Bibliothek* (156,950 vols.).

The chief Bavarian libraries outside Munich are the State (formerly Royal) library at Bamberg (400,000 vols., 4,320 mss.) and the University library at Würzburg (600,000 vols., 1,750 mss.). The University of Erlangen, Augsburg and Nuremberg have large libraries, at the last is also that of the *Germanisches Nationalmuseum* (300,000 vols., 4,000 mss.).

Dresden.—In 1906 there were in Dresden 78 public libraries with about 1,495,000 volumes. The *Sächsische* (formerly *Königliche*) *Landesbibliothek* in the Japanese palace was founded in the 16th century, specializes in history and literature, and has 694,800 vols. and 460,000 pamphlets, with 7,000 mss.

Leipzig University library has 675,000 vols., the *Pädagogische Central-Bibliothek der Comenius-Stiftung* (283,010 vols.) is perhaps the largest educational library in the world. The *Deutsche Bucherei* has already been mentioned. The University library of Tübingen (713,589 vols. and 4,409 mss.) is the largest library in Württemberg.

Stuttgart.—The Royal Public Library of Stuttgart (1765) possesses 481,236 vols., 263,041 pamphlets, and 6,797 mss., with a famous collection of Bibles. The library also enjoys the copy-right in Württemberg. The former Royal private library, founded in 1810 contains about 100,000 vols.

Darmstadt.—The former Grand-ducal library of Darmstadt,

now the Hessische Landesbibliothek, was established by the grand duke Louis I in 1819 on the basis of a 17th century library, and includes 678,651 vols. and 3,857 mss.

Among the other libraries of Hesse the chief are the University library at Gießen and the Stadtbibliothek at Mainz (including the Gutenberg museum)

In the Grand Duchy of Baden are the Badische (formerly Hof- und) Landes-Bibliothek at Carlsruhe (276,947 vols., 4,830 mss.), the University libraries at Freiburg i/B (420,000 vols., 700 mss.), and Heidelberg (1386), the oldest of the German University libraries. In 1623 the whole collection of the last named was given to the pope, and only the German mss were returned. The library was re-established in 1703, and after 1800 enriched with monastic spoils, it now contains 928,301 vols., apart from dissertations etc., 3,721 mss., and about 5,200 papyri, for the most part of great value.

In other German States should be mentioned Jena, Rostock, Schwerin, Weimar, all possessing rich collections of mss.

The Ducal library of Gotha was established by Duke Ernest the Pious in the 17th century, and contains many valuable books and mss from monastic collections. It numbers about 250,000 vols., with 7,728 mss. The catalogue of the oriental mss., chiefly collected by Seetzen, and forming one-half of the collection, is one of the best in existence.

The Herzog August (formerly Landes) library at Wolfenbüttel, founded in the second half of the 16th century by Duke Julius, was made over to the university of Helmstedt in 1614, whence the most important treasures were returned to Wolfenbüttel in the 19th century, it now numbers 350,000 vols., and 8,400 mss., and is exceptionally rich in incunabula.

The chief libraries of the Hanse towns are those of Bremen, Lübeck and Hamburg (Staats- und Universitäts- formerly Stadtbibliothek), made public since 1648 (680,000 vols. 12,652 mss., among them many Mexican). Hamburg has also, in the Kommerzbibliothek (175,000 vols.), a valuable trade collection.

Austria.—The *Adressbuch der Bibliotheken der Oesterreich-ungarischen Monarchie*, by Bohatta and Holzmann (1900), described the libraries of the Austro-Hungarian empire. The largest library in Austria, and one of the chief in Europe, is the Nationalbibliothek (before 1920 Hofbibliothek) (1440), including a portion of the library of Matthias Corvinus. Since 1808 the library has also been entitled to the copy-privilege. The number of printed vols is 1,210,000, 9,000 incunabula. The mss. amount to 27,000 (2,360 oriental), with 100,000 papyri of the collection of Archduke Rainer. The main room is one of the most splendid in Europe. The collection of prints was separated from the books in 1911 and annexed to the Albertina. The University library of Vienna (1775) 1,050,000 vols., was established by Maria Theresa and is open to all, this library also lends.

The number of libraries in Vienna enumerated by Bohatta and Holzmann is 165, 25 of the chief are described by R. Teichl, *Wiener Bibliotheksführer und Plan* (1926).

The number of monastic libraries in Austria is very considerable. They possess altogether more than 2,500,000 printed vols., 25,000 incunabula and 25,000 mss. The oldest library in Austria is that of the monastery of St Peter at Salzburg (785-821) 70,000 vols., nearly 1,500 incunabula. Kremsmünster (100,000), Admont (86,000) and Melk (70,000), date from the 11th century. Account of their mss appear from time to time in *Zentralblatt für Bibliothekswesen*. Many of their librarians are trained in the great Vienna libraries.

Switzerland.—Among the Swiss libraries, which numbered 2,096 in 1868, there is none of the first rank. The University library at Basle (1460) the Cantonal library at Lausanne, and the Stadtbibliothek at Berne, which, since 1003 is united to the University library of that city, the Landes-Bibliothek (Bibliothèque Nationale) at Berne, and the City library of Geneva are considerable. All the Swiss literature since 1828 is collected by the Landes-Bibliothek at Berne, established in 1895 for this special object. There is now no legal, but only a voluntary, deposit of Swiss books. Older Helvetiana are collected in the subsidized Bürgerbibliothek at Lucerne. The monastic libraries of St. Gall

(830) and Einsiedeln (946), are of great historical interest. The League of Nations has its library at Geneva; The Rockefeller foundation made, 1927, a large gift to the League for a library building.

OTHER EUROPEAN COUNTRIES

Hungary.—Information about the chief libraries in Hungary under the dual monarchy was given annually up to 1911 in the Hungarian *Statistical Year Book*. The largest library in Hungary is the Szechenyi-Nationalbibliothek at Budapest founded in 1802 by the gift of the library of Count Franz Szechenyi. It contains 400,000 printed vols. and 16,000 mss., and has 11 lending and four reference branches. The University library of Budapest (1635) includes 543,572 printed books and 3,401 mss. Since 1807 there has been in Hungary a chief inspector of museums and libraries. He has charge of a general catalogue of all the mss and early printed books in Hungary.

After the war, the central bureau of public libraries organized exchange, distributing the literature received in this way from abroad. It also produces a general catalogue of accessions (which serves as a current national bibliography).

The library of the Benedictines at St. Martinsberg (11th century) is the central library of the order in Hungary, and contains nearly 170,000 vols. Its principal treasures were, on the secularization of the monasteries distributed among the State libraries in Budapest.

Czechoslovakia.—The most considerable libraries in the Republic are the University library, Prague (1306-1773) with 591,245 vols. the National library at Prague (1918) with over 70,000 vols. and many State documents and the Central library (1891) with 378,562 volumes.

During the 19th century, free libraries were founded by the clergy and school teachers, while the library periodical, *Česká Osvěta* (1004), helped to spread a knowledge of Anglo-American popular library methods. By this each community was to establish a public library, administered by special locally-elected bodies, a minimum library tax of 50, 60, 70 or 80 hellers (0.75d., 0.9d., 1.05d., or 1.2d.) per head is levied in towns of less than 5,000, 10,000 or 100,000, or of over 10,000 inhabitants respectively. All libraries thus established are controlled by the Ministry of Education, which issues statistics. In 1920 there were 3,343 libraries with 1,644,558 vols. 310,880 borrowers, 3,180,509 issues for home use, and a total income of 3,211,026 Czech crowns; in 1927 there were 15,355 libraries with 5,444,844 vols., 830,326 borrowers, 14,440,593 home issues, and income 16,275,308 Czech crowns. The average or readers to a library was 860, and one book to every two readers. The expenditure per head was 1.55 Czech crown (2.33d.) as against the sum of one Czech crown (1.5d.) laid down by the law of 1919.

Italy.—As the former centre of civilization, Italy is the home of the oldest libraries. The Vatican at Rome and the Laurentian at Florence are sufficient in themselves to give Italy primacy in respect of rare and valuable mss. and for antiquity there are the venerable relics at Vercelli, Monte Cassino and La Cava. The local rights which so long impeded the unification of Italy created and preserved many libraries which would have been lost under a Central State. Italy is still, in spite of war and collectors, rich in books. Official statistics of 1896 gave particulars of 1,831 libraries, of which 419 are provincial and communal. In 1893 there were 542 popular and circulating. A *Bollettino* for these *biblioteche popolari* was commenced in 1907, and a congress held at Rome in 1908.

Governmental Libraries.—Governmental libraries (*biblioteche governative*) are under the minister of public instruction. The pre-Fascist *Regolamento* controlling them was issued in the *Bollettino Ufficiale*, Dec 5, 1907. They consisted of the national central libraries of Rome (Vittorio Emanuele) and Florence, of the national libraries of Milan (Braidense), Naples, Palermo, Turin and Venice (Marciana), the Biblioteca governativa at Cremona, the Marucelliana the Mediceo-Laurenziana and the Riccardiana at Florence, the governativa at Lucca, the Estense at Modena, the Brancacciana and that of San Giacomo at Naples; the Palatina at Parma, the Angelica, the Casanatense and the

Libraries at Rome: the university libraries of Bologna, Cagliari, Ferrara, Genoa, Messina, Modena, Naples, Padua, Pavia, Pisa, Rome and Sassari; the Vaticaniana (with the university library at Catania); the Vallicelliana and the musical library of the R. Acc. di St. Cecilia at Rome; the musical section of the Palatine at Parma; and the Lucches-Pauline (added to the national library at Naples). The minister of public instruction is assisted by a technical board. Each library was to possess a general inventory of books, was to register an alphabetical author-catalogue and a subject-catalogue. Catalogues of the special collections were next to be compiled. A general catalogue of the mss. was in 1910 being issued together with catalogues of oriental codices and musical books are chosen by the librarians in Government libraries and in the university libraries partly by a professional board. The *Reg. Bol. U. fasc. 17* (1908) allow lending to other countries under special circumstances.

The *bilancio consuntivo* annually spent in 1908 about 20,000 lire in books. Their accessions were 122,930; there were 1,000 readers. Out of 1,700 libraries confiscated from suppressed monasteries containing two million and a half volumes, about 250 were added to public libraries already in existence; the remainder served to form new communal libraries.

The Fascist Government supervises not only the libraries dependent upon it but also communal, provincial, special and corporation libraries by means of 12 *Soprintendenze bibliografiche* with heads and one of the chief libraries of each region and inspectors in all library centres.

Two publications, the *Bollettino della pubblicazione italiana* and *Bollettino delle opere moderne straniere acquistate dalle biblioteche governative* for many years issued from the national libraries of Florence and Rome respectively take the place of a collective catalogue of accessions. The former is the current national bibliography.

The Vittorio Emanuele library at Rome acts as an information bureau as it is especially well equipped with works of reference.

Vatican.—The Biblioteca Vaticana (now in the newly created Vatican State (1929)), stands in the very first rank among European libraries as regards antiquity and wealth of mss. We can trace it back to the earliest records of the *Scrinium Sedis Apostolicæ*, kept first at the Lateran, and later on partly in the Turris Chantularia, but one, the doubtful survival, is the Codex Amiatinus now in the Laurentian library. There remains an inventory made under Boniface VIII. The library was moved to Avignon, where it was renewed and was increased, but this collection has only in part, and in later times, been taken into the Library of the Vatican. The latter is a new creation of the 15th century. Eugenius IV. planted the first seed, but Nicholas V. was the real founder of the library, to which Sixtus IV. consecrated an ornate abode, in the Court of the Pappagallo. Sixtus V. erected the present magnificent building in 1588, and greatly augmented the collection. The most noteworthy librarians were Marcello Cervini (the first *Cardinale Bibliotecario*, later Pope Marcel II.), Sirleto and A. Carafa. In 1600 it was further enriched by the acquisition of the Library of Fulvio Orsini. Pope Paul V. (1605-21) separated the library from the archives and added the two "Pauline" halls for the new codices. Under him and under Urban VIII. many mss. were purchased from the Convent of Assisi, the Mirafra at Rome, the Capranica college, and above all the Rossano, of Basilio (q.v. above, under "Mediaeval Period"). Gregory XV. (1621) received from Maximilian I., duke of Bavaria, the valuable library of the Elector Palatine, seized by Count Tilly at the capture of Heidelberg. Alexander VII. (1652) added the mss. of the dukes of Urbino. The *Libreria della Regina*, i.e., of Christina of Sweden, of ancient mss., some from French monasteries, from St. Gall and elsewhere and others of importance for French literature from the collection of Petau was in great part purchased by Alexander VIII. in 1689. Under Clement XI. were purchased 54 Greek mss. which had belonged to Pius II., and also oriental mss. Under Benedict XIV. was bequeathed the Capponi library rich in Italian books, and by purchase, the Biblioteca Greco-bianca which, in Greek, Latin and Hebrew mss. was, after the Vatican, the richest in Rome. Clement XIII. in 1758. Clement

XIV. in 1769, and Pius VI. in 1775, were also benefactors. After three centuries of uninterrupted growth the Vaticana was to undergo a severe blow. In 1798 after the Treaty of Tolentino 500 picked mss. were sent to Paris. These, however, were chiefly restored in 1815, though most of the Palatine mss. found their way back not to Rome but to Heidelberg. Pius VII. acquired the library of Cardinal Zelaña in 1800, and among important purchases of the 19th century were the splendid Cicognara (archaeology and art, 1823), Cardinal Mai, 40,000 vols. (1856), some 300 Borghese mss. from the papal library of Avignon, the Barberini library and the Borgia collection *De Propaganda Fide*.

The printed books in the Vaticana number some 350,000, the mss. about 53,000, and the incunabula about 6,000 with many vellum copies, 500 Aldines and a great number of bibliographical rarities, including very many presentation copies. Among the Greek and Latin mss. are some of the most ancient and valuable in the world; e.g., the famous biblical *Codex Vaticanus* of the 4th century, the two Virgils of the 4th and 5th centuries, the Bembo Terence and the palimpsest *De Republica* of Cicero.

Many important catalogues of special classes of mss. and important single volumes have been published in facsimile. A new catalogue of the printed books was made in 1927-29 to make easily available the library's rich treasures. This catalogue made possible by the aid of the Carnegie Endowment, was worked out mainly according to the code of the American Library Association by four Vatican librarians and four American librarians.

Other Roman Libraries.—The most important library in Italy for modern requirements is the Nazionale Centrale Vittorio Emanuele (1875) (495,000 vols., 300,000 pamphlets and 5,223 mss.). This contains the *biblioteca minor o secreta* of the Jesuit college of Rome and the cloister libraries of the Provincia Romana, and has the right to copies of new Italian books. Noteworthy among the mss. are the Tarfensi and the Sessoriani of Santa Croce in Jerusalem, some of these last being of the 6th to the 8th centuries. The library was reorganized in 1910. It is rich in the renaissance, in Roman topography, and generally in books of reference and in journals. A monthly *Bollettino* is issued of modern foreign literature received by the libraries of Italy. The library acts as the central bureau of bibliographical information for Italy.

The Biblioteca Casanatense, founded by Cardinal Casanatense in 1698 (131,778 printed vols., 2,086 incunabula, with many Roman and Venetian editions, and 6,124 mss., some of the 8th-10th centuries) is rich in theology, mediaeval history, law and the social sciences. An incomplete catalogue of the printed books by A. Audiffredi (1761-88) still remains a model.

The Biblioteca Angelica, founded in 1624 by Angelo Rocca (120,000 printed vols. and 3,000 mss.) was the first library in Rome to be opened to the public. The library of the University of Rome is the Alessandrina, founded by Alexander VII. in 1661, with the greater part of the printed books belonging to the dukes of Urbino, and opened in 1676. In 1815 Pius VII. granted to it the right to receive a copy of every book printed in the States of the Church, which grant was continued by Italian law but limited to the province of Rome. The library possesses 200,000 printed books.

The library of the Senate, established at Turin in 1848, contains 150,089 vols. rich in the history and statutes of Italian cities. That of the Chamber of Deputies (1848) contains 250,000 vols., and specializes in more modern history, law and politics. The Vallicelliana (1581) controlled by the R. Società Romana di Storia Patria has some important mss., including one attributed to Alcman; the Lancisiana (1711) is valuable for its medical collections; the Accademia di San Luca possesses a good art library, the Biblioteca Militare Centrale (1893) has 100,000 printed vols. and 72,000 maps, and the Biblioteca della R. Accad. di S. Cecilia (1875), a musical collection of 150,000 vols. and 6,000 mss.; the Corsiniana, founded by Clement XII., is rich in incunabula and prints, and, since 1884, belongs to the Accademia dei Lincei. The Deutsches Institut, École Française and British and American Schools, and the International Institute of Agriculture may be mentioned. All these and many other Roman libraries are open at least to advanced students.

Subiaco.—At Subiaco, about 40 m from Rome, the Benedictine monastery of Santa Scolastica has only 6,000 printed vols and 400 mss, but it is remarkable as having been, in 1465, the first seat of typography in Italy, and students may inspect the series of Sweynheim and Pannartz's original editions preserved in their first home.

Florence.—The Biblioteca Nazionale Centrale of Florence, formed from the union of Magliabechi's library with the Palatina, is the largest after the Vittorio Emanuele at Rome. The Magliabechiana became public in 1714, and in 1861 Palatina (formed by Ferdinand III., grand duke of Tuscany), was joined with it. It had long had a right to a copy of every work printed in Tuscany, a right maintained more rigorously since 1860. Since 1870 the Nazionale receives, by law, a copy of every book published in the kingdom. Its monthly *Bollettino* is the current bibliography of the national literature. The mss. include the most important extant *codici* of Dante and later Italian poets and historians. The Galileo collection numbers 308 mss. Of the 25 mss portolani, the oldest is dated 1417, and several seem to be the original charts executed for Sir Robert Dudley (duke of Northumberland) in the preparation of his *Arcano del Mare*. Amongst the early printed books is a great number of 16th century *Rappresentazioni*, books printed on vellum, municipal histories and statutes, *testi di lingua* and maps. The library contains 750,000 printed vols., 22,207 mss and 3,601 incunabula besides prints and maps. A new building was completed on the Corso dei Tintori in 1929.

Milan.—The Biblioteca Nazionale of Milan, better known as the Braidense founded in 1770 by Maria Theresa, has 500,000 printed vols., 2,000 mss, 2,500 incunabula and 913 Aldines. Amongst the mss are letters of Galileo, poems in Tasso's autograph, and a fine series of Italian illuminated service-books, 12th to 16th centuries.

Naples.—The Biblioteca Nazionale at Naples (founded in 1734 and opened in 1804) is the largest library of that city, and has recently been splendidly re-housed. To the collection of Cardinal Seripando were added especially in 1848 and 1860, many private and conventual libraries. The biblical section is rich. Other features are the collections of *testi di lingua*, and of books on volcanoes, the best in existence of the publications of Italian learned societies and a nearly complete set of the Bodoni press. The mss include many illuminated books, the autographs of Leopardi and portolani. The library contains about 1,000,000 printed vols., 11,868 mss and 4,623 incunabula. Annexed to it is the *Officina dei Papiri Ercolanesi*.

The Biblioteca Nazionale of Palermo, founded from the Jesuits' libraries is rich in 15th century books (catalogue printed in 1875), in Aldines and Sicilian 16th century books, many being unique. The library contains 283,227 printed volumes.

Turin.—The Biblioteca Nazionale Universitaria of Turin took its origin in the private library of the House of Savoy, given in 1720 to the university by Vittorio Amedeo II. The fire of 1904 destroyed about 24,000 out of 300,000 vols., and of the 4,138 mss there survive but 1,500, and those in a damaged condition. Among those that perished were the palimpsests of Cicero, Cassiodorus, the Codex Theodosianus and the famous *Livre d'Heures*. The 1,095 incunabula escaped. Since the fire the library has been enriched by new gifts, notably Baron A. Lumbroso's of 30,000 vols., principally on the French Revolution and Empire. The library was, in 1910, transferred to the premises of the Palazzo of the *Debito Pubblico*.

Venice.—The Biblioteca Marciana or library of St. Mark, at Venice, was traditionally founded in 1362 by Petrarch's gift of mss (all now lost) and opened by Cardinal Bessarione in 1468. It has 330,000 printed books, 12,106 mss of great value (more than 1,000 Greek codices given by Bessarione), collections on Venetian history, music and theatre, and on early geographical research, a codex of the laws of the Lombards, and the autograph ms of Sarpis's *History of the Council of Trent*. Since the fall of the republic and the suppression of the monasteries, many private and conventual libraries have been incorporated first in the Libreria del Sansovino, from which the library was transferred in 1812 to the Palazzo Ducale and in 1904 to the Palazzo della

Zecca (the Mint).

University Libraries.—Among the university libraries under Government control some deserve special notice. First in historical importance comes that of Bologna founded by U Aldrovandi (1605). Count Luigi F Marsili in 1712 increased the library and established an Istituto delle Scienze, reconstituted as a public library by Benedict XIV in 1756. The printed books number 214,991 vols., and the mss 5,400, the oriental being noteworthy. The grand hall, with its fine furniture in walnut wood, merits particular attention. The Biblioteca della Università at Naples, established by Joachim Murat in 1812 in the buildings of Monte Oliveto, and thence sometimes called the "Biblioteca Gioacchino," was transferred to the Royal university and opened in 1827. It is strongest in medicine and science, its chief mss and early printed books were transferred about the middle of the 19th century to the Nazionale. Other important university libraries are those of Catania (1755), Genoa (1773); Pavia (1763); Padua (1629) (314,000 vols.), which in 1910 was housed in a new building, Cagliari and Sassari. Messina was destroyed in the earthquake of 1908, but the more important part of the furniture was saved and by 1910 the library was already restored to active work.

Chief among the remaining Government libraries comes the world-famed Biblioteca Mediceo Laurenziana at Florence, formed from the collections of Cosimo the Elder, Pietro de' Medici, and Lorenzo the Magnificent. It was made public by Clement VII, who charged Michelangelo to construct a suitable edifice for its reception. Opened by Cosimo I in 1571, it has steadily grown. The accessions in the 18th century alone were enough to double it. Its printed books number probably only 11,000, and though almost all of the highest rarity and interest, the 10,017 mss give its chief importance to this library. More than 700 are earlier than the 12th century. Some of them are the most valuable codices in the world—the famous Virgil of the 4th or 5th century, Justinian's *Pandects* of the 6th, a Homer of the 10th, and several other very early Greek and Latin classical and biblical texts, as well as copies in the handwriting of Petrarch, about 100 codices of Dante, a *Decameron* copied by a contemporary from Boccaccio's own ms and Benvenuto Cellini's ms of his autobiography. Administered with the Laurentian as the Riccardiana, rich in mss of Italian, and especially the Florentine literature. The Biblioteca Marcelliana (founded 1703, opened 1753) is remarkable for its early woodcuts and engravings; the printed volumes number 310,000 and the mss, 2,000.

Modena.—At Modena is the Biblioteca Estense, founded by the Este family at Ferrara in 1393; it was transferred to Modena by Cesare D'Este in 1598. Muratori, Zaccaria and Tiraboschi were librarians here. The printed vols. number 151,057, the incunabula 1,600 the mss 8,567 besides the 4,958 mss and the 100,000 autographs of the Campori collection.

The oldest library at Naples is the Brancacciana, founded in 1647 by Cardinal F. M. Brancaccio, and opened by his heirs in 1675. The Regia Biblioteca di Parma was founded definitely in 1779 by the grand-duke Philip, who employed Paciaudi to organize it. It contains 323,208 vols and 5,290 mss., including De Rossi's biblical and rabbinical mss. Also worthy of note are the Bibl. Pubblica or governativa of Lucca, and that of Cremona.

The Ambrosiana.—Among the great libraries not under Government control, the most important is the Ambrosiana at Milan, founded in 1609 by Cardinal Fed. Borromeo. It contains 400,000 printed vols., 3,000 incunabula and 10,000 mss. Amongst the mss are a Greek Pentateuch of the 5th century, the famous Peshito and Syro-Hexaplar, a Josephus on papyrus, supposed to be of the 5th century, several palimpsest texts, and a 7th century copy of St. Jerome's commentary on the Psalms, full of contemporary glosses in Irish Gothic fragments of Ulfilas, and a Virgil with notes in Petrarch's handwriting. Cardinal Mai and Pope Pius XI. were former custodians here. At Genoa the Biblioteca Franzoniana (40,000 vols.), founded about 1770 for the instruction of the poorer classes, is noteworthy as being the first European library lighted up at night for the use of readers.

Monte Cassino.—The monastery of Monte Cassino (59) is

the most costly of them. The library of the *Real Academia de Ciencias Exactas, Físicas y Matemáticas* consists of the *archivo*, which comprises more than 30,000 bulls, diplomas, charters and other documents besides 1,000 mss. dating from the twelfth to the thirteenth century. There are good written catalogues, and descriptions with extracts are published in the *Bibliotheca Casimirensis*. The monastery was declared a national monument in 1866. At Valencia the *Biblioteca Clavense* has a 10th century codex of Aristotle's *Metaphysics*. At Verona the *Biblioteca dell' Archivio Capitolare* comprises nothing but mss. of great antiquity and value, and of them the *Evangelium S. Eusebii*, supposed to be of the 4th century, also a famous codex of Anglo-Saxon homilies.

La Cava.—The *Monastero della S. Trinità*, at La Cava dei Tirreni in the province of Salerno (beginning of the 11th century) has only some 10,000 vols. but these include mss. from the sixth to the ninth century, amongst them a *Codex Legum Longobardorum* dated 1004, besides a well-known geographical chart of the 12th century, over 200 Greek mss., and about 1,000 charters reaching with the year 840 more than 100 of which belong to the Lombard and Norman periods. The library is now national property, the abbot holding the office of keeper of the archives.

Not a few of the communal and municipal libraries are of great extent and interest: Bologna (1507); Brescia, *Civica Quirmana* (1747); Ferrara (1753); Macerata, the *Mozzi-Borgetti* (1783-1835, united 1855); Mantua, Novara, *Negrone e Civica* (1847 and 1892); Padua, Palermo (1760), Perugia (1852), founded by P. Podani, Siena (1759), founded by S. Bandini, fine art collection, Venice, *Museo Civico Correr* (1830), Verona (1792 public since 1800), Bertoliana (1708). Italian librarians are organized and there is a school for professional training in the *Archiginnasio* at Bologna.

Spain and Portugal.—Most of the royal, State and university libraries of Spain and Portugal have Government control and support.

The chief library in Spain is the *Biblioteca Nacional* (formerly *Real*, at Madrid (1716), with 1,210,520 printed books, including 222 incunabula, 30,172 mss. and 120,000 prints. Theology, canon law, history, etc. are very complete. The collection of prints was principally obtained from Don Valentin Carderera in 1865. Other Madrid libraries are *Biblioteca de la Real Academia de la Historia*, 1730 (50,000 vols. and 8,400 mss.), which contains Spanish books of great value including the Salazar collection. In 1808, the year the Escurial contained approximately 30,000 printed vols. and 3,400 mss. Joseph removed the collection to Madrid, but when it was returned by Ferdinand 10,000 vols. were missing. There are now about 40,000 printed volumes. The *Biblioteca Provincial y Universitaria de Barcelona* (1841) contains about 100,000 vols. and that of Seville (1767) has 110,000 volumes. Among other provincial and university libraries is that of Salamanca (1751).

Among the libraries of Portugal the *Biblioteca Nacional* at Lisbon (1796) naturally takes the first place. In 1841 it was largely increased from the monastic collections, and now has 300,000 vols. of printed books, largely on theology, canon law, history and Portuguese and Spanish literature, 16,000 mss., and 42,000 coins and medals. The *Academia das Sciencias* (1779), in the suppressed convent of the *Ordem Terceira da Penitencia*, in 1816 acquired the library of that convent (30,000 vols.) which has since been kept apart. The *Arquivo Nacional* was brought here in 1749.

The *Biblioteca Pública Municipal* at Oporto, founded during the siege of 1842, and till 1874 styled the *Real Biblioteca do Porto*, is one of the largest in Portugal (about 300,000 vols.). The regent gave to the town the libraries of the suppressed convents in the northern provinces. The important Camoens collection is described in a printed catalogue (1850) and the mss. by H. da Cunha Rivara (1830-70). The University Library of Coimbra (1591) 300,000 vols., the *Instituto Jurídico*, Coimbra (1912) 51,000 vols., and the *Biblioteca Provincial* Cadiz 40,000 vols., may be mentioned.

Much interest in libraries has not been shown in Latin America. Most of the libraries which exist are national or legislative libraries.

Cuba.—The chief are in Havana, and the best is the *Biblioteca Nacional* (1901), 256,000 vols., the *Biblioteca Pública*. The *Biblioteca Pública* is one of the most actively-managed libraries in Latin America.

Mexico.—Of the 29 States the territories of the Mexican republic, many possess rare and valuable books from the libraries of the suppressed religious bodies, but few have much modern literature. Many scientific and literary associations in the republic possess books. The *Society of Geography and Statistics* in Mexico City (founded 1833, reorganized 1851), the most important of them, owns a fine museum and library. The ecclesiastical libraries of Mexico City were amalgamated as the *Biblioteca Nacional*, this now possesses over 200,000 volumes. Two copies of every book printed in Mexico must be deposited in it. Most of the libraries of Mexico, city or provincial are subscription, and belong to societies and schools of various kinds. The American Library Association is spreading Anglo-American library technique in Mexico, and also in the Philippines.

Argentina.—There are more than 200 public libraries in Argentina. They are due to benefactions, but the Government adds an equal sum to endowments. A central commission exists to facilitate the acquisition of books and to secure good administration. The most considerable is the *Biblioteca Nacional* at Buenos Aires (1810), which is passably rich in mss. concerning the early history of the Spanish colonies and has 350,000 printed volumes. The *Biblioteca Popular del Municipio* (1879) has about 30,000 volumes. There are also libraries attached to colleges, churches and clubs.

Brazil, Chile and Peru.—The chief library in Brazil is the *Biblioteca Nacional* at Rio de Janeiro (1810), now comprising over 483,000 printed vols., with many mss., largely on South America. Other libraries of the capital are those of the Faculty of Medicine, Marine library, National museum, Portuguese Literary club, *Biblioteca Fluminense*, Benedictine monastery, and the *Biblioteca Municipal* (60,000 vols.). There are provincial and town libraries throughout Brazil.

The *Biblioteca Nacional* at Santiago (1815) is the chief library in Chile. It possesses about 232,000 volumes. There is also a university library at Santiago (40,000 vols.) and the *Biblioteca Pública* at Valparaiso (50,000 vols.).

The *Biblioteca Nacional* at Lima was founded by a decree of the liberator, San Martín, in 1820, from those of the university of San Marcos and of several monasteries, and books presented by the liberator, it is rich in the history of Peru.

Netherlands.—Since 1900 there has been considerable progress made in both Belgium and Holland in the development of public libraries, and many towns in the latter country have established popular libraries after the fashion of the municipal libraries of the United Kingdom and America.

Belgium.—The national library of Belgium is the *Bibliothèque Royale* at Brussels, based on the *Bibliothèque des ducs de Bourgogne* the library of the Austrian sovereigns of the Low Countries in 1772. In 1794 a number of volumes were transferred to Paris, the majority being returned in 1815, in 1795 the remainder were formed into a public library under the care of La Serna Santander who was also town librarian, and who was followed by van Hulthem. At the end of the administration of van Hulthem a large part of the precious collections of the Bollandists was acquired. In 1830 the *Bibliothèque de Bourgogne* was added to the State archives. Van Hulthem died in 1832; his private library (catalogue printed 1836), mostly relating to Belgian history, was purchased in 1837, and, having been added to the *Bibliothèque de Bourgogne* and the *Bibliothèque de la Ville* (open since 1794), formed the *Bibliothèque Royale de Belgique*. The printed volumes now number over 300,000, with 31,200 mss., 34,600 maps, 1,267,700 prints and 80,000 coins and medals. There are printed catalogues of special collections of mss., of accessions, etc. There is no free legal deposit of books in Belgium; the Government purchases new books from the publishers and deposits them in the

Royal library. The financial crisis after 1918 led to proposals by a governmental committee of economics, to divide the foreign accessions of the library among those of various ministries, but in 1928 the scheme had been severely annulled and seemed unlikely to be pressed. There are libraries attached to most of the departments of the Government. Other important libraries are the Bibliothèque Collective des Sociétés Savantes (1906), with a union catalogue on cards, and the Bibliothèque du Conservatoire Royal de Musique (1832) with 31,000 volumes. The popular or communal libraries of Brussels (1842) and of the suburbs are distributed through the schools. At Antwerp the town library (1505) has now 500,000 volumes. The valuable collection of books in the Musée Plantin-Moretus (1640) should also be mentioned. It contains 427 mss. and 20,000 printed books, comprising the works issued by the Plantin family and many 15th century books, besides the archives of the firm.

The university library of Ghent (declared public in 1707, opened in 1798), was known successively as the Bibliothèque de l'École Centrale and Bibliothèque Publique de la Ville. On the foundation of the university in 1817 the town placed the collection at its disposal, but it has since remained under State control. The printed volumes now amount to 450,000 and the mss to 2,650. The Bibliothèque de l'Université Catholique of Louvain (1636) is based upon the collections of Beyerlinck, bequeathed in 1627, and of Jacques Romain, professor of medicine. There were over 211,000 vols in 1914, when the library was totally destroyed by fire at the German occupation. On the foundation of the University of Liège (1817) the old Bibliothèque de la Ville was added to its library (now 454,000 printed vols, 184,500 pamphlets, and 2,140 mss.). The Liège collection, bequeathed by M. Ulysse Capitaine and the Bibliothèques Populaires of Liège (1862), are circulated among the school children. The Bibliothèque publique of Bruges (1798) contains 145,000 printed books and mss housed in the old Tonlieu (1477). Every town has a communal library, mostly small and open only part of the day; the chief are those of Alost Arlon (1842), Ath (1842), Courtrai, Malines (1864), Mons (1797), Namur (1800), Ostend (1861) and Tournai (1794, housed in the Hotel des Anciens Prêtres, 1755); those of Ypres and other towns in the war area were destroyed in 1914-18. A complete list will be found in the *Annuaire de la Belgique scientifique, artistique et littéraire* (1908).

By a law of Oct. 17, 1921, communes may singly or in conjunction establish public libraries, and if complying with certain conditions receive State subsidies.

The "Union des villes et communes belges" at Brussels is planning a national scheme of federation and mutual lending between public libraries; and similar associations at Louvain, Antwerp, Bruges, Ermeton, near Namur (for the Walloon districts) are similarly engaged. Rural circulating libraries are brought by the law of 1921 under the same control as those of the communes (See J. van Meel, *Bibliothèques publiques*, 192).

Holland.—Information on Dutch libraries can be obtained from J. D. C. von Dukkum and G. A. Evers, *Nederlandische Bibliotekgids*, 2nd ed. 1924.

The national library of Holland is the Koninklijke Bibliotheek at The Hague (1798). The library of the princes of Orange was then united with those of the defunct Government bodies to form the national Bibliotheek. In 1805 the present name was adopted, and since 1815 it has become the national library. In 1848 the Baron W. Y. H. van Westreenen van Tiellandt bequeathed his library and antiquities to be preserved in his former residence as a branch of the royal library. There are now about one million printed books and over 6,000 mss. Books are lent all over the country. The library is the richest in the world in books on chess, Dutch incunabula, Elzevirs and in Spinoza. In 1800-11 a printed catalogue was issued, and since 1866 a yearly list of additions.

The next largest library is that of the Academia Lugduno-Batavia, which dates from the foundation of the University of Leyden in 1575. Valuable additions include those from the libraries of Golius, Joseph Scaliger, Isaac Voss, Ruhnken and Henssterhuis. The library of the Society of Netherland Literature,

placed here in 1877, Legatum Warnerianum of oriental mss., and the collection of maps bequeathed in 1870 by J. J. Bodel Nyenhuis are noteworthy. Published catalogues are books and mss. 1716, supplements of books added in 1814-47, and of mss., 1850 and oriental mss., 1851-77. The Bibliotheek der Rijks Universiteit (1575) at Leyden contains about 800,000 vols and 3,400 oriental mss., many of value.

The University library at Utrecht (290,500 vols.) is based on conventual collections brought together in 1581. The public library thus formed was soon enriched by books bequeathed by Hub Buchehus and Ev. Pollio, and was transferred to the university on its foundation in 1636. Among the mss. is the famous 'Utrecht Psalter,' which contains the oldest text of the Arian-Asian creed. Printed catalogues are of printed books of 1834 (supplement 1845, index from 1845-55, and additions 1856-1870), and of mss., 1887. Titles of accessions are printed.

The University library at Amsterdam is based on a 15th century collection. Since 1877 the collection has been known as the University library, and in 1881 it was removed to a building modelled on the British Museum library. It includes the best mediaeval collection in Holland, and the Bibliotheca Romaniana of Hebraica (30,000 vols., catalogue 1875). The libraries of the Dutch Geographical and other societies are preserved here. The library contains about 800,000 volumes. There are popular subscription libraries with reading-rooms in all parts of Holland, and in Rotterdam there is a society for the encouragement of social culture which has a large library. At The Hague, Leyden, Haarlem, Dordrecht and other towns popular libraries have been established, but ecclesiastical divisions hamper free development. Dutch librarians are organized in a professional body.

The library of the Genootschap van Kunsten en Wetenschappen at Batavia contains books printed in Netherlandish India, or relating to the Indian archipelago.

Denmark.—Owing largely to so many Scandinavian librarians having been trained and employed in American libraries, a greater approach has been made to Anglo-American library ideals in Norway, Sweden and Denmark than anywhere else on the continent of Europe.

A survey of 384 Danish libraries in 1915 (*Dansk Biblioteksfoerker*) was published by Svend Dahl, and a statistical list of popular libraries appears yearly in *Bogens Verden*.

The beginning of the national library the great Royal library (Kongelige Bibliothek) at Copenhagen may be credited to Christian III (1553-59); but to Frederick III (1648-70) is mainly due the collection of Icelandic literature and the acquisition of Tycho Brahe's mss., and also the present building (in the Christiansborg castle), begun in 1667. In 1793 the library was opened as the national library. Two copies of every book published in Denmark must be deposited here. The incunabula and block books form an important series. In foreign literature it specializes in the humanities. There are printed catalogues of the de Thott collection (1789-95), French mss., Oriental mss. (1846), the Danish collection (1875), etc. There are now 350,000 printed books and 30,000 mss. The Royal library has nearly completed publication of *Bibliotheca Danica*, a bibliography of Danish books, 1482-1830.

The University library (1482), destroyed by fire in 1728, but soon re-established, receives, since 1894, a copy of every Danish publication, and has 430,000 vols. and 7,000 mss., including the Arne-Magnean collection specializing in the natural sciences. The Statsbiblioteket at Aarhus (1894) possesses about 270,000 vols. and the Landsbokusafn Islands (National library) of Reykjavik, Iceland, about 118,000 printed books and 7,830 Icelandic mss. A State library commission supervises the State-supported libraries. An association for promoting public libraries was formed in 1905, and in 1909 the minister of public instruction appointed a special adviser.

Modern developments show, perhaps more clearly than elsewhere in Europe, a tendency to co-ordinate all the libraries.

Norway.—The Norsk Bibliotekforening in 1924 published a statistical account of 266 libraries (*Handbok over norske Biblioteker*).

Library at Oslo has over 700,000 vols. in the collection. The Deichmansk Bibliotek at Oslo was founded by Carl Deichmann in 1780 as a free library, and is maintained by endowments and by the city. It now contains about 195,000 volumes. The Free library at Bergen (1871) has 205,758 vols. and has been re-housed. The Norske Videnskabs Selskab at Trondhjem has also a large library.

Sweden and Finland.—Swedish libraries were surveyed in 1911 in Einar Sandström's *Swedish Bibliotek*.

The Royal Library at Stockholm, established in 1585, was given to the University of Uppsala by Gustavus II. Charles X's library was burned in 1697 and the present library was organized since afterwards. The Benzeltjerma-Engestrom library (rich in Swedish history) is now annexed to it. Natural history, medicine and mathematics are left to other libraries. Among the mss. the *Codex Arvensis* of the 6th or 7th century, with an Anglo-Saxon inscription, is noteworthy. The library contained, in 1924, 460,000 printed books and over 12,000 mss. The Karolinska Institutet, in Stockholm, contains a library of medical books numbering over 70,000.

The University library at Uppsala was founded as mentioned above by Gustavus Adolphus in 1620, from the remains of convent libraries and endowed. The mss. chiefly relate to the history of the country, but include the *Codex Argenteus* of the Gothic Gospels of Ulfilas, published in facsimile by the library in 1928. Printed catalogues are general (1814), foreign accession lists annually from 1850, and Arabic, Turkish and Persian mss. (1845). The library now contains about 600,000 printed books and mss. The University library at Lund (1668) was based upon the old cathedral library. The mss. include the de la Gardie archives, acquired in 1818. There are about 145,385 vols. in the library. The Stadtbibliotek of Gothenburg (1890) contains about 240,000 vols., and has a printed catalogue.

Finland has the University library of Helsingfors (1640-1827), about 500,000 vols. and the parliamentary library (1872), 55,500 volumes.

Russia.—The Gosudarstvennaya Publichnaya Biblioteka at Leningrad formerly the Imperial public library at St. Petersburg, the state library of the Union of Soviet Socialist Republics, is perhaps the largest library in the world. In 1910 it had about 1,500,000 printed vols. and 34,000 mss., as well as large collections of maps, autographs, photographs, etc. It is now said to contain 4,556,943 printed books and 240,000 mss., and autographs. It originated in the books seized by Peter the Great in Courland in 1704; the library however only attained to the first rank in 1795, by the acquisition of the famous Zaluski collection. The Zaluski library was formed by the Polish count, Joseph Zaluski, who collected 200,000 vols. added to by his brother Andrew, bishop of Cracow. At his death it was left to the Jesuit college at Warsaw; on the suppression of the order it was taken by the Commission of Education, and in 1795 it was transferred by Suvarov to St. Petersburg as a trophy of war. It then had 260,000 printed vols. and 10,000 mss., but in consequence of the dispersal of many works among other institutions, hardly 238,000 vols. remained in 1910. After the World War the Zaluski collection was returned to Poland. By a law passed in 1810 two copies of every Russian publication must be deposited in the library. Very many valuable special collections have been added, such as the Tolstoy Slavonic collection (1830), Tischendorf's mss. (1858), the Dolgorouisky mineral mss. (1859), and the Firkowitsch Hebrew (Karaitic) collection (1862-63), and the national mss. of Karamzin (1867); some departments are thus exceedingly rich, while others are comparatively meagre.

The glory of the mss. is the *Codex Sinaiticus* of the Greek Bible, brought from the convent of St. Catherine on Mount Sinai by Tischendorf in 1859. Other important biblical and patristic codices are to be found among the Greek and Latin mss. The Hebrew mss. include some of the oldest extant, and the Samaritan collection is one of the largest, the oriental mss., and the French

mss. (not only the historical are of great value. The Biblioteka (sem. no.) Literary (1919) has about 90,000 and the University library (1925) 711,000 volumes.

The library at the Hermitage was founded by the empress Catherine II's purchase of Voltaire's and Diderot's books and mss. In 1861 it possessed 150,000 vols., of which nearly all but those on the history of art were then transferred to the Imperial library. There are many large and valuable libraries attached to the Government departments in Leningrad, and most of the academies and colleges and learned societies are provided with libraries. The national library published in 1928 material for a directory of the learned libraries of the city.

The second largest library in Russia is the Lenin Memorial Library in Moscow (formerly Rumyantsov Museum collection renamed after Lenin's death in 1924). It has over three million volumes, is rich in early printed books, Russian history, and mss. The latter number 5,000, including many ancient Slavonic codices, historical documents and the archives of the masonic lodges in Russia between 1816 and 1821, catalogues of the mss. and of some special collections are printed. The University at Moscow (1755) has a library of over 320,000 vols., and the Duchovnaya academy has 120,000 volumes. The (formerly Imperial) Russian Historical museum (1875-83) in Moscow contains nearly 200,000 volumes. Among Russian university libraries mention may be made of Kazan (1804), Kharkov (1805), Kiev (1832) and Odessa (1865). There are also communal or public libraries at Kharkov (1886), Odessa (1830) in the Ukraine and many other towns. The Soviet Government has established many popular libraries. The Lenin Institute of Library Science at Moscow trains librarians and has published text-books.

Poland.—The Jagiellonska library at Cracow (1400) 524,000 vols. and 6,711 mss., at present serves as national library for Poland. As the headquarters of the Government is at Warsaw however, it is now debated whether all publications concerning Poland should be housed in the National Library there (1917) 91,532 vols., or whether they should be divided between the two cities. It is suggested that the Jagiellonska library be made into a historical collection containing books to the year 1918, the date of the reconstitution of the Polish State, and that the Warsaw library be confined to accessions since that date, and organized on the lines of the Deutsche Bucherei at Leipzig. A bibliographical institute will be attached to the Warsaw collection and will disseminate information through a special bureau, the functions of which are at present fulfilled by the Jagiellonska and by the Warsaw section of the libraries of the Ministry of Public Instruction. The National Library at Warsaw has also been enriched by the famous Zaluski collection, described in the paragraph on Russian libraries. The Warsaw university library (1817) has 730,000 volumes. Besides the Cracow and Warsaw libraries, that of Posen (formerly Kaiser Wilhelm Bibliothek) may be mentioned. Lemberg (Lwów) has three noteworthy collections housed in the University library, the Ossolinsky library and Museum and the Bavorovsky library. Chwalewik's *Les Collections polonaises* (2 vols.) gives a complete list of Polish libraries, and 427 libraries are listed in the Mianowski Foundations Year Book (1927), pp. 162-221. There is no general catalogue, but its place is taken at present by Charles Estracher's *Bibliografia Polska* (1870-). The Lett city of Vilna also has a public library (1856).

Elsewhere in Eastern Europe.—Latvia has the city and university libraries of Riga (with 375,000 and 60,000 vols.). Estonia has the university library of Tartu (Dorpat 1806) with 270,000 vols., and the city library of Tallinn.

The university libraries of Belgrade and Sofia (1883), 192,039 vols., and the national library at Sofia (1924), over 200,000 printed books and 5,500 mss., are the chief in the Balkans. There is a Bulgarian State Library Commission, which organizes local libraries and trains librarians.

At Athens the national library (1842) possesses about 400,000 vols., 3,800 mss., and 200,000 historical documents.

Constantinople has a National library (1925) and a public library, the Oumoumiye, of about 300,000 volumes. There are over 110,000 vols. in the University library (1910) and there are

also libraries at the Greek literary society and the Theological school. The mosque of St Sophia contains a library of some thousands of mss, of which a printed catalogue is obtainable, consisting mostly of Korans and service books. The old Seraglio contains many important books.

THE FAR EAST

China.—The earliest notice of a library in China is that of the imperial Chou dynasty whose capital was at Loyang in the modern province of Honan. According to a tradition preserved in Ssu-ma Chien's "Historical Record" the philosopher Lao-tse, who lived in the seventh century before Christ, was keeper of books in this library. National collections of books in the modern sense, however, originated with the attempts made to recover the books scattered or destroyed by the so-called 'First Emperor' in 220 B.C. Hence the earliest catalogue of Chinese books is preserved in the "History of the Former Han Dynasty" (206 B.C.—23 A.D.) and written in the first century of our era. The histories of nearly all succeeding dynasties have likewise left catalogues of books preserved in their libraries or known to their times. After the invention of printing in China private libraries became increasingly numerous. From time to time these were destroyed or dispersed, but catalogues of many of them remain. There are still some fourteen large private libraries in various parts of China some of which contain as many as two hundred thousand volumes.

According to a survey made by the Library Association of China in 1927 there were then 503 public and private libraries in China proper and Manchuria. Of this total the province of Kiangsu has 145, the city of Shanghai 60, Peking 42, and Nanking 20. The largest single collection of books is found in the Metropolitan Library, Peking. Each provincial capital also has its own library. The following universities boast large and rapidly growing collections of both Chinese and western books: Peking National University, Sun Yat Sen University (Canton), Tsinghua University (Peking), Yenching University (Peking), Amoy University, and Nanking University. The most common classification of books in Chinese libraries—the so-called *Ssu K'u* system which has been in vogue for fifteen centuries—divides all Chinese literature into four classes: classics, history, philosophy, and belles lettres. A few of the modern Chinese libraries have discarded this system entirely, but most of them combine with it a modified Dewey or Library of Congress classification. (See the files of the Library Science Quarterly, *T'u Shu Kuan Hsueh Chu K'an*, the official organ of the Library Association of China which was founded in 1925.)

Japan.—The ancient history of libraries in Japan is analogous to that of China.

Perhaps the most extensive library of the empire is that of the Imperial Cabinet (1885) at Tokyo with 507,600 vols, consisting of the collections of various Government departments.

The Imperial library at Uyeno Park (1872) contains 387,208 vols, of which some 297,000 are in Japanese or Chinese. At Tokyo there is also the Ohashi library (1902), 81,154 vols, the Hibiya library (1908), 153,000 vols, and the Nanki library (1899), 87,000 vols. The library of the Imperial University of Kyoto (1899) contains nearly 650,000 vols, of which a large proportion are in European languages. Kyoto and other towns have considerable municipal libraries. Kasan in Korea has a library (1804) of about 250,000 vols.

LIBRARY ASSOCIATIONS AND TRAINING

The first and largest association established for the study of librarianship was the American Library Association (1876), which includes Canada. The Library Association of the United Kingdom was formed in 1877, as an outcome of the first International Library Conference, held at London, and in 1898 it received a royal charter. It publishes a *Year Book*, the quarterly *Library Association Record*. It also holds examinations. The Library Assistants' Association was formed in 1895 and has branches in different parts of England, Wales and Ireland. It issues a monthly magazine entitled *The Library Assistant*. The Association des Bibliothécaires Français was founded in 1906 and publishes an

important journal. There are two associations in Germany, the Verein deutscher Bibliothekare, and the Verein deutscher Volksbibliothekare, which issues a year-book giving information concerning the libraries of the country, a similar organization in Austria-Hungary is now merged into the former. An Association of Archivists and Librarians was formed at Brussels in 1907, and there are similar societies in France, Italy, Spain, Holland, Denmark, Norway, Sweden, and, since 1927, in China also. In every country there is now some kind of library association.

The movement since the World War, partly because of the financial crisis in Europe, and partly because of the increased consciousness of each other among the nations, has been one of co-operation and closer organization, so that the world's library resources are far better utilized.

Two agencies further international co-operation between libraries. (1) The Institut International de Bibliographie, founded in 1897 at Brussels by Paul Orlet and Henri Lafontaine, but shortly to be moved to Geneva, aims at amalgamating the catalogues of the world's chief libraries into an universal card bibliography. It has also produced a more thorough (decimal) classification for books and papers. (2) The Institut International de Co-opération Intellectuelle at Paris, an institution of the League of Nations, by its committee of library experts (mostly the heads of the great national libraries), has brought into mutual relations the national bureaux of bibliographical information, and publishes reports from them.

It has been calculated by E. Sparr (*El Crecimiento de las grandes Bibliotecas de la Tierra*) that the larger libraries of the Old World were doubled, and those of North America trebled, in content in the first quarter of the 20th century.

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(N; A E-)

THE UNITED STATES

The earliest libraries in the colonial period of America were private. Among the notable libraries of this kind were those of Elder William Brewster of Plymouth, Gov. Winthrop of Connecticut, Dr. Cotton Mather of Boston, Col. Ralph Wormeley of Virginia and the Rev. John Harvard. Toward the end of the 17th century the so-called Bray parish libraries began to appear. These were collections mainly of religious books sent to America through the efforts of the Rev. Dr. Thomas Bray of London, designed particularly for the use of the clergy though open to the public. The first subscription library in the colonies was projected by Benjamin Franklin in 1731 in Philadelphia. Many of the early subscription and proprietary libraries have become the foundations of public libraries. A few of them however still flourish. The Boston Athenaeum (1807) had in 1908 a collection of 305,000

volumes and was especially rich in historical material. The Providence Athenaeum (1753) had 104,000 volumes. The New York Society library (1754) had a general collection of 125,000 volumes its special strength being in fine arts, early fiction and Americana.

Endowed Libraries.—The gift or bequest of great private libraries or large sums of money for the erection of library buildings and the organization and maintenance of libraries for free public use has been a favourite form of philanthropy in America. In New York the Astor library, founded by a bequest of John Jacob Astor, was incorporated in 1849 and opened to the public in 1854 as a reference library of the most valuable books on all subjects. The Lenox library was established in 1870 by James Lenox a New York merchant and one of America's greatest book collectors. In addition to funds for a library building and endowment amounting to \$1,247,000, he gave his valuable collection of books and art treasures. From the estate of Samuel J. Tilden, the City of New York in 1892 received the private library of the former governor of the State and about \$2,000,000 for library purposes. In 1895 the Astor library, the Lenox library and the Tilden Trust were consolidated under the name of the New York Public library, Astor, Lenox and Tilden Foundations, which was soon to become the largest public library system in the world (2,971,309 volumes and pamphlets). In 1901 the New York Free Circulating library, with 11 branches and later other circulating libraries, were consolidated with the new system as the Circulation Department of the New York Public library. In 1901 also Andrew Carnegie gave \$5,200,000 for the construction and equipment of free circulating libraries in Greater New York. Chicago has two important endowed reference libraries, the Newberry library (1887), with 443,757 volumes and pamphlets, and the John Crerar library (1894), with 820,000. The Enoch Pratt Free library (1886) of Baltimore and the Providence (R.I.) Public library (1878) are typical of the numerous endowed public libraries, many of which are supported in part by municipal appropriations.

At the head of the list of library benefactors stands the name of Andrew Carnegie, whose first library gift was made in 1881 to Dunfermline, his native town in Scotland. His second gift of a library was made in 1890 to Allegheny, Pa. Pittsburgh received a large central building in 1895 and later eight branches. The total amount given by Carnegie and the Carnegie Corporation for library building in the United States and Canada was \$43,665,000. In its gifts for library buildings the corporation, organized in 1911 followed the wishes of its founder, until its gifts for libraries were discontinued in 1917.

College and University Libraries.—The history of college and university libraries is also a record of generous gifts from private collectors and friends of education. Harvard college library dates from 1638 when John Harvard bequeathed to it his collection of 330 volumes. By 1764 the library had grown to 5,000 volumes, when all but one of the original volumes were destroyed by fire. The library of Yale college was founded in 1700, but grew so slowly that even with the 1,000 volumes received from Bishop Berkeley in 1733 it had only 4,000 volumes in 1766, and some of these were lost in the Revolutionary War. The library of King's college, renamed Columbia college after the Revolutionary War, dates from 1756, when Joseph Murray, a governor of the college, bequeathed to it his private library. It is estimated to have had only about 2,000 volumes at the outbreak of the Revolution. Though stored in the city hall for safe keeping, many of the books were carried off by British soldiers and the rest scattered and never recovered except for a few volumes which are now in the library of Columbia university. The rehabilitation of the library after the Revolution was accomplished very slowly. In 1863 it had only 14,941 volumes.

The Harvard college library has about doubled in size every 20 years for over a century, and this rate of growth has been equalled or exceeded by most of the larger college and university libraries, especially in recent decades. In 1927 the number of volumes in these libraries were: Harvard, 2,622,400; Yale, 1,838,099; Columbia, 1,092,343; University of California, 665,680; University of Chicago, 708,559; Cornell university, 787,127; University of Illinois, 708,850; University of Michigan, 649,912; University of

Minnesota, 501,507; University of Pennsylvania, 635,070; Princeton university, 594,195.

Library of Congress.—The Library of Congress has become in fact if not in name the national library of the United States. It was established in 1800 by Act of Congress as a legislative library and was housed in the Capitol until 1837 when it was moved to its own building which is the largest most ornate and most costly library building in the world. It occupies 3½ ac. of ground, contains over 10,000,000 cu. ft. of space, and has a floor area of over 13½ acres. The original cost was \$6,347,000—including the site, close to \$7,000,000.

On June 30, 1927, the Library of Congress contained 3,556,767 books and pamphlets, making it the third largest library in the world. The principal sources of growth have been deposits under the copyright law, exchanges of official publications with foreign Governments, and the Smithsonian exchanges which add extensive files of the transactions of foreign learned societies. The main collections are strongest in bibliography, history, political and social sciences, public law and legislation, the fine arts, American local history, biography and genealogy.

Besides its research and other services for members of Congress and the Government Departments it offers excellent facilities for serious scholars. It is also performing the functions of a national library by extending bibliographic and other services to all the libraries of the country. It stands at the head of a recognized inter-library loan system, by lending to college, university, State, municipal and other libraries books which they do not possess and cannot obtain elsewhere.

Public Libraries.—The modern public library, maintained by the municipality or some other unit of local government from the proceeds of taxation, was scarcely known before 1850 and has developed for the most part since the formation of the American Library Association in 1876. The earliest tax-supported library is supposed to have been the town library of Salisbury, Conn., established in 1803. The oldest existing library of this kind is said to be the one at Peterborough, N.H., which dates from 1833. Legislative sanction for the use of taxation to maintain public libraries was given in New York in 1835 the school district being the library area. By the Michigan Constitution of 1835 the legislature was given power to establish a library in every school district. In 1848 the Massachusetts general court authorized the city of Boston to raise \$5,000 a year to maintain a public library, and in 1851 this Act was applied to all towns in the State. Similar laws were soon passed in other States. In 1928 legislation authorizing the establishment and maintenance of municipal public libraries was found in every State except Delaware where the school district was the only unit recognized for this purpose.

The latest statistics show about 6,000 public libraries in the United States, with an average *per caput* income of \$0.33 and an annual *per caput* circulation of 2-13 volumes. It is estimated, however, that 5% of the urban population and 82% of the rural population live in areas with no local public library service at all. Most of the well organized city library systems spend from \$0.75 to \$1.00 or more *per caput*. In 1926 Cleveland led all other cities with a *per caput* library expenditure of \$1.69, followed by Boston with \$1.42, Indianapolis with \$1.14, Los Angeles with \$1.05 and Minneapolis with \$1.00.

One of the ways in which the modern public library attempts to make its service of value to the community is by specialization in its service and organization. Specialization by subject is frequently represented by separate departments, in charge of specialists, of business, technology, art, music, education, etc. In some of the recent central library buildings book stacks and reading rooms are arranged to facilitate departmental organization. Specialized service such as work with children and co-operation with schools is usually not confined to the central library but operates also through different kinds of distributing agencies. Branch libraries and sub-branches have their own collection of books and are located near the centre of the local business or residence area to be served. It is assumed in the best library systems that there should be one branch to every 25,000 to 40,000 population. In less densely populated districts a branch cannot effectively serve so

ge a number. Deposit stations are located in stores, schools, churches, etc., and are provided with collections of from ten to several hundred volumes which are changed frequently. Deposit stations have no books on hand but fill orders from a central stock. Travelling libraries consist of small collections of books, 50 to several hundred lent to factories, stores, clubs, etc. In many communities the public library has undertaken to supply books needed in the public schools by furnishing classroom libraries. In some cases the school and library authorities cooperate in providing what are known as school libraries and in some States travelling libraries are established in school buildings.

The governing body of the municipal public library supported wholly or in part by public funds is usually a board of trustees, composed of the mayor or some other official or body designated by law. In some cases the library board is self-perpetuating. In some States the public library is operated under the board of education and in certain cities which are under the city manager or commission form of government there is no library board at all, the public library being administered as a department of the city government with the librarian directly responsible to the mayor or city manager.

A special library for children was established in New York city as early as 1835. In 1890 a separate room for children was opened in the public library at Brookline, Mass. and in the next few years public libraries began generally to provide special rooms or other facilities for children. By 1900 a separate children's room, with specially trained children's librarians to give skilled and sympathetic guidance in the use of books and periodicals had come to be considered an essential part of every well conducted public library. To-day in public libraries in which organized work with children is carried on the juvenile circulation amounts to from 30 to 50% of the total. From one-quarter to one-third of the average public library is considered a reasonable proportion for the average public library to devote to children's books. In libraries which combine the children's department and work with schools, the children's librarians select books to be sent to classrooms, visit schools to talk to the children, give talks to parents and teachers and give instruction in the use of books and libraries to classes sent to them regularly from the schools.

State Libraries.—In the beginning the State library was essentially a law and legislative library for State officials. The State library of New Hampshire was started in 1770 as a colonial library. The New Jersey State library dates back to 1796. A legislative library was established in South Carolina in 1814. The oldest and best State library, that of New York at Albany, was founded in 1818. While the State library is primarily a special legislative library for the legislative or executive departments of the State government, or for both, it is generally open to the public for reference purposes. About 1887 state libraries began to assume leadership of the State commission movement and in 13 States library extension work is now a function of the State library. In 13 States the State law library is separate from the State library. In nine States the legislative reference bureau is also separate. In certain States miscellaneous functions have been assumed, such as historical research and the care of museums.

The term library extension is usually applied to the efforts of some State authority to aid in providing local public library service or some substitute for it in the smaller towns and rural districts. Over 90% of the population living in towns and cities of more than 2,500 population in the United States enjoy the service of a local public library of some sort, while less than 20% of the population in the smaller towns and in the open country have any kind of local public library service. The first State to attack this problem was Massachusetts, which in 1890 created a State board known as the Free Public Library Commission, whose function was to aid in establishing and developing free libraries throughout the State. New Hampshire followed in 1891. In 1892 the New York State library was made a central bureau for promoting, stimulating, aiding and directing local libraries. A commission similar to that in Massachusetts was created in Connecticut in 1893, in Vermont in 1894 and in Wisconsin in 1895. Other States quickly followed their examples. In 1904

the League of Library Commissions was organized "to promote by co-operation such library interests as are within the province of library supervision by the State." In 1928 39 States had a library extension agency in operation, three more had laws providing one leaving seven States that had no extension agency nor legal provision for one. In 13 States, as noted above, the State library is the extension agency, in 12 the function is performed by the State board or department of education, and in 14 there is an active library commission. The functions actually performed by library commissions or other State agencies responsible for library extension include aid in improving local public library service, establishment of new libraries where needed, promotion of co-operation between libraries, assistance in providing library service for schools, and for State charitable, penal and reformatory institutions, provision for library service where local service is impracticable, distribution of State documents, library service for the blind and legislative reference work.

The travelling library represents one of the earliest forms of State library extension. In 1892 a system of travelling libraries was created in New York under the leadership of Melvil Dewey. Travelling collections of books were used in 1928 in 35 States. The State travelling library is a collection varying from 50 to several hundred volumes for general reading, although special collections are sent out in some States. "Package libraries," consisting of pamphlets and magazine and newspaper clippings on current events and topics on which there are no books, are sent out through the mail by some extension agency in several States for the use of high school debaters, club women, discussion groups, etc. Nearly all the extension agencies make a practice of mailing one or several volumes directly to individuals.

County Libraries.—The most effective form of library extension being carried on is the development of county library systems. The county library is a tax-supported library serving an entire county (excluding in some cases the larger towns and cities which have their own library service) through a central library, usually located at the county seat and a system of branches and deposit stations, all served and directed by skilled librarians. To reach the more isolated sections book automobiles are used by some county libraries. From the middle of the 19th century sporadic efforts were made to establish county libraries, and some of them met with a fair degree of success, but it was in California beginning about 1909 that the first real system of county libraries developed. The California library law of 1911 gave that State the leadership in the county library movement and has had much influence on county library legislation in other States. Thirty-three States have laws authorizing county library service in some form. Management is usually in the hands of a county library board. In a few States, California for example, the county library system is managed directly by the county supervisors. To maintain the highest standard of service the county library system should be under the supervision of some State agency. In 1928 public funds were being appropriated for county public library service in only 251 out of the 2,806 counties in the United States. California headed the list of States with 46 counties out of a total of 53, less than 3% of the population being outside public library service areas.

School Libraries.—The new curriculum of the high school and the newer methods of teaching have made the school library a necessity. The first modern high school libraries were started by the librarians of public libraries, and all of them have appeared since 1905, when full time high school librarians began to be appointed. Strictly speaking a library even though located in a school building is not a school library unless maintained and administered primarily for the benefit of pupils and teachers. Administration of school libraries of this kind may be undertaken by the school authorities themselves or turned over to the public library. The importance attached to the school library in modern education is reflected in the State laws and the regulations of State education authorities. The standards prescribed usually apply only to high schools and cover such matters as the annual appropriation, the initial cost or value of the books, the expenditure per pupil, the number and kind of books selected, the housing

and equipment of the library and the qualifications, education, training and duties of the librarian. In some States the standards adopted are not compulsory but are merely recommended to local school boards. It is usually assumed that a full time librarian is required in schools of 500 or over. In the smaller high schools a teacher—most frequently the teacher of English—serves as teacher-librarian.

Special Libraries.—Specialization in all fields of endeavour necessarily has its counterpart in library service. A very large tax-supported public library can specialize its collections and service to some extent particularly in the direction of some dominant industrial or other interest of the community. Endowed public libraries have more freedom to neglect certain fields and concentrate their efforts on others. Public libraries, on the other hand, may build up special collections in various subjects and provide specialized service for schools, for children, for the blind, for business men, for Government officials, etc., but it is seldom possible for them to carry specialization in either collections or service to the extent that is required by the educational, business, professional and other interests of the community. Professional and other groups, therefore, find it desirable to organize and maintain their own libraries so that in populous centres are to be found privately supported libraries of law, medicine, engineering, etc. Some of these are for the use of members or subscribers only, others are open to the public. Educational institutions require libraries that are built up and administered to meet the special needs of students and teachers. With the development of the modern business corporation the need arose for a specialized library service which could not ordinarily be furnished by the public library. The result has been the rapid development since about 1910 of collections of printed matter in special fields, in charge of persons familiar with the subject matter, for the use of a more or less limited group. In 1909 a Special Libraries Association was organized and began publishing the monthly journal *Special Libraries*. While the association draws its membership from many types of special libraries, the business interests predominate. It has now become quite common to find special libraries maintained by banks and investment houses, insurance companies, advertising agencies, newspaper offices, public service corporations and a great variety of industrial and commercial companies.

The American Library Association, organized in 1876, is an association of libraries, librarians, trustees and other friends of libraries, pledged to carry out the purpose of its founders "by disposing the public mind to the founding and improving of libraries." It had in 1927 a membership of more than 10,000. Its total budget in the fiscal year 1927 was more than \$325,000, the largest items of expenditure being for the promotion of professional library education and the publication of text-books, professional literature and aids to book selection. Headquarters are located in Chicago. During the World War, the association provided libraries for soldiers, sailors and marines, sending more than 2,000,000 books overseas from 1917 to 1920. Other associations affiliated with the A. L. A. are the American Association of Law Libraries, the League of Library Commissions, the National Association of State Libraries, and the Special Libraries Association. Nearly every State has its own library association or joins with neighbouring States in a regional association. Library clubs are found in many of the larger cities.

(C. C. W.)

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Administration.—In the United States details of administration differ because of varying requirements from local and State governments, with marked tendency toward uniformity due to the influence of library schools and the A. L. A.

In general the public library is administered by a board of trustees or directors elected by the community or chosen or

appointed by the mayor, city manager, council, or some similar officer or board. A few libraries are controlled by the local school boards, and a smaller number are administered by self-perpetuating boards related to the city by contract or agreement. Frequently the size, tenure of office, duties and responsibilities of a board receiving public funds are specified by State law.

The trustees are charged with the duty of fixing the policy for the institution, establishing principles governing the staff, determining the kind of library best fitted for the community. They usually have committees for more immediate and intimate supervision of current work than is possible by means of the whole board. Their tenure of office and length of service may differ in detail, but the aim and intent generally seem to be the choice of a middle ground between changes so frequent and rotation in office so constant as to make impossible continuity of policy; and so infrequent as to suggest danger of dry rot. The librarian is usually recognized as executive officer of the board.

The spirit of current rules seems to emphasize fair play for all users of books, equitable treatment for the public, rather than convenience for the staff. How many volumes may be taken at one time, length of withdrawal before renewal, fines for failure to return books for renewal, regulations for summer or vacation privileges, special consideration for teachers or other classes of readers, these and similar administrative controls differ so widely because of varying local conditions that generalization is dangerous. Most libraries limit loans for ordinary books to two weeks, set fines of one or two cents a day for books not renewed, grant special privileges when general harm or inconvenience will not follow.

In most cases support comes from public funds granted as a result of request to the committee or board fixing the local tax levy. In some cases money thus granted is turned over to the library board for spending under proper accounting and supervision, in other cases it is paid from the office of the local disbursing agent when warrants are presented bearing proper authorization and certification by the library officials.

Some boards select new books themselves or by a committee, but in the larger systems this task is usually turned over to the librarian. Occasionally books must be bought by public bids and tenders, but the tendency seems towards giving the librarian greater discretion as to purchase of books and supplies. The preliminary steps and the details of control up to the time of purchase of books and supplies are in many cases regulated by statute or local ordinance, but once the books have passed this stage their administrative processes are fairly uniform, thanks to standardizing of methods and processes resulting from the influence of the library schools and the training classes. Cataloguing, accessioning, subject heading, classifying, charging to borrowers, registration of borrowers, inventory work, reading the shelves are all coming to show little variation from one end of the country to the other. One important element in uniformity of cataloguing is the growing use of printed cards supplied by the Library of Congress. Several classification schemes had ardent advocates a generation ago, today the Dewey decimal system is almost universal among the more popular libraries, and the Library of Congress system bids fair to equal it among the larger college, university, and reference libraries. A similar tendency toward uniformity in the reporting of activities is shown by the growing use of the system recommended by the A. L. A. (H. M. L.)

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LIBRARY ARCHITECTURE. Architecturally, the library is a modern problem. There were, of course, many famous libraries before modern times, but from the description that we have of those of antiquity, and from the examples still existing of libraries of the Renaissance on to the end of the 18th century, it is clear that the great collections of books were kept simply in rooms or galleries furnished with shelves or cupboards, and sometimes with heavy pulpit-like counters on which the ponderous folios could be rested. Aesthetically the treatment of these

LIBRARY ARCHITECTURE

was often mistaken as in the Vatican, the Biblioteca Marciana in Venice and the old Ste Genevieve library (now Lycée Henri IV) in Paris, but it was never developed as a solution of a regular problem and differed in no special way from the treatment of other equally delightful examples of the architecture of the time. For private libraries or for open ones to a selected public such as those of clubs

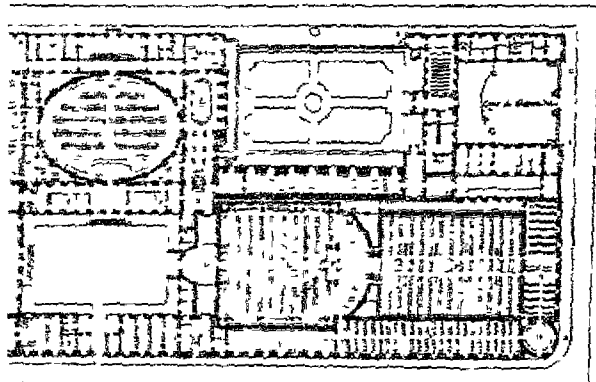


FIG. 1. — LE PLAN DE "L'ÉCOLE DE LA CONSTRUCTION" (LIBRAIRIE DE LA CONSTRUCTION)
 1ST FLOOR PLAN OF THE BIBLIOTHÈQUE NATIONALE, PARIS

consultations and special departments in our modern times the old scheme in which the shelves of books provide a surface for the walls rivalling the finest tapestries, can hardly be repeated. But for the requirements of the modern public which has to meet demands peculiar to modern conditions, the old plan cannot serve.

The modern problem first presented itself early in the 19th century with the tremendous growth in the number of books and the development of the democratic desire to place the great collections at the service of the general public. The mere extension of the type of libraries as then existed was no longer a solution. We have the record of such a scheme in the project of Boullée (1729-99) entitled *Mémoire sur le projet d'une bibliothèque pour le Roi* (1755). This memoir is accompanied by a drawing showing a gigantic gallery covered by a barrel vault supported on two colonnades which vanish in the distance at a distance, and admitting the light only through a rectangular opening in the centre. Under the colonnades there are three platforms supporting a series of bookshelves. Aesthetically, the design is without merit in its severity, and it shows, moreover, an appreciation of the magnitude of the new problem. But the solution was not to be found in a mere increase in size, rather in a segregation of the public in reading rooms and of the books in separate store-rooms for the books. These store-rooms, what we now call the "stacks," where in general the books were not admitted and an intensive use of space can be made. As early as 1825, the French architect Benjamin Dellessert, in his plan for the proposed Bibliothèque Nationale in Paris, a circular reading room, with the book-stacks surrounding it, lying in a circle about the centre. The old Wolfenbützel library (1706), and also the Radcliffe library at Oxford, had already been planned on a circular plan but without the separate book-stacks. The circular reading room recommended itself by allowing the books to be installed on a raised platform in the centre, an easier position for the readers. Dellessert's plan probably suggested the reading room of the British Museum (R and S. architects, 1850), where, however, the stacks are rather irregularly arranged around the central dome.

Henri Labrousse was appointed architect for the new Ste Genevieve library in Paris (1854), the site selected being long and narrow, almost forced the solution of a reading room occupying the upper floor of the building and containing many of the books in the old libraries but with other spaces for books — a scheme that in recent years has been used in many of our libraries. Although the shape of the lot unfortunately necessary to divide the book storage into two sections, he had, nevertheless, evolved a masterly solution of his

problem, a solution so modern in his frank treatment of structural elements that this building remains one of the prototypes of modern architecture.

Later, in the plans for the Bibliothèque Nationale in Paris (1854), where he was less hampered by the exigencies of space Labrousse gave another remarkable building. The main reading room is square, with an apse, where the librarians are installed facing its entrance and commanding that to the stacks. The reading room is surrounded by three tiers of shelves with the light coming through a large opening on the north side, and from nine domes which each rest on four light steel columns. The atmosphere of the rooms is quiet and restful and the light is excellent. The most remarkable part of the composition, however, is the book-stack (*magasin des imprimés*), a huge room, 90 ft by 120 feet. Here the principle of the modern book-stack is first evolved. The shell of masonry is covered by a glass skylight, which allows daylight to penetrate every corner, while inside this shell, the metal framework of the book tiers and the passages between is an entirely independent construction resting on the basement floor. These are the essentials of the modern book-stack, the invention of which has been attributed quite incorrectly to W. H. Ware and Bernard Green, the only improvement contributed by these gentlemen many years later, was the closer packing of the shelves and the elimination of such woodwork as remained.

MODERN LIBRARY PLANNING

The three types of libraries represented by the two works of Labrousse and the British Museum are the elementary types on which virtually all large modern libraries are based. To the type of the Ste Genevieve, *etc.*, with a reading room lighted on both sides, with books along the walls or in alcoves, and with a storage room under the reading room, belong the New York public library (Carrère and Hastings, architects, 1897), the library of the University of Chicago (Shepley, Rutan and Coolidge, architects, 1910) and the Philadelphia free library (H. Trumbauer architect, 1905-7). To the type of the Bibliothèque Nationale, *etc.*, with a reading room parallel or perpendicular to the stacks, belong the project for the library of Berlin by Hosfeld (1875), the Widener Memorial library at Harvard, the Toronto library and many university libraries. To the type of the British Museum, *etc.*, with a circular reading room surrounded by the book-stacks and lighted by high windows or skylights, belong the Columbia university library, New York (McKim, Mead and White, architects, 1897), the library of Strasbourg (Hartel and Neckelmann, architects, 1895) and the library of Congress, Washington, D. C. (Smithermeyer Pelz and Casey, architects, 1886-97). The original scheme for this last library had radiating book-stacks, like the Delessert scheme, but it was abandoned for a block entirely filling the light courts. The economy of space which this effects cannot be questioned, but opinions differ widely as to the advisability of packing

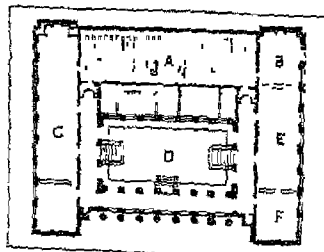


FIG. 2. — SECOND FLOOR PLAN OF THE INDIANAPOLIS CENTRAL LIBRARY

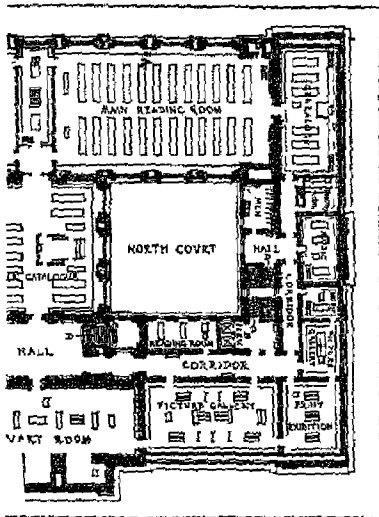
the book-stacks so closely without allowing other than artificial light. Local customs and special locations and purposes have necessarily effected many variations from these types of which the most characteristic is that of the American library. In the United States the number of people who borrow books for home reading exceeds the number of those who use the reading rooms in the library. This has given rise to a new service, the essential feature of which is the delivery room with its desk in direct communication with the stacks, and its catalogues and open shelves so arranged that the readers in the reading rooms need not be disturbed. A recent interpretation of this programme is the Central library of Indianapolis, Ind. (Paul Cret and Zantlinger, Boric and Medary, architects, 1914). Here the floor levels are regulated by the unit of height of the tiers in the book-stacks, which are placed at the rear of the building. Thus the delivery room which is in the centre of the composition, corresponds in height

cks. and is surrounded by shelves s can select their books, register desk for any book taken from the above, is occupied by the reading munication with the stacks, and by shelves and alcoves in which casual eryone, book borrower, or visiting sk The four tiers of stacks are id can be enlarged either vertically onomy of space and expense has on of the monumental stairs, which in two-storeyed libraries of this

larger libraries, the card-catalogue it as to require a special room In ublic library the catalogue room e readers must pass it on their way brary, the seven tiers of the book- ding room, in the centre of which with open shelves for home readers pecial reading rooms (periodicals, ibrary for the blind, etc.) and the the two front wings and their

dic library, i.e., with the delivery id the reading rooms secondary to es, such as those at Washington, by Albert R. Ross, and those at St. , both by Cass Gilbert ty library was evolved for Johns Md., by Parker, Thomas and Rice emphasis was laid on affording the enis working in classes in the build- access to the stacks For this pur- re placed in the centre of the block the seminar rooms, which are on The main reading room is at the

United States, a standard type has of smaller communities or for the g., branch libraries in Detroit and

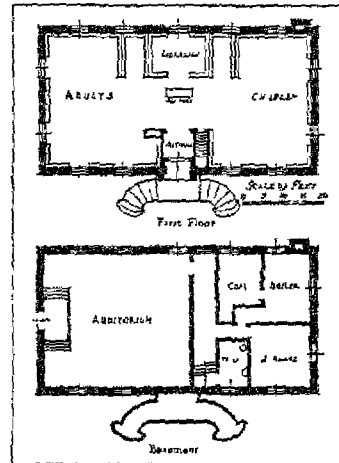


THE NEW YORK PUBLIC LIBRARY

oraries in England). Although the to admit some special requirement allery, it is generally that of a one ver a basement and standing free lighting from every side The en- directly to the delivery desk, while e devoted to the adult reading room room, separated, in the majority of , to afford general supervision by a lesk

EXTERIOR AND INTERIOR TREATMENT

In the large libraries, the exteriors of the buildings have been treated either in the modernized classic tradition or, as in some university libraries, in the general style of collegiate Gothic architecture adopted for the group. As remarkable studies for elevations may be mentioned the Ste Geneviève library, the library of the École de Medecine, by Guain both in Paris, the New York public library, the Boston public library and the Columbia university library, the last two by McKim Meade and White and the Detroit public library



FROM THE "ARCHITECTURAL FORUM" BASEMENT AND FIRST FLOOR PLAN OF SHARON (MASS.) LIBRARY

In the smaller libraries in the United States, there is a wider range in the styles of the façades, which are often inspired by the dominant note in the suburban architecture (e.g., colonial types or Spanish mission) In Europe, where the branch libraries are for the most part annexes to public buildings and schools, there has been less opportunity for the creation of distinctive types

The technical equipment of libraries has followed the general trend of the times in the progressive elimination of all woodwork in the shelving, unless kept for decorative reasons, in the effort to utilize a maximum of space for storing books, and in the simplification of service by book-lifts, conveyors, etc. The lighting, by day-time, is more satisfactory when obtained by windows on one or two sides of the reading room rather than by skylights, while the lighting of stacks in the majority of cases must depend largely on electricity. Obviously, provision should be made in library planning for future extension of stacks. The very large libraries in Europe are at present crowded by the huge collections they are obliged to maintain and are contemplating the necessity of dividing into separate departments, in separate buildings.

(P. P. CR.)

LIBRATION, a slow oscillation, as of a balance, in astronomy especially the seeming oscillation of the moon around her axis, by which portions of her surface near the edge of the disc are alternately brought into sight and swung out of sight.

LIBRETTO (It., dim of *libro*, a book) term for the text, or "book" of an opera

LIBYA, the Greek name for the northern part of Africa (*Λιβύη*). It is mentioned in Homer as a land of great fertility (*Odyssey*, iv 85). It did not include Egypt, which was considered part of Asia and first assigned to Africa by Ptolemy, who made the isthmus of Suez and the Red Sea the boundary between the two continents. The name Africa came into general use through the Romans. The old name was reintroduced by Diocletian, by whom Cyrenaiia was divided into Marmarica (*Libya inferior*) in the east and Cyrenaiia (*Libya superior*) in the west. A further distinction into *Libya interior* and *exterior* is also known. The former (*ἡ ἐντὸς*) included the interior (known and unknown) of the continent, as contrasted with the N. and N.E. portion; the latter *ἡ ἐξωθεν* was called simply *Libya*. See AFRICA, ROMAN

LICATA, seaport, Sicily, province of Girgenti, 24 m S E of Girgenti direct or 54 m by rail. Pop. (1921), 25,473. The river Salso, east of the town, is the ancient *Humera meridionalis*. On the promontory, which has the town at its foot, and is called the Poggio di Sant' Angelo, the Ecnomus of the Greeks, is the site of the town Phintias of Aeragas built after the Mamertines destroyed Gela (281 B.C.). It was off this promontory that the Romans defeated the Carthaginian fleet in the spring of 256 B.C., while in the plain to the north, Hamlicar defeated Agathocles in 310 B.C. The modern port refines and exports sulphur.

LICENCE, permission, leave, liberty, hence an abuse of liberty, in particular, a formal authority to do some lawful act. Such authority may be either verbal or written when written the

document containing the authority is called a 'licence'. Many of these licences in themselves are regulated by statutory authority, and licences may be obtained (See LIQUOR LAWS etc.)

LICENSED VICTUALLER. A licensed victualler "in the original English meaning of the term was the keeper of what the old licensing statutes called a 'victualling house'. As a descriptive term the name is one of considerable historical interest and importance. It bears clear witness to the intention and purpose of the State in the institution of the liquor licensing system, and also to the character of the social service which the licensee was expected and required to render to the community. He was not and was not intended to be a mere dram-seller, i.e., a retailer whose primary and practically exclusive business it was to supply alcoholic liquors to the public, but a *victualler*, i.e., a retailer of food and drink other than and in addition to the alcoholic beverages commonly consumed the sale of which by the licensed victualler was merely an ancillary part of his victualling trade.

The idea, like other institutional ideas, did not long endure in practice, although until the 17th century at least it continued to represent the intention and object of the State. Law and negligent administration and—much later—fiscal and legislative changes obscured the idea until it ceased to govern or even to influence the trading methods of the licensee. The "licensed victualler" became a profession whose primary and practically sole business was and is the retailing of alcoholic beverages. The name has lost its ancient and specific meaning. In modern (and accepted trade) usage it applies only to the holder of an ordinary "full" (publican's) licence and is so restricted in the rules of the Incorporated Society of Licensed Victuallers, the oldest and most prosperous of "trade" benevolent societies.

Changes in the connotation of names and terms are not uncommon in the history of social institutions but such changes are usually changes of expansion, involving an enlargement and improvement of the scope of the service rendered. In the case of the public-house (the licensed 'victualling house') the change has been of a different kind. It has not been, in the strict sense, an evolutionary change, but a departure from a governing idea which was the *raison d'être* of the institution itself, and it has involved not an enlargement, but an unhappy restriction, of the social service which the institution was intended to render. In the process of the change the "victualling house" became against law and State intention a 'drinking house.' That the State subsequently but not until the beginning of the 18th century, accepted and accelerated the change by legalizing the worst form of dram-shop is true, but the "victualling house" by that time had disappeared, and the name alone survived in the statute-book. It is only in recent years that the name itself has fallen into legal (legislative) disuse.

Why "Victualling" Disappeared.—This was not, as is sometimes assumed, due to changes in social and economic conditions. These emerged as co-operating causative factors at a much later stage in British social history. It was due primarily to the play and pressure of commercial motives and was made possible by the default of the controlling authority. The incentives were plain. The victualling trade was, in the nature of things, a limited trade with natural bounds set to its expansion. It ministered to a limited demand. Profits were relatively small and not easily earned. The sale of liquor on the other hand, was a simple trade; the expenses were small, the profits ample and quickly earned and the demand was one which was easily fostered and dependable. The liquor business drew a larger, surer, more profitable patronage than a strictly victualling business. Given facilities, it provided a livelihood for a much greater number of sellers.

Even so, the incentives powerful as they were, could not, unless tolerated and encouraged, have prevailed over the intention of the law. They found their opportunity in lax administration of the law. Licences were granted by justices in many districts with a careless and often a shameless disregard of local needs which drew upon them repeated admonitions from the Privy Council and from judges of assize and required frequent resort to summary measures of licence suppression. These suppressions were

sporadic and intermittent and they had no appreciable effect in re-establishing the public-house as a "victualling house." The intention of the law, nevertheless, remained clear and it was the reassertion of this intention in the notorious Tippling Acts of James I (1602-4 and 1623-24) and Charles I (1625) that gives these futile acts their historical significance. The object of this special legislation was made plain in the preamble to the first of the Tippling Acts. It was to restore the "ancient, true and principal use of mns, ale-houses, and victualling houses" as places for the receipt relief and lodging of waytaring people travelling from place to place, and for such supply of the wants of such people as are not able by greater quantities to make their provision of victuals and not meant for entertaining and harbouring of lewd and idle people to spend and consume their money and time in lewd and idle manner."

The Tippling Acts notoriously failed. Prolonged inefficiency in regulative control and widespread maladministration of the licensing statutes had gone too far to make a summary cure possible, but the clearly avowed object of the Tippling Acts is of great historical importance in a survey of the original purpose and intention of the English licensing system. The ultimate responsibility for the final departure from the original idea of a victualling house rests, however, with the State, which, by its unhappy fiscal and legislative policy at the end of the seventeenth and in the early decades of the eighteenth century, took the first of two steps, each of which had demoralizing social effects, which finally sealed and disastrously aggravated a departure in aim and policy which heretofore had casually developed from administrative negligence.

The Gin Shops.—The economic and fiscal policy of William and Mary at the end of the 17th century, continued as it was by Anne in 1704, brought in its train a flood of gin shops which established in England a new and immeasurably worse type of "tippling" house whose increase and activities put a vicious stamp upon the character of the English public-house which it has never wholly lost. In the Gin Acts, the old idea and ideal of the "victualling house" was not merely ignored but destroyed. The evil wrought by these acts was further aggravated, a century later, by the Act of 1830, which established the beer-houses—a new form of drinking saloon—which, although subsequently restricted, but endowed with a vested interest, still exist in large numbers.

It is to these departures from the original aim and purpose of the English licensing system that we owe the difficulties and complexities of the public-house problem as it exists in England to-day. It is these departures, due partly to negligence and partly to lamentable mistakes in fiscal and legislative policy, that have saddled Great Britain with a "drink problem." Their effects are manifest. They have created a problem of redundancy which is not disputed but which is buttressed and beset by legal interests which make an equitable adjustment of facilities for sale to public need and demand difficult and slow. A return to the idea of the "victualling house," which, if preserved, would automatically have determined and controlled the supply of facilities, is not easy. Modification of the original requirement and long permitted departure from the "victualling house" idea have stimulated and fostered a habit of dram and "bar" drinking which cannot be summarily suppressed. Sweden is the one country in Europe which has slowly but progressively retraced its steps and, by eliminating private profit interests in the sale of spirits (the national beverage), has been able to substitute the "victualling house" for the dram-shop by compulsorily coupling the "on" sale of spirituous liquors with the sale of food.

The British Parliament in 1910 made it a ground of refusal of the renewal of an "old on-licence" (other than an ante-1869 beer-house licence) that the holder of the licence has persistently and unreasonably refused to supply suitable refreshment (other than intoxicating liquor), at a reasonable price. The Act of 1921 went a step further. By abolishing the old-time "closing-hour," but limiting the sale of intoxicants to what are called "permitted hours," it leaves the publican free to keep his premises open for the sale of food and non-intoxicants at any hour of the day or night. The privilege has not so far (1928) been used. (A. S. H.)

LICHENS are with few exceptions land plants of simple structure. They grow almost everywhere spreading over soil, rocks, the trunks, branches and leaves of trees, etc., as flat crusts, leaf, expansions, shrub-like tufts or pendulous filaments in various colour shades of white, grey, yellow, brown or almost black. The term lichen, a word of Greek origin, was first definitely given to lichens as we know them by Tournefort (1700).

Lichens are of unusual interest in that the vegetative body or thallus is a composite plant formed by the interdependent growth of unicellular or filamentous green or blue-green algae Myxophyceae or Chlorophyceae (fig. 1), with the filaments (hyphae) of one of the higher fungi—Ascomycetes or, in one or two genera only, Basidiomycetes. On this basis of combination or symbiosis there has been evolved a great series of distinctive plants, capable of vigorous life and of reproduction from generation to generation. Phycolichens signify those that contain blue-green, Archilichens those with bright-green algae designated as lichen gonidia. The fungus is the dominant partner as it provides the fruiting bodies.

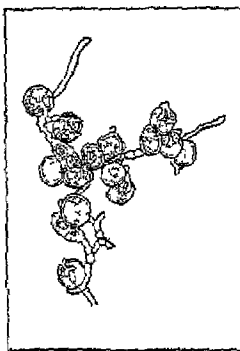


FIG. 1.—LICHEN HYPHAE AND GONIDIA, ASSOCIATION OF LICHEN HYPHAE AND GONIDIA X 250 (AFTER BONNIER)

Lichen Gonidia.—For long it was accepted that the green bodies in the lichen plant were cells budded off from the colourless hyphae that gradually acquired a green colour. It was known that minute portions of a lichen plant—the soredia—each composed of a few green cells with entangled colourless filaments were agents of propagation. Wallroth (1835), for that reason, coined for the green cells the term *gonidia* to signify their reproductive function (fig. 2). In most lichens there is a gonidial zone near the surface and to that he gave the name *stratum gonimion*. In a lesser number the gonidia are distributed through the thallus (fig. 3). These two types he distinguished as *heteromerous* with distinctive layers, and *homomerous* where there is no such diversity.

The belief in the genetic origin of the green cells within the thallus held sway for many years, though observations of a disturbing character were not lacking. Agardh (1821) had suggested that they were transformed algae as he had followed the development of the blue-green alga, *Nostoc*, to the complete thallus of the lichen, *Collema*. The view gradually gained ground that the bright-green gonidia of many lichens were comparable to the alga *Protococcus*. The explanation given was that these free growing algae were lichen gonidia escaped from the thallus that had continued independent growth.

Wallroth spoke of them as 'unfortunate brood cells' that could not again form a lichen plant. Finally in 1867 Schwendener published his bold theory that lichen gonidia were true algae imprisoned and parasitized by fungal hyphae. The statement was welcomed by many as enlightening and convincing. Others, among whom were the renowned Finnish lichenologist, W. Nylander and the British J. M. Crambie, scornfully rejected the new view. The theory was, however, successfully tested by cultures of lichen spores with free-growing algae—first by Rees (1871), then by Bornet (1872) and others who followed the development from spore to fruiting stage, a slow growth of several years' duration.

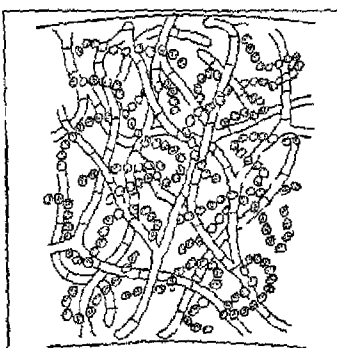


FIG. 2.—THALLUS WITH GONIDIAL ZONE, SECTION OF HETEROMEROUS THALLUS X 500 (AFTER SCHWENDENER)

Symbiosis.—The relation between the two organisms was regarded at first as a parasitism of the fungus on the alga, or as *helotism*. Reinke (1873) pointed out the insufficiency of a condition of parasitism to explain the healthy lichen, and he therefore proposed the term *consortium* as a truer conception. A few years later de Bary (1873) suggested *symbiosis* as an adequate

term and it is now generally accepted as a *mutual symbiosis*. This view has been confirmed by culture experiments. In general the alga supplies carbohydrates by photosynthesis, the fungus provides salts and water storage. Symbiosis in lichens is a fairly stable life-balance which may tip, however, to the detriment of one or other of the organisms: there are instances, perhaps more frequent than we have supposed, of gonidia perishing in the grip of the fungi, but there are also cases where owing to some unfavourable condition, the fungus has succumbed while the algae increased enormously. There is no doubt as to the normal healthy condition of the thallus and of both symbionts. The interest in lichen gonidia has of late centred in the globose bright-green alga for many years considered to be a species of *Protococcus*, but that alga multiplies by cell division and is now recognized as the gonidium of only a few lichens. The ordinary lichen gonidium was found by Paulson and Somerville Hastings (1920) to have a massive parietal chromatophore, and to multiply freely and abundantly in the thallus by the free cell formation of aplanospores. The season of greatest increase was from February to April, or after heavy rain following a season of drought, zoospores were not seen in the gonidial state. The sporulating gonidia were most abundant in the actively growing regions. More recently Puymaly (1924) has proposed a new genus *Trebouzia*, for the alga without and within the lichen thallus. He describes it, however, as possessing a massive stellate chromatophore. In view of Paulson's observations again renewed, it is impossible to regard the gonidium chromatophore as of stellate form.

Lichen Algae.—The algal constituents of the thallus belong to two classes: I Myxophyceae (blue-green algae) and II Chlorophyceae (bright-green algae). They are, in general, aerial forms and in a free condition inhabit moist shady situations. Though

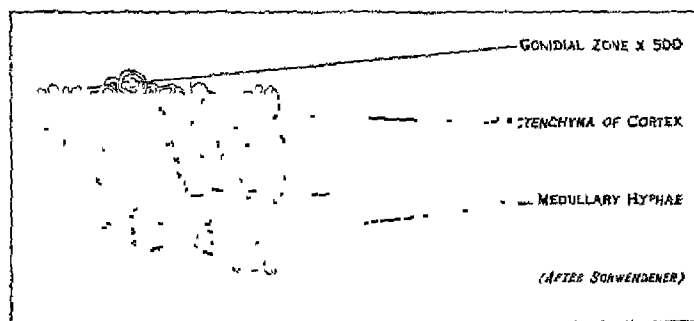


FIG. 3.—THALLUS WITH DISPERSED GONIDIA, SECTION OF HOMOMEROUS THALLUS X 250. (AFTER B. M. HANDBOOK OF BRITISH LICHENS)

the determination of algal species is somewhat uncertain, the genus can be more easily recognized.

I. Myxophyceae associated with Phycolichens in Collemaeae and other families. The algae of most frequent occurrence are *Gloeocapsa*, *Nostoc*, *Scytonema* and *Stigonema*.

II. Chlorophyceae associated with Archilichens. Those of most importance are the globose algae belonging to the Protococcaceae and *Trentepohlia*, a filamentous alga.

The alga may become modified in the gonidial state. *Gloeocapsa* loses colour, *Nostoc* chains, and *Trentepohlia* filaments may be broken up into cell units.

Lichen Hyphae.—These undergo considerable modification as lichen symbionts. The fruiting form indicates their origin as ascomycetous or basidiomycetous, and their affinity can be traced to ancestral groups of fungi. Bonnier (1889) in describing their development from the spores in synthetic cultures noted three distinct types—(1) clasping filaments with repeated branching which surround and secure the alga, (2) filaments with short swollen cells destined to form several lichen tissues and (3) towards the periphery, searching filaments that form the hypothallus and annex new algae. In five days after germination the clasping hyphae had laid hold of the alga and symbiotic growth had begun. In the growing regions the hyphae remain comparatively thin-walled. In other parts—especially in the cortex, etc.—the walls frequently become thick and gelatinized. In lichens as in fungi there is no true cell structure or parenchyma, but in the cortices of many lichens a pseudo-parenchyma or plectench

ugh on the surface owing to small noticeable are they that Acharius to include isidiose lichens. They in generally as a small swelling or ions of the tissues and the cortex is sometimes they are darker in colour *Evernia furfuracea*.

iens.—There are three genera recal lichens. *Cora*, *Corella* and *Dic-tyonema*. The gonidia, *Chroococcus* or *Scytonema* are Myxophyceae *Cora* and *Dictonema* are of a thin bracket-like form, they grow on the trunks and branches of trees, very rarely on the ground, and are attached by rhizinae. No proper cortex is formed, but in *Cora* the hyphae take an upward direction towards the surface where they become horizontal, so that a compact protective tissue lies over the top, the gonidia (*Chroococcus*) from and hyphae. In *Corella* and *Dic-tyones* retain their form and are sur-

the fungal family *Thelephoraceae* spores borne on the under-surface

PRODUCTION

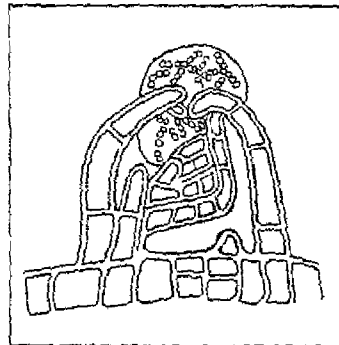
is (Basidiolichens and primitive lichens. their method of reproduction mycetes, *ie*, by the production of iscophores—apothecia or perithecia plants these fruit bodies have been tive tissues that secure prolonged n this respect from the fugitive

ese are of several forms to which n —ardellae, the irregular spor-like e, elongate, slit-like, dark-coloured he larger majority of lichens open rrounded by a protective thalloid (fig 10), such as occur in the genus solely of hyphal tissue surrounded n" only as in *Lecidea* are described margin is obscure with the disk often torne, as in the sub-genus, *Biatora*

These are true distinctions, and are of value in the determination of genera and species. The difference is due to their origin in the thallus in the lecanorine series gonidia are carried up with the developing fruit, and algal cells extend along the base and, entering into the "thalline margin," surround the apothecium. The lecidine tissues, solely hyphal pass up through the gonidial zone, N pierce the cortex and expand above it, the outer sterile hyphae per margin." Minor differences in /pes of apothecia—sessile or stalked, te body to one of over three centi- to the genus or species of lichen used of a compact series of filament- ed paraphyses and of asci—club-like spores (fewer or more numerous) formation. These, constituting the a layer of tissue, the hypothecium, projecting above the asci form the

epithecium generally coloured the surrounding sterile filaments represent the parathecium; the thalline margin when present forms the amphithecium

Perithecia—These differ from the apothecia in being comparatively small globose or pear-shaped, closed bodies immersed or semi-immersed in the thallus and opening above by a pore, the ostiole. When the outer dark wall is continuous it is described

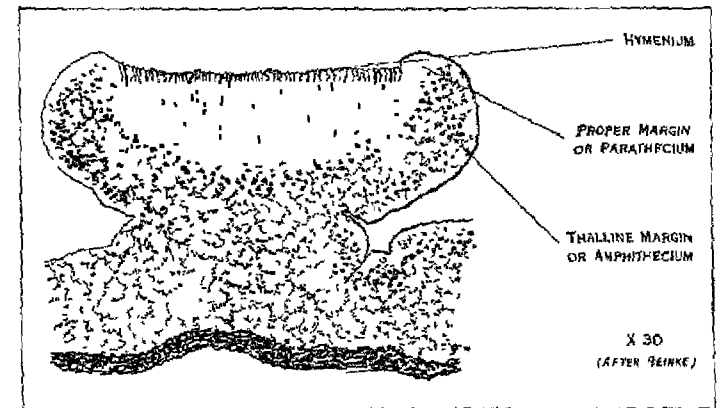


FROM J. BABIKOFF, "DU DEVELOPPEMENT DES CEPHALODIES SUR LE THALLUS DU LICHEN PELTIGERA APHTOSA" BOFFIN BULLETIN (ACADEMY OF SCIENCE, U.S.S.R.)
FIG 9.—CEPHALODIUM OF PELTIGERA APHTOSA EARLY STAGE MUCH MAGNIFIED

as entire, and when absent at the base as dimidiate. In some genera the paraphyses dissolve as the asci mature. Apothecia and perithecia are long lived like the thallus and may produce spores continuously or at definite seasons for several years, in *Solorina saccata*, for instance over a period of two to four years, as observed by Hiltner (1926)

Spermogonia or Pycnidia.—These are small closed bodies outwardly resembling perithecia; the hyphae that line the interior walls bud off minute pycnidiospores. As spermogonia they were considered of great importance as the male organs that produce the spermatia. There is no reliable evidence of their sexual nature and they are now generally classified as pycnidia resembling similar bodies that form a secondary stage in the fruit cycle of the Ascomycetes. It has been proved that the spermatia germinate and produce hyphae a characteristic of spores

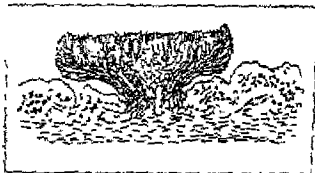
Cytology.—This aspect of reproduction has excited great interest since Puusting (1866) observed in a crustaceous *Lecidea* the fruit primordium or ascogonium as a coiled hypha. Stahl (1877) announced the further discovery in a *Collema* of a trichogyne, a filament that travelled upwards from the ascogonium and emerged above the surface. He noted also an empty spermatium (pycnidiospore) adhering to the tip of the trichogyne after presumed fertilization. Other workers made similar observations both in gelatinous and in non-gelatinous lichens, and in open and closed fruits. Copulation with the spermatium has also been demonstrated but the behaviour of the spermatial nucleus has escaped observation. The ascogonium may be a coiled hypha or simply a complex of cells distinguished by their richer



BY COURTESY OF MESSRS BORNTRAGER
FIG 10.—SECTION OF LECANORINE APOTHECIUM, (*LECANORA SUBFUSCA*)

contents and changes in these cells have been observed that seem to imply spermatial fertilization. It may be that in some lichens fusion takes place between neighbouring cells in the ascogonium. F. Bachmann (1912) found that copulation took place deep down in the thallus of *Collema* sp. between an internal trichogyne and a free spermatial cell. Apogamy, however, undoubtedly prevails in many lichens, either no trichogynes are formed or they fail to reach the surface and fertilization by spermatia is doubtful. Zahlbruckner (1924) has expressed the opinion that reproductio

... The ... in these slow growing ... with the perithecia of interpretation, the function of the ... a multispore hypha of vigorous growth is not understood, but it may be of some service to the ... From the ascogonium arise the hyphae ... to form the asc. As in fungi the nuclei of two ... at the tips of these ... and become the ... nuclei of the ascus. These are normally eight spores, ... different ... from one ... to the large ... They are ... and simple ... separate or mariform, ... in size from a few ... etc., to the large one-septate spore in *Verrucaria* (350 x 115 μ) Large simple spores as in *Peltigera*, are multinucleate. Spore ejection is brought about by pressure of the paraphyses when moistened.



PROF. A. L. SMITH, LICHENS UNIVERSITY PRESS, CAMBRIDGE.
FIG. 11.—SECTION OF LECIDEINE APOTHECIUM (LECIDEA PARASEMA) (AFTER B. M. HANDBOOK OF BRITISH LICHENS)

PHYSIOLOGY AND BIONOMICS

Cells and Cell-contents.—In the study of lichen physiology attention must be given to the activities of the symbionts as well as to those of the symbiotic plant. Conidia do not greatly differ from the allied algae growing in the open; they possess chloroplasts and form starch by photosynthesis. Mameñ (1920) and Tobler (1921) demonstrated minute granules of starch on the inside of the gonidia—a ready food for the fungus. The hyphal cells have been more affected by symbiosis and a much slower growth than in fungi has become a fixed character as proved by axenic cultures. The cell-walls as in fungal tissues are formed of semi-celluloses *chitin* being present in nearly all lichens. There is no true cellulose, but a substance, lichenin (C₂₄H₄₀O₈), allied to starch has been demonstrated as well as a slightly different substance isulichenin, the latter proved by Ziegenspeck (1914) to be a reserve material. Amyloa hyphae giving a blue reaction with iodine are present in the medulla of several species. Swollen cells filled with oil, probably an excretory substance occur in many lichens especially in limestone species. Oxalic acid is also frequently found in lichen tissues in the form of crystals, small granules or in large clear masses as in *Peltigera communis*.

Lichen Acids.—These are the most interesting and characteristic of lichen products. They are deposited on the outside of the hyphal cells as minute coloured specks or as colourless substances and show a wide range of chemical formulae and a great variety of crystalline form. They are the product of the symbiotic plant as was proved by Tobler (1909) in his cultures of lichen tissues. Many of them are bright yellow, orange or red, and give the clear pure tone of colour to many familiar lichens. They are strongly influenced by light. *Xanthoria parietina*, a brilliant yellow plant on full exposure becomes grey green in the shade with a small acid content. Some of these acids are rare, others are widely distributed e.g.—usnic acid, found in some 70 widely diverse species, atrarorin, first discovered in *Lecanora atra* in about 70 species, salutaric acid is equally common. They are abundant chiefly on well-ventilated portions of the thallus—the sororial hyphae, the outer cortex, the loose medullary tissue, and on the disc of the apothecia.

Chemical Grouping. The acids have been arranged by Zopf (1907) in 1. the fat series and 2. the benzole series.

1. The fat series. Zopf includes five groups in this series; three of the series are colourless substances; the coloured include vulpinic acid from the yellow lichen, *Leickria vulpina*, stictaurin derived in orange-red crystals on the hyphae of *Sticta aurata*, and rhizocarpic acid obtained from the yellow lichen *Rhizocarpon* *graphocarpum*.

2. The benzole series with two subseries—orceine and anthra-

... The colourless orceine contains the colouring principle of commercial orchil. In the anthracene derivatives some of the acids are also coloured, such as parietin from *Xanthoria parietina* and solormic acid from *Solorina crocea*.

The question has been debated as to the service rendered by the acids: to some extent they protect the plants from wholesale destruction by snails, insects, etc., as they render the thallus more or less unpalatable. Goebel (1927) has demonstrated that they are also a protection against water-logging. He found that our growths of hyphal hairs, cilia, etc., formed efficient water conductors, but if acids were abundant they remained dry when the acids were removed by chemical means saturation was easily achieved. As acids are present on all aerated portions, they must be a powerful aid in keeping the air-channels open and thus serve a useful purpose.

General Nutrition.—Water is supplied by rain mist or dew, mist being the most favourable for lichen requirements (Stocker 1927). Dew is important in extremely dry localities such as deserts. Inorganic substances are obtained to some extent from the substratum but mainly from air borne particles. Organic food is provided by the algae or may be procured by the hyphae from humus, etc.

Lichens show marvellous resistance as regards heat or cold. They survive the high temperatures of direct illumination and they endure seasons of extreme cold on mountains or in the polar zone. It is to their power of drying up to a condition of latent vitality that they owe this resistance. Light that can penetrate the thickened cortex and reach the gonidial zone is essential, but the same dense cortex protects the gonidia from too intense sunlight as do the acids and pigments. Light is of first importance in fruit formation and the fruit bodies are therefore situated on well lighted portions of the thallus.

Colour of Lichens.—Soft grey colours predominate, the thick cortex and the underlying gonidia combining to produce this effect, when wetted the cortex becomes transparent and the green colour is more evident. Acids and pigments, the latter usually some shade of brown, give various colours from yellow to brown or almost black. Strong sunlight induces the formation of both acids and pigments, and intensifies colour as seen in exposed situations. Blue, violet or red colours occur more rarely and generally in connection with the fruiting bodies. Some lichens become rust-coloured by infiltration from an iron soil. It is only when we compare untouched nature with the ugly gash of recent quarrying that we realize the beauty given to the rocks by the variety of lichen colouring.

Bionomics.—The response of lichens to their environment is intimately associated with their physiological properties. Their scanty subsistence entails slow development though a few may be ranked as relatively quick growers—mostly soil lichens in touch with moisture. Such are *Peltigera canina* that spreads over damp lawns, etc., and crustaceous forms such as *Baromyces* spp. *Lecanora tartarea*, and *Lecidea uliginosa*; the latter has been known to spread over an area several feet in diameter in one season, and has been reported as a pioneer plant forming a dark film over sand dunes in Alberta. But in many lichens growth is often almost stationary. The large foliose *Lobaria pulmonaria* and the crustaceous *Rhizocarpon geographicum* have been observed to make practically no advance during a period up to 50 years. Accurate measurements of more active *Parmelias*, etc., have given a general increase of 1 cm per annum, their fruiting bodies require in general four to eight years to develop.

Lichens do not grow on friable rocks or on peeling bark. They require, for the first stages at least a substratum to which they can be firmly attached by filaments or by rhizinae. In fruticose branching and straggling forms compactness is often secured by *haptera*, which form a bridging connection between the fronds of the same lichen or to other vegetation, as for instance, *Cladonia sylvatica* which becomes detached from the soil and adheres to the growing heather, thus securing not only attachment but light and air. Some few species become loose and continue growth while they drift about as erratic lichens. Several *Parmelias* *Alectoria* and *Lecanora esculenta* etc. are erratic forms.

PHYLOGENY AND CLASSIFICATION

Phylogeny.—It would be interesting to know when the symbiotic plant originated and whether the first association of the fungus was with Myxophyceae or Chlorophyceae, but lichens, owing to the gelatinous nature of the thallus, become soft in water and there is little or no evidence in the rocks as to their antiquity there is only a doubtful record of an *Opegrapha* in Mesozoic chalk. It is concluded from their elaborate morphology and physiology that they are very old plants, but the symbiotic organism—the lichen—is obviously of more recent descent than its component ancestors. Both symbionts are polyphyletic in origin: the algae are blue-green or bright green, the hyphae belong to various phyla of the fungi from which they are late derivatives. Basidiolichens are related to one fungus family, Telephoraceae, Ascolichens to Ascomycetes and to several distinct phyla within that class. There is no haphazard agglomeration of forms in the lichen group, but a closely related and easily recognized series of plant phyla. The ascophore, which marks the phylum, has undergone considerable alteration which is recognized in classification. Phylogenetic development has, however, mainly taken place in the thallus which presumably began as a loose association of straggling hyphae with algal cells. It progressed to the definite crustaceous structure, and finally to the foliose and fruticose lichen. The greatest advance must have occurred when the thalline particle took an upward direction—a small outgrowth that was to develop into numerous forms.

The intimate relation between lichens and fungi is evident in the species that have remained on the border line. Some with scanty thallus appear to lose the algal symbiont as the ascophore matures, and the hyphae apparently revert to saprophytism as exemplified, for instance, in *Calocium*, a lichen genus, with *Mycocalcium*, the fungal counterpart. Others classified now as lichens and now as fungi live on an alien lichen thallus though not always as simple parasites, in a number of cases their hyphae penetrate the thallus and draw sustenance by symbiosis with the algal cells: these have been designated half-parasites. Lichen thalli are, however, a favourite host for many micro-fungi.

The main divisions of Ascolichens are traced to their fungal ancestors by the form of the ascophore:—

- | | | |
|---------------|-------------------|--------------------|
| Lichen Series | I Pyrenocarpineae | } to Pyrenomycetes |
| | II Coniocarpineae | |
| | III Graphidineae | to Hysteriaceae |
| | IV Cyclocarpineae | to Discomycetes |

Within these series is represented a number of phyla with an orderly progression of thalline structure. Both types of gonidia are sometimes represented in the same phylum and even in the same family e.g., Stictaceae.

The leading phyla of the different series are —

I PYRENOCARPINEAE. In this are included phyla of Phycolichens and Archilichens. In the former crustaceous only, in the latter advancing from the crustaceous Verrucariaceae to the squamose or lobed Dermatocarpaceae—a large and varied series.

II CONIOCARPINEAE. An isolated group characterized by the *masaedum* type of ascophore—half closed and filled with loose spores at maturity—mostly crustaceous with a few rare squamulose genera, and a world-wide fruticose genus, *Sphaerophorus*.

III GRAPHIDINEAE. A large series with *Trentepohlia* as gonidium. The progression is from crustaceous forms to the fruticose *Rocellae*.

IV CYCLOCARPINEAE. With phyla both of Phycolichens and Archilichens. There is a somewhat limited type of thallus in the Phycolichens, the foliose structure is not however uncommon and reaches high development in *Sticta* and in *Peltigera*, fruticose structure is rare.

In the Archilichens there are three great phyla —

I LECIDEALES. These are distinguished by the discoid fruit with proper margin only, and include many crustaceous genera, foliose Gyrophoraceae and the almost fruticose Cladoniaeae.

II LECANORALES. Fruit with a thalline margin, the most numerous and most highly developed phylum, from the lowest to the highest development not only in form and size but in the

special thalline structure (See section Morphology, p 30)

III POLARILOCULARES. A phylum including all types of structure but with a distinctive and characteristic spore—ellipsoid and mostly one-septate, with the median septum becoming so thick that the spore loculi are often relegated to minute spaces at the tips, hence the name *polarilocular*. A delicate canal passes through the thickened septum and forms a connection between the polar cells.

Classification.—Basidiolichens are few in number and now present no problems. It is mainly with Ascolichens that workers have been concerned. Before the true nature of lichen plants was understood, many attempts had been made to classify them in relation to each other and to other members of the plant kingdom—to mosses, hepatics or algae. Tournefort (1700) placed them all in one genus *Lichen*, and was followed by Linnaeus (1753). Knowledge of their number and variety increased and Acharius (1803) gave diagnoses of 23 genera with their included species. Nylander (1854) issued what he considered a final statement on lichen families and genera and of their relationships. His arrangement began with those nearest akin to algae, gelatinous blue-green forms, and wound up with those he considered to be most like fungi—the Pyrenocarpineae. Later students have worked on this basis and now a system of classification has been achieved that largely satisfies modern views. The arrangement of lichens in a natural order has presented great difficulties: it is by following the lines of development as outlined above that a way through the maze of forms—like and unlike—has been reached. The four series of Ascolichens, for instance, are marked by fruiting characters. These are subdivided into families (58 in number) largely on the structure of the thallus. The genera in these families are distinguished by minor differences of thalline though mainly of fruiting characters.

DISTRIBUTION AND ECOLOGY

Distribution.—Lichens are widely distributed: members of nearly all the different families are to be found in every quarter of the globe. Winds or other agencies carry the spores of thalline particles immense distances, and these grow to full stature when they alight on a favourable substratum. It is impossible at the present stage of faulty co-ordination of knowledge to reckon their numbers, but many thousands have been recorded, and new families, genera and species are constantly being discovered. Some lichens flourish best in temperate zones, others in tropical regions, a few are restricted to polar areas, the same species appearing both in the Arctic and Antarctic. They grow best where they can secure light: they are abundant on the tundra or on rocks and walls with a sunny exposure, but a few are shade-plants and grow even in caves. Some can withstand the heat and scanty rainfall of the desert and others advance to the limits of perpetual snow. A fairly large number are cosmopolitan, a lesser number are endemic in larger or smaller areas.

Ecology.—Though self-supporting, lichens exhibit a considerable choice of habitat and form more or less constant associations of lichens only or with other plants. They are the pioneers of vegetation and soil-formation. By their delicate filaments they cling to the rock surfaces which they gradually penetrate and disintegrate. By mechanical action due to alternate wetting and drying of the gelatinous hyphae a sucker-like detachment of minute rock particles is constantly taking place (Fry 1924, 1926), by chemical action the acids discharged by the hyphae (carbonic, oxalic or lichen acids) dissolve the hardest rocks and even old window glass. The detached particles and the humus of cast-off portions of the thallus, together with blown dust, form a nidus for other vegetation—mosses and flowering plants—and mixed associations arise. The chief ecological factors are the types of substratum: the associations or communities are therefore naturally divided into.—1, arboreal and lignicolous, 2, terricolous, 3, saxicolous and 4, localised communities such as maritime lichens. Within these great groups there are minor associations influenced by the kind of bark, the nature of the soil (sand, clay or humus), the character of the rock (siliceous or calcareous) and also by conditions of temperature, moisture and A very dis

Their association is that of microphilous lichens. It constantly occurs on any kind of habitat in places frequented by birds and small mammals and near to farm-yards or on road-sides where the turf is crusted with nitrogenous animal matter. As in other such communities there is a struggle for place and light. Crustaceous species are in the end ousted by those of thicker or a more elastic thallus or by the larger foliose species. Some mushrooms may in some circumstances them all and colonization begins afresh. Leaf lichens so abundant in the tropics also form distinctive associations. Lichens are rare or absent in the neighbourhood of large towns or industrial areas owing to the impure and over-heated atmosphere.

ECONOMIC AND TECHNICAL

Lichens occupy a not unimportant place in the economic field. Insects and other small insects, caterpillars and slugs feed on them especially when they are moist and the acids not too pronounced. Pouch has stated that they are the staple food of the wild animals in Ceylon. Abbe Hue considered that the abundance and perfect development of lichens in the Antarctic was due to the absence of insect life. In northern latitudes several kinds for example *Cleoma alpestris* are of great service as food under or domestic animals. *Cleoma rangiferina*, the reindeer moss, is the special food of the reindeer. In times of scarcity it has been found advantageous to grind up lichen thallus after elimination of acids and to mix the powder with meal for human consumption. *Leccinum scaberrimum* a rock lichen and often erratic is abundant in eastern deserts and has been similarly used. It has been considered that that lichen was the manna of the Israelites. Species of *Umbilicaria* and *Gyrophora* called *tripe de roche* have been used by Arctic explorers to stave the pangs of hunger. *Gyrophora escaensis* an eastern maritime rock lichen is greatly esteemed as an edible plant both in Japan and in China.

Their value in medicine rested in the past on a somewhat fanciful basis—that of the doctrine of signatures—certain characteristics of form by their resemblance to organs of the body, were considered to indicate curative properties. Some very bitter species such as *Pertusaria ruficarpa* served as a substitute for quinine. *Cetraria islandica*, the "Iceland Moss," owing partly to its gelatinous consistency has been used with good effect in chest troubles, and is now the only lichen recognized in the British Pharmacopœia.

Their use as dye-plants has been known from the earliest times, and before the discovery of aniline dyes the rich and varied colours obtained from lichens were highly valued. The colouring principle of the dyes is contained in the peculiar lichen-acids. Treatment with an alkali is generally necessary to extract the colour, mordants are frequently used. With some lichens boiling the plants with the material to be dyed is sufficient to secure the desired colour. The dyes can be used only on animal fibres such as wool and silk, they have no effect on linen or cotton. Purple lichen dyes—orchil, kermes or cudbear—are obtained from *Roccella tinctoria*, a maritime lichen, *Leccanora tartarea* and a few others. Other serviceable colours are the varied yellows and browns so much used in home or village industries. But abundant though dye lichens are, they can only furnish a limited quantity and could never meet any large demand.

LITERATURE—Lichens are discussed in general text-books, especially in those devoted to cryptogamic botany. Only the publications concerned exclusively with lichenology are cited here. In most of these will be found lists of books and papers that deal with various aspects of the subject as outlined above.

General—M. Faustsch, *Lichenes, d. Allgemeiner Teil*, in Engler and Prantl's *Die Natürlichen Pflanzenfamilien VIII* (Leipzig, 1906), Albert Schneider *Text-book of Lichenology* (Binghampton, N.Y., 1907); A. Lorrain Smith, *Lichens* (Cambridge Botanical Handbooks, 1910); F. Tobler, *Biologie der Flechten* (Berlin, 1925), W. Rehm, *Die Flechten Stoffe* (Jena, 1907).

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Complete Floras—Bruce Park, *The Lichens of Minnesota* (Washington, 1910), A. Jatta, *Flora Rubica Botanica, Pars III, Lichenes* (1909-11), H. Olivier *Exp. Syst. Descr. Lich. de l'Ouest et N. Ouest*

de France, 2 fasc. (Paris, 1897-1903), A. Lorrain Smith *Monogr. Brit. Lichens* (London, 1918-26), P. Sivadov, *Flechten Deutschlands* (Berlin, 1887); A. Zahlbruckner *Lichenes. B. Spezialteil* (A. L. S.M.)

LICHFIELD, a city, county of a city, and municipal borough in Staffordshire, England, 118 m NW from London Pop. (1921) 8,393. The town is situated on a stream draining eastward to the Trent, with low hills to the east and south.

There is a tradition that "Christianfield" near Lichfield was the site of the martyrdom of 1,000 Christians during the persecutions of Maximian about 286. At Wall 3 m distant, there was a Romano-British village of Letocetum ("grey wood"), from which the first half of the name Lichfield is derived. The first authentic notice of Lichfield occurs in Bede's history, where it is mentioned as the place where St. Chad fixed the episcopal see of the Mercians. After the foundation of the see by St. Chad in 669, it was raised in 786 by Pope Adrian to an archbishopric, but in 803 the primacy was restored to Canterbury. In 1075 the see of Lichfield was removed to Chester, and thence a few years later to Coventry, but it was restored in 1148. At the time of the Domesday Survey Lichfield was held by the bishop of Chester. The lordship and manor of the town were held by the bishop until the reign of Edward VI., when they were leased to the corporation. Richard II gave a charter (1387) for the foundation of the guild of St. Mary and St. John the Baptist, this guild obtained the whole local government, which it exercised until its dissolution by Edward VI., who incorporated the town (1548). The only existing fair is a small pleasure fair of ancient origin held on Ash-Wednesday, the annual fête on Whit-Monday claims to date from the time of Alfred. In the Civil Wars Lichfield was divided. The cathedral authorities were for the king, but the townsfolk sided with the parliament, and this led to the fortification of the close in 1643. The close yielded to the parliament and was retaken by Prince Rupert, but on the breakdown of the king's cause in 1646 it again surrendered.

The cathedral is small, and stands near the Munster Pool. The present building dates from the 13th and early 14th centuries. The fine exterior of the cathedral has a lofty central and two lesser western spires, of which the central, 252 ft high, is a restoration attributed to Sir Christopher Wren after its destruction during the Civil Wars. The west front is composed of three stages of ornate arcading. Within, the south transept shows simple Early English work, the north transept and chapter house more ornate work of a later period in that style, the nave, with its geometrical ornament, marks the transition to Decorated, while the Lady chapel is Decorated. The west front falls in date between the nave and the Lady chapel. Here is the "Sleeping Children," a masterpiece by Chantrey (1817). Among numerous monuments are memorials to Samuel Johnson, a native of Lichfield, and to David Garrick, who spent his early life and was educated here and a monument to Major Hodson, who fell in the Indian mutiny and whose father was canon of Lichfield.

The bishop's palace (1687) is adjacent to the cathedral. The diocese covers the greater part of Staffordshire and about half the parishes in Shropshire, with small parts of Cheshire and Derbyshire. The church of St. Chad is ancient though extensively restored. There are many half-timbered and other old houses, among which is that in which Johnson was born. Brewing is the principal industry, but there is some metal-working, and in the neighbourhood are large market gardens.

LICH-GATE or **LYCH-GATE**, the roofed-in gateway to churchyards (OE. *lic*, "a body, a corpse", of Ger. *Leiche*). Lich-gates existed in England thirteen centuries ago, but comparatively few early ones survive, as they were almost always of wood. One at Bray, Berkshire, is dated 1448. Here the clergy meet the corpse and some portion of the service is read. The gateway served to shelter the pall-bearers. In some lich-gates there stood large flat stones called lich-stones upon which the corpse was laid. The most common form of lich-gate is a simple shed composed of a roof with two gabled ends, covered with tiles or thatch. At Berrynarbor, Devon there is a lich-gate in the form of a cross, while at Troutbeck, Westmorland, there are three lich-gates to one churchyard. Some elaborate gates have chambers over them.

LICHNOWSKY, KARL MAX, PRINCE (1860-1928) German diplomat, was born at Kreuzenort, Upper Silesia, on March 8, 1860, the son of the 6th Prince Lichnowsky and of Princess Marie de Croy. He entered the German Foreign Office in 1884, and served in various legations until 1889, employing his vacations in travel in America and the Far East in order to study political and economic conditions outside Europe. In 1889 Bulow, who reposed complete confidence in him, recalled him to the Foreign Office, where he had charge of the personnel. He retired in 1904 to give attention to his estates, but was recalled to the service in 1912 to become ambassador in London. During his stay in London he worked hard for pacific relations between England and Germany; and the colonial agreement which was ready for signature in 1914 was largely his work. When the Serbian crisis arose in the summer of that year Lichnowsky urgently recommended the acceptance in Berlin of Sir E. Grey's mediation proposals. He had repeatedly warned Berlin of the dangers underlying the Anglo-German rivalries, but he had ceased to possess the complete confidence of his government, and his warnings were neglected. At the supreme crisis he was not in possession of all the facts. On the outbreak of war he returned to Berlin a broken man, and found that in some quarters he was held guilty of not having done his utmost to prevent British intervention. He wrote an apology *Meine Londoner Mission*, of his conduct of affairs in London for private circulation, which fell into the hands of German pacifists who printed it in 1918. He was then excluded from the Prussian Upper House, and found refuge in Switzerland. After the Revolution he returned to Germany, and in 1927 wrote *Auf dem Wege zum Abgrund* (Eng. trans. 1928), dealing with the origins of the World War. He died at his estate of Kuchelna on Feb. 27, 1928.

LICHTENBERG, GEORG CHRISTOPH (1742-1799) German satirical writer and physicist, was born at Oberramstadt, near Darmstadt, on July 1, 1742. In 1763 he entered Göttingen university, where in 1769 he became extraordinary professor of physics, and six years later ordinary professor. This post he held till his death on Feb. 24, 1799. As a physicist he is best known for his investigations in electricity, more especially as to the so-called Lichtenberg figures.

As a satirist and humorist Lichtenberg takes high rank among the German writers of the 18th century. His biting wit involved him in many controversies with well-known contemporaries, such as Lavater, whose science of physiognomy he ridiculed, and Voss, whose views on Greek pronunciation called forth a powerful satire, *Über die Pronunciation der Schoppe des alten Griechenlandes* (1782). In 1769 and again in 1774 he resided for some time in England and his *Briefe aus England* (1776-78), with admirable descriptions of Garrick's acting are the most attractive of his writings. He contributed to the *Göttinger Taschenkalender* from 1778 onwards, and to the *Göttingisches Magazin der Literatur und Wissenschaft*, which he edited for three years (1780-82) with J. G. A. Forster. He also published in 1794-99 an *Ausführliche Erklärung der Hogarth'schen Kupferstiche*.

Lichtenberg's *Vermischte Schriften* were published by F. Ktes in 9 vols. (1800-05, new editions in 8 vols. 1844-46 and 1867). Selections by E. Grisebach, *Lichtenbergs Gedanken und Maximen* (1871), by F. Robertag in Kurschner's *Deutsche Nationalliteratur* (vol. 141, 1886), and by A. Wilbrandt (1893). Lichtenberg's *Briefe* have been published in 3 vols. by C. Schüddekopf and A. Leitzmann (1900-02); his *Aphorismen* by A. Leitzmann (3 vols., 1902-06). See also R. M. Meyer, *Swift und Lichtenberg* (1886), F. Lauchert, *Lichtenbergs schriftstellerische Tätigkeit* (1893), and A. Leitzmann, *Aus Lichtenbergs Nachlass* (1899).

LICHTENBERG, formerly a small German principality on the Rhine, enclosed by the Nahe, Blies and Glan, now belonging to the district of Trier, Prussian Rhine province. The principality includes parts of the electorate of Trier and Nassau-Saarbrücken. Originally called the lordship of Baumholder, it owed the name of Lichtenberg and its elevation in 1819 to a principality to Ernest, duke of Saxe-Coburg, to whom it was ceded by Prussia, in 1816. The duke restored it to Prussia in 1834, in return for an annual pension. The area is about 210 sq.m.

LICINIANUS, GRANIVS, Roman annalist, probably lived in the age of the Antonines (2nd century A.D.). He was the author

of a brief epitome of Roman history based upon Livy. Accounts of omens and portents apparently took up a considerable portion of the work. Some fragments of the books relating to the years 163-178 B.C. are preserved in a British Museum ms.

Editions by C. A. Pertz (1857), seven Bonn students (1858), M. Flemisch (1901); see also J. N. Madvig, *Kleine philologische Schriften* (1875), and the list of articles in periodicals in Flemisch's edition (p. iv).

LICINIUS (FLAVIUS GALERIUS VALERIUS LICINIANUS), Roman emperor, A.D. 307-324 of Illyrian peasant origin, was born probably about 250. After the death of Flavius Valerius Severus he was elevated to the rank of Augustus by Galerius, his former friend and companion in arms, on Nov. 11, 307, receiving as his immediate command the provinces of Illyricum. On the death of Galerius, in May 311, he shared the entire empire with Maximinus, the Hellenist and the Thracian Bosphorus being the dividing line. In March 313 he married Constantia, half-sister of Constantine, at Mediolanum (Milan), in the following month inflicted a decisive defeat on Maximinus at Heraclea Pontica, and established himself master of the East while his brother-in-law, Constantine, was supreme in the West. In 314 his jealousy led him to encourage a treasonable enterprise on the part of Bassianus against Constantine. When his perfidy became known a civil war ensued, in which he was twice severely defeated—first near Cibalae in Pannonia (Oct. 8, 314), and next in the plain of Mardia in Thrace, the outward reconciliation, which was effected in the following December, left Licinius in possession of Thrace, Asia Minor, Syria and Egypt, but added numerous provinces to the Western empire. In 323 Constantine again declared war against him, and, having defeated his army at Adrianople, succeeded in shutting him up within the walls of Byzantium. The defeat of the superior fleet of Licinius by Flavius Julius Crispus, Constantine's eldest son, compelled his withdrawal to Bithynia, where a last stand was made; the battle of Chrysopolis, near Chalkedon, finally resulted in his submission. He was interned at Thessalonica and executed in the following year on a charge of treasonable correspondence with the barbarians.

See Zosimus ii. 7-28, Zonaras xii. 1, Victor, *Caes.* 40, 41, Eutropius x. 3, Orosius vii. 23.

LICINIUS CALVUS STOLO, GAIUS: see *ROME, History*, and *PATRICIANS*.

LICINIUS MACER CALVUS, GAIUS (82-47 B.C.), Roman poet and orator, the son of the annalist Licinius Macer. As a poet he followed his friend Catullus in style and choice of subjects. As an orator he was the leader of the opponents of the florid Asiatic school, who took the simplest Attic orators as their model and attacked even Cicero as wordy and artificial. Calvus held a correspondence on questions connected with rhetoric, perhaps (if the reading be correct) the *commentarii* alluded to by Tacitus (*Dialogus*, 23, cf. also Cicero, *Ad Fam.* xv. 21). Twenty-one speeches by him are mentioned, amongst the most famous were those delivered against Publius Vatinius. Calvus was very short of stature, and is alluded to by Catullus (*Ode* 53) as *Salaputium disertum* (eloquent Liliputian).

For Cicero's opinion see *Brutus*, 82, Quintilian x. 1. 115, Tacitus, *Dialogus*, 18. 21, the monograph by F. Plessis (Paris, 1896) contains a collection of the fragments (verse and prose).

LICTORS [Lat. *lictores*], in Roman antiquities, a class of the attendants (*apparitores*) upon certain Roman and provincial magistrates. As an institution they went back to the regal period and continued to exist till imperial times. The majority of the city lictors were freedmen, they formed a corporation divided into decuries, from which the lictors of the magistrates in office were drawn, provincial officials had the nomination of their own. In Rome they wore the toga, on a campaign and at the celebration of a triumph, the red military cloak (*sagulum*), at funerals, black. As representatives of magistrates who possessed the *imperium*, they carried the fasces (see *FASCES*). They were exempt from military service, received a fixed salary, theoretically they were nominated for a year, but really for life. They were the constant attendants of the magistrate to whom they were attached. They cleared a passage for him (*summo*) through

to road and saw that he was received with the marks of respect due to his rank. They stood by him when he took his seat on the tribunal: mounted guard before his house, against a wall of which they stood the fasces, summoned offenders before him, seized, bound and scourged them and (in early times) carried out the death sentence. Directly a magistrate entered an armed independent state he was obliged to dispense with his lictors. Each of the consuls had 12 lictors, the dictator, as representing both consuls, 24; the emperors 12, until the time of Domitian, who had 24. The Flamen Dialis, and each of the vestals were also accompanied by lictors. These lictors were probably supplied from the lictores curiati, 30 in number, whose duties were specially religious, one of them being in attendance on the pontifex maximus. They originally summoned the criminal curia, and when its meetings became merely a formal assembly acted as the representatives of that assembly.

LIDCOMBE — For the fullest account of the lictors, see Mommsen, *Römische Staatsrecht*, 255, 374 (3rd ed., 1887), cf. J. E. Sandys, *Companion to Latin Studies* (1921).

LIDCOMBE: see SYDNEY (New South Wales, Australia).

LIDDELL, HENRY GEORGE (1811–1898), English scholar and divine was born at Binchester near Bishop Auckland, on Feb. 6, 1811. He was educated at Charterhouse and Christ Church, Oxford, became a college tutor, and was ordained in 1835. In the same year Dean Gaisford appointed him Greek reader at Christ Church, and in 1846 he became headmaster of Westminster school. As early in 1834 he and Robert Scott had begun the great *Lexicon* (based on the German work of F. Passow) which became his life work, and the 1st edition was published in 1843. It is still the standard Greek-English dictionary (revised ed. by H. S. Jones in 1925). In 1855 he became dean of Christ Church, and took an active part in the first Oxford University Commission. He resigned the deanery in 1891 and retired to Ascot, where he died on Jan. 18, 1898.

He also published *History of Ancient Rome* (1855, abridged edition as *Students' History of Rome*).

See H. L. Thompson, *Henry George Liddell* (1899).

LIDDESDALE, the valley of Liddell Water, Roxburghshire, Scotland, extending 21 m. from the Peel Fell to the Esk. The Waverley route of the L.N.E.R. runs down the dale, and the Catraik or Picts' Dyke crosses its head. At one period points on the river were occupied with freebooters' peel-towers, but many have disappeared. Larmston Tower belonged to the Elliots, Mangerton to the Armstrongs and Park to "little Jock Elliot," the outlaw who nearly killed Bothwell in 1566. Hermitage Castle, a massive H-shaped fortress and one of the oldest baronial buildings in Scotland, stands on a hill overlooking Hermitage Water, a tributary of the Liddell. It was built in 1244 and captured by the English in David II's reign. It was retaken by Sir William Douglas who received a grant of it from the king. In 1492 Archibald Douglas, 5th earl of Angus, exchanged it for Bothwell castle on the Clyde with Patrick Hepburn, 1st earl of Bothwell. It passed to the duke of Buccleuch. It was here that Sir Alexander Ramsay of Dalhousie was starved to death by Sir William Douglas in 1342, and that James Hepburn, 2nd earl of Bothwell, was visited by Mary queen of Scots, after the assault referred to.

LIDDON, HENRY PARRY (1829–1890), English divine, was the son of a naval captain and was born at North Stoneham, Hampshire, on Aug. 20, 1829. He was educated at King's College school, London, and at Christ Church, Oxford. As vice-principal of the theological college at Cuddesdon (1854–59) and as vice-principal of St. Edmund's Hall, Oxford, he withstood the liberal reaction against Tractarianism, which had set in after Newman's secession in 1845. In 1864 he became prebendary of Salisbury cathedral. In 1866 he delivered his Bampton Lectures on the *Divinity of Our Lord* (13th ed., 1889), which established his fame. In 1870 he was made canon of St. Paul's Cathedral, London, where his preaching attracted vast crowds. In 1870 he had also been made Ireland professor of exegesis at Oxford, and the combination of the two appointments gave him extensive influence over the Church of England. With Dean Church he may be said to have the influence of the Tractarian school,

and he succeeded in popularizing the opinions which, in the hands of Pusey and Keble, had appealed to thinkers and scholars. His forceful spirit was equally conspicuous in his opposition to the Church Discipline Act of 1874, and in his denunciation of the Bulgarian atrocities of 1876. In 1882 he resigned his professorship. He travelled in Palestine and Egypt, and showed his interest in the Old Catholic movement by visiting Dollinger at Munich. In 1886 he became chancellor of St. Paul's, and it is said that he declined more than one offer of a bishopric. He died on Sept. 9, 1890.

Liddon's great influence was due to his personal fascination and the beauty of his pulpit oratory rather than to any high qualities of intellect. See J. Johnston, *Life and Letters of Dean Liddon*.

LIE, JONAS LAURITZ EDEMIL (1833–1908), Norwegian novelist, was born on Nov. 6, 1833, close to Housund (Eker), near Drammen. In 1838, his father being appointed sheriff of Tromsø, the family removed to that Arctic town. Here Lie gained acquaintance with the wild seafaring life which he was afterwards to describe. He studied at Christiania (Oslo), where Ibsen and Bjornson were among his fellow-students. On completing his studies he began to practise as a solicitor at Kongsvinger. In 1860 he married his cousin, Thomastine Lie, who collaborated with him in his works. In 1866 he published his first book, a volume of poems. Financial embarrassment drove him to Christiania to try his luck as a man of letters. As a journalist he had no success, but in 1870 he published a melancholy little romance, *Den Fremsynte* (Eng. trans., *The Visionary*, 1894), which made him famous. Lie proceeded to Rome, and published *Tales* in 1871 and *Tremasteren "Fremtiden"* (Eng. trans., *The Barque "Future,"* Chicago, 1879), a novel, in 1872. *Lodsen og hans Hustru* (*The Pilot and his Wife*, 1874) placed him at the head of Norwegian novelists and brought him a small government stipend. Lie spent the next few years partly in Dresden partly in Stuttgart. He then returned to Norway for a short time, and there wrote some novels of contemporary Norwegian life. But he was back in Germany very soon. From 1882 to 1891 he made Paris his headquarters. His later years were spent in Norway, and he died at Christiania on July 5, 1908. Two of the most successful of his numerous novels were *The Commodore's Daughters* (1886) and *Njobe* (1894), both of which were included in the International library. In 1891–1892 he wrote, under the influence of the new romantic impulse, twenty-four folk-tales, printed in two volumes entitled *Trold*. Some of these were translated by R. N. Bain in *Wend Tales* (1893), illustrated by L. Housman. His *Samlede Vaerker* were published at Copenhagen in 14 vols. (1902–1904). As a novelist Jonas Lie stands with those minute and unobtrusive painters of contemporary manners who defy arrangement in this or that school. He is with Mrs. Gaskell or Ferdinand Fabre, he is not entirely without relation with that old-fashioned favourite of the public, Fredrika Bremer.

LIE, MARIUS SOPHUS (1842–1899), Norwegian mathematician, was born at Nordfjordeid, near Bergen, on Dec. 17, 1842, and was educated at the University of Christiania (now Oslo). In 1869 he went to Berlin and there met Klein, in conjunction with whom he afterwards published several papers. In 1871 he was appointed assistant tutor in Christiania university, in the same year submitting for his doctor's degree his famous memoir *Ueber Complexe, insbesondere Linsen- und Kugel-Complexe, mit Anwendung auf die Theorie positiver Differential-Gleichungen*, in which he advanced the theory of tangential transformations. He was appointed extraordinary professor in 1872, and the following year began his researches on transformation groups, and discovered his transformation, making a sphere correspond to a straight line (*Comptes Rendus*, vol. lxxi). In 1884 Engel went to assist Lie, and after nine years' work was published *Theorie der Transformationsgruppen* (3 vols., Leipzig, 1893), a work of wide range and great originality. In 1886 Lie succeeded Klein in the chair of mathematics at Leipzig. Engel being appointed his assistant. In 1898 he returned to Christiania to accept a special post created for him but his health was already broken.

and he died on Feb 18 1899 Besides his development of transformations, Lie made contributions to differential geometry, but his primary aim was the advancement of the theory of differential equations

An analysis of Lie's works is given in the *Bibliotheca Mathematica* (Leipzig, 1900)

LIEBER, FRANCIS (1800-1872), German-American publicist, was born at Berlin on March 18, 1800 He served with his two brothers under Blucher in the campaign of 1815 fighting at Ligny, Waterloo and Namur, where he was twice dangerously wounded Shortly afterwards he was arrested for his political sentiments, the chief evidence against him being several songs of liberty which he had written After several months he was discharged without a trial, but was forbidden to pursue his studies at the Prussian universities He accordingly went to Jena, continuing his studies at Halle and Dresden He subsequently took part in the Greek War of Independence, publishing his experiences in his *Journal in Greece* (Leipzig, 1823, and under the title *The German Anacharsis*, Amsterdam, 1823) In 1827 he went to the United States and as soon as possible was naturalized He settled at Boston, and for five years edited *The Encyclopaedia Americana* From 1835 to 1856 he was professor of history and political economy in South Carolina college at Columbia, S C, and during this period wrote his three chief works, *Manual of Political Ethics* (1838), *Legal and Political Hermeneutics* (1839) and *Civil Liberty and Self Government* (1853) In 1857 he was elected to a similar post in Columbia college New York, where in 1865 he became professor of constitutional history and public law During the Civil War Lieber rendered services of great value to the Government Upon the requisition of the president, he prepared the important *Code of War for the Government of the Armies of the United States in the Field* This code suggested to Bluntschli his codification of the law of nations, as may be seen in the preface to his *Droit International Codifié* During this period also, Lieber wrote his *Guerilla Parties with Reference to the Laws and Usages of War* He died Oct 2, 1872

His *Miscellaneous Writings* were published by D C Gilman (Philadelphia, 1881) See T S Perry, *Life and Letters* (1882), and biography by Harby (1899) Consult also Ernest Nys, "Francis Lieber, His Life and Work," *Am Jour Internat. Law*, vol. v, pp 84-117, 335-393 (1911), Chester Squire Phinney, *Francis Lieber's Influence on American Thought* (1918); and Louis Martin Sears, "The Human Side of Francis Lieber," *So Atlantic Quar*, vol xxvii, p 42-61 (1928).

LIEBERMANN, MAX (1847-), German painter and etcher, was born in Berlin on July 20, 1847. After studying under Steffek he entered the school of art at Weimar in 1869 Though the straightforward simplicity of his first exhibited picture,

"Women plucking Geese" (Berlin, National gallery) in 1872, presented already a striking contrast to the conventional art then in vogue, it was heavy and bituminous in colour In his course he was confirmed by Munkacsy's influence in Paris in 1872 A summer spent at Barbizon in 1873, where he became acquainted with Millet and studied the works of Corot, Troyon and Daubigny, resulted in the clearing and brightening of his palette He subsequently went to Holland, where the example of Israels confirmed him in the method he had adopted at Barbizon, on his return to Munich in 1878 he caused much unfavourable criticism by his realistic painting of "Christ in the Temple," which was condemned by the clergy as irreverent Henceforth he devoted himself exclusively to the study of light and to the painting of the life of humble folk He found his best subjects in the orphanages and asylums for the old in Amsterdam, among the peasants in the fields and village streets of Holland, and in the beer-gardens, factories and workrooms of his own country

Liebermann has done for his country what Millet did for France His pictures hold the fragrance of the soil and the breezes of the heavens His people move in their proper atmosphere and their life is stated in all its monotonous simplicity His work being at variance with the academic tradition he became the leader of the Secession His first success was a medal awarded him for "An Asylum for Old Men" at the 1881 salon Then followed "The Cobbler Shop" (1881) and "The Flax Spinners" (1887) both of

which are now in the National gallery, Berlin In 1884 he settled in Berlin, where he became president of the Academy He became a member of the Societe nationale des Beaux Arts of the Societe royale belge des Aquarellistes, and of the Cercle des Aquarellistes at The Hague and a corresponding member of the Institut de France Liebermann is represented in most of the German and other continental galleries The new section of the National gallery in the former palace of the crown prince contains a representative collection of his work showing his development, the Munich Staatsgalerie, "The Woman with Goats", the Hamburg gallery, "The Net-Menders", the Hanover gallery, the "Village Street in Holland" "The Seamstress" is at the Dresden gallery the "Man on the Dunes" at Leipzig, "Dutch Orphan Girls" at Strasbourg; "Beer-cellar at Brandenburg" at the Luxembourg museum in Paris, and the "Knopflerinnen" in Venice Among his portraits are those of F Maunann, Gerhart Hauptmann and E Meyer His etchings are to be found in the leading print rooms of Europe

See Hans Rosenhagen, *Liebermann* (Bielefeld and Leipzig, 1900)

LIEBIG, JUSTUS VON, BARON (1803-1873), German chemist, was born at Darmstadt in May, 1803 His father, a dyer and dealer in colours, used sometimes to make experiments in the hope of improving his processes and thus the son early acquired familiarity with practical chemistry For the theoretical side he read all the text-books which he could find At the age of fifteen he entered the shop of an apothecary at Appenheim, near Darmstadt, but he soon found how great is the difference between practical pharmacy and scientific chemistry He next entered the university of Bonn, but migrated to Erlangen with the professor of chemistry, K W G Kastner (1783-1857) He then went to Paris, where, by the help of L J Thénard he gained admission to the private laboratory of H F Gaultier de Claubry (1792-1873), professor of chemistry at the Ecole de Pharmacie, Paris, and soon afterwards by the influence of A von Humboldt, to that of Gay-Lussac There he concluded, in 1824, his investigations on the composition of the fulminates On Humboldt's advice he determined to become a teacher of chemistry, and after overcoming many difficulties he was appointed extraordinary professor of chemistry at Giessen in 1824, becoming ordinary professor two years later His most important work was accomplished at Giessen He persuaded the Darmstadt government to provide a chemical laboratory in which the students might obtain a proper practical training This laboratory, unique of its kind at the time, in conjunction with Liebig's unrivalled gifts as a teacher, soon rendered Giessen the most famous chemical school in the world In it were trained many accomplished chemists and it gave a great impetus to the progress of chemical education throughout Germany Liebig remained at Giessen for twenty-eight years, until, in 1852, he became professor of chemistry at Munich university He died at Munich on April 10, 1873

Work on Pure Chemistry includes improvements in technique of organic analysis, his plan for determining the natural alkaloids and for ascertaining the molecular weights of organic bases by means of their chloroplatinates, his process for determining the quantity of urea in a solution, and his invention of the simple form of condenser known in every laboratory His contributions to inorganic chemistry were numerous, including investigations on the compounds of antimony, aluminium silicon, etc on the separation of nickel and cobalt, and on the analysis of mineral waters, but they are outweighed in importance by his work on organic substances In this domain his first research was on the fulminates of mercury and silver, and his study of these bodies led him to the discovery of the isomerism of cyanic and fulminic acids Further work on cyanogen and connected substances yielded a great number of interesting derivatives, and he described an improved method for the manufacture of potassium cyanide

In 1832 he published, jointly with Wohler, one of the most famous papers in the history of chemistry, that on the oil of bitter almonds (benzaldehyde), wherein it was shown that the radicle benzoyl might be regarded as forming an unchanging constituent of a long series of compounds Berzelius hailed this dis-

Liebknecht remained faithful to his principles and resigned his editorship. He became a member of the *Arbeiterverein*, and after the death of Ferdinand Lassalle he was the chief mouthpiece in Germany of Karl Marx, and was instrumental in spreading the influence of the newly-founded *International*. Expelled from Prussia in 1865, he settled at Leipzig, and it is primarily to his activity in Saxony among the newly-formed unions of workers that the modern social democrat party owes its origin. Here he conducted the *Demokratisches Wochenblatt*. In 1867 he was elected a member of the North German Reichstag where he opposed Lassalle's policy of compromise.

Liebknecht was strongly influenced by the 'great German' traditions of the democrats of 1848, and distinguished himself by his attacks on the policy of 1866 and the "revolution from above," and by his opposition to every form of militarism. His adherence to the traditions of 1848 are also seen in his dread of Russia, which he maintained to his death. His opposition to the war of 1870 exposed him to insults and violence, and in 1872 he was condemned to two years' imprisonment in a fortress, for treasonable intentions. The union of the German Socialists in 1874 at the congress of Gotha was a triumph of his influence, and from that time he was regarded as founder and leader of the party. From 1874 till his death he was a member of the German Reichstag, and for many years also of the Saxon diet. He was one of the chief spokesmen of the party, and he took an important part in directing its policy. In 1881 he was expelled from Leipzig, but took up his residence in a neighbouring village. After the lapse of the Socialist law (1890) he became chief editor of the *Vorwärts*, and settled in Berlin. If he did not always find it easy in his later years to follow the new developments, he preserved to his death the idealism of his youth, the hatred both of liberalism and of state socialism, and though he was to some extent overshadowed by Bebel's greater oratorical power, he was the chief support of the orthodox Marxian tradition. Liebknecht was the author of numerous pamphlets and books, of which the most important were *Robert Blum und seine Zeit* (Nuremberg, 1892), *Geschichte der Französischen Revolution* (Dresden, 1890), *Die Emser Depesche* (Nuremberg, 1890) and *Robert Owen* (Nuremberg, 1892). He died at Charlottenburg on Aug. 7, 1900.

See Kurt Eisner, *Wilhelm Liebknecht, sein Leben und Wirken* (1900).

LIECHTENSTEIN, one of the smallest independent sovereign States of Europe (see SAN MARINO and MONACO), 65 sq m. in extent, and bounded by the right bank of the Rhine a few miles above Lake Constance. Westward lies the canton of St. Gallen (Switzerland). The eastern border marches with Austrian Vorarlberg, and southwards are the western crests of the Rhatikon, between Liechtenstein and Graubünden (Switzerland). The country, geographically, is more Austrian than Swiss—politically its interests have oscillated between both countries. The major physical divisions are (1) A small narrow strip along the Rhine valley, widening northwards into the triangular lowland of the confluence of the Rhine and the Austrian Ill. (2) The much larger upland area, practically bisected by the Samna which feeds the Ill. The highest peaks lie southward with Falkais (8,401 feet), central south, and Naafkopf (8,432 feet), south-east, at the meeting points of the three frontiers. The chief settlements are at the western foot of the uplands and not on the Rhine itself. In order from the south, they are Balzers, Triesen, Vaduz (capital and seat of government, pop. 1,405), Schaan and Nendeln. They are linked by the road joining Ragaz (Switzerland) with Feldkirch (Austria). Two small settlements, Eschen and Mauern, lie in the northern triangular lowland. Liechtenstein's only railway crosses the centre of the western frontier from Buchs (Switzerland) and then parallels the road through Schaan and Nendeln. Pop. about 11,500, is largely German in origin and speech, Roman Catholic in religion and agricultural in interest. Corn, wine and fruit are grown and cattle are reared. There are also small manufactures of cotton, leather and pottery.

The principality, founded in 1719, consisted of the lordships of Schellenburg and Vaduz, and formed part of the Holy Roman empire. From 806-1719 it was included in the Rhine Confedera-

tion, and from 1815-66 in the German Confederation. Since 1866 it has been independent. Prince Johann II (b. 1840) succeeded his father in 1858. The Constitution has, since 1921, provided a *Landtag* of 15 members elected by direct vote, suffrage is universal. The standing army was abolished in 1868 and there is no national debt. Until 1919 Liechtenstein was closely allied with Austria, in 1921 it adopted Swiss currency, and since 1924 it has been included in the Swiss Customs Union. Switzerland administers its telegraph and postal services though it has a distinctive postage stamp issue. Prince Johann II died Feb. 11, 1929.

See *Tätigkeits- und Rechenschaftsberichte der fürstlichen liechtensteinischen Regierung* (Vaduz Annual), J. von Falke, *Geschichte des fürstlichen Hauses Liechtenstein* (Vienna, 1868-83); J. C. Heer, *Vorarlberg und Liechtenstein Feldkirch* (1906); A. Helbock, *Quellen zur Geschichte Vorarlbergs und Liechtenstein* (Berne, 1920).

LIED: see SONG

LIEDERTAFEL (Ger. lit. "song table"), a type of musical society formerly very popular and numerous in Germany, devoted to four-part singing for male voices, and combining refreshments and social intercourse with its music, whence the name. In recent years the older Liedertafeln have been more or less superseded by the larger male voice choirs, though the name has been retained for the public invitation concerts given by the latter.

LIÈGE, one of the nine provinces of Belgium, the successor of the old prince-bishopric, touching on the east Dutch Limburg and Rhenish Prussia. Its towns are Liège, Verviers, Spa, Seraing Huy, etc. The Meuse flows through the centre and its valley from Huy to Herstal is one of the most productive mineral districts in Belgium. Agriculture in the Condroz district south of the Meuse has been much developed. There are 26 cantons and 374 communes, and the districts of Eupen, Malmédy, St. Vith and the former neutral district of Moresnet are now within the province. Area 971,750 ac. or 1,518 square miles. Pop. (1925) 949,301 or 625 per square mile.

LIÈGE (Walloon, *Lige*, Flemish, *Luik*, Ger. *Lüttich*), capital of the Belgian province of Liège, on the Meuse long the seat of a prince-bishopric, the centre of the Walloon country.

The great cathedral of St. Lambert was destroyed in 1794, and in 1802 the church of St. Paul, dating from the 10th century but rebuilt in the 13th, was declared the cathedral. The law courts are installed in the old palace of the prince-bishops, constructed between 1508 and 1540. The university has separate schools for mines and arts and manufactures.

Liège had a population in 1921 of 165,096, and is the centre of the iron and armament manufacture of Belgium and of a coal-mining district. The production of zinc and of motor-cars has also become important. Of the 56 blast furnaces in the country in 1925 Liège had 20. There is also a large cattle market. Suburbs have arisen on the heights to the north and a circular boulevard has been laid out with connecting roads.

HISTORY

Liège first appears in history about the year 558, at which date St. Monulp, bishop of Tongres built a chapel near the confluence of the Meuse and the Legia. A century later the town, which had grown up round this chapel, became the favourite abode of St. Lambert, bishop of Tongres, and here he was assassinated. His successor St. Hubert, raised a splendid church over the tomb of the martyred bishop about 720 and made Liège his residence. It was not, however, until about 930 that the title bishop of Tongres was abandoned for that of bishop of Liège. The episcopate of Notger (972-1008) was marked by large territorial acquisitions, and the see obtained recognition as an independent principality of the empire. The popular saying was "Liège owes Notger to God, and everything else to Notger." By the munificent encouragement of successive bishops Liège became famous during the 11th century as a centre of learning, but the history of the town for centuries records little else than the continuous struggles of the citizens to free themselves from the exactions of their episcopal sovereigns, the aid of the emperor and of the dukes of Brabant being frequently called in to repress the popular risings.

The long episcopate of Eberhard de la Marck (1505-38) was a

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 ... the opening of the 17th century Bishop Maximilian Henry of Bavaria (1630-88), at last put an end to the anarchy and imposed a regulation (*règlement*) which abolished the free institutions of the citizens and the power of the nobles. The French revolutionary armies overran the principality in 1794 and from 1794 to the fall of Napoleon it was annexed to France and was known as the department of the Ourthe. The Congress of Vienna in 1815 decreed that Liege, with the other provinces of the southern Netherlands, should form part of the Kingdom of the Netherlands under the rule of William I, of the house of Orange. The town of Liege took an active part in the Belgian revolution of 1830, and since that date the ancient principality has been incorporated in the kingdom of Belgium.

On Aug. 6, 1914, immediately after the outbreak of the World War, the German division of the Belgian army retired on Liège, trusting to the fortifications of the town to withstand attack. For ten days Liège was subjected to terrific bombardments, and on Aug. 16 the town was occupied by the German troops. Although finally defeated, the Belgians by their sustained resistance gave the Allies time to make plans of campaign and to reassemble their forces.

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LIEGE, an adjective of uncertain derivation which seems originally to have meant "simple," "unconditioned." The word is historically important because it was early used as a qualification of legal terms such as homage. In feudal law liege homage is the homage due from a tenant to his chief lord. In course of time the idea prevailed that liege homage was due to the king, above and beyond the homage done to any immediate lords. From this idea is ultimately derived the employment of the abstract noun "allegiance" to denote the subject's duty to his sovereign.

See Pollock and Maitland *History of English Law* (2nd ed., 1898), 268-269.

LIEGNITZ, a town in the Prussian province of Silesia, situated on the Katzbach just above its junction with the Schwarzwasser, and 40 m. WNW of Breslau, on the main line of railway to Berlin via Sommerfeld. Pop. (1925) 73,153. Liegnitz is first mentioned in an historical document in the year 1004. In 1103 it became the seat of the dukes of Liegnitz who greatly improved and enlarged it, and who are buried in the church of St. John. On the death of the last duke of Liegnitz in 1675, the duchy came into the possession of the Empire, which retained it until the Prussian conquest of Silesia in 1742. On Aug. 15, 1760 Frederick the Great gained a decisive victory near Liegnitz over the Austrians. It consists of an old town, and several suburbs. The palace, formerly the residence of the dukes of Liegnitz and rebuilt after a fire in 1835, is now used as the administrative offices of the district. The Ritter Akademie, founded by the emperor Joseph I, was reconstructed as a gymnasium in 1810. The church of SS. Peter and Paul (restored in 1892-1894) dates from the 14th century. The manufactures are considerable, the chief articles made being cloth, wool, leather, tobacco, pianos, cigars, sugar, carriages and machinery. Its trade in grain and its cattle-markets are likewise important. There are large market gardens in the suburbs.

LIEN. The word lien signifies the right of a person in possession of property belonging to another to detain such property until some debt or demand in connection with the property detained is satisfied. This right of lien arises either by implication of law or by express contract. Where, however, an express contract for security is made between parties such agreement extends to the extent of the express contract any lien upon prop-

erty to which it might otherwise have been subject. The possessory right conferred by lien is not a right *ad eam* that is to say does not convey to the person in possession of goods any property in them, it merely gives him a legal ground on which his demand is satisfied. Consequently, apart from statute or legal process authorizing him so to do, he is not entitled to sell the goods to recover what is due to him.

If the goods be not in possession of the claimant of lien, as in the case of the furniture of a tenant owing rent to a landlord the law will indeed assist the landlord to seize the property and enable him to sell it in one course in order to pay himself out of the proceeds, but it will not give him any property in the furniture itself.

There are two descriptions of lien recognized by the English law, particular and general. Particular liens exist where persons have a right to retain possession of property in respect of labour or money expended by them on the identical chattel which constitutes the *res gestae* or subject matter of the dispute. Liens of this description are usually favourably regarded by the court. General liens are claims made in respect of a general balance of account between the parties.

Liens are created in three ways, either (1) by express contract, (2) by usage of trade, or (3) by some legal relation between the parties where there is no express contract nor any usage of trade. The term legal relation applies either to those persons on whom the law throws an obligation to perform certain services whenever required so to do by any member of the public, such as an inn-keeper or a common carrier, or else to a person who usefully expends time, work or money on the reparation of the chattel of another, such as a jobbing tailor, a boot-repairer, a turner, a calico printer, or indeed any person to whom goods are delivered in order to have some service performed in connection with them for which such delivery is necessary. But the mere safeguarding of the article, apart from work done upon it, will convey no right to lien in this particular form of deposit.

Again, a ship-master (on behalf of the owner) has a lien upon cargo for freight, and if, upon landing, notice of such lien is given to the wharfinger or warehouseman the cargo is bound thereby in his hands, and may be subsequently sold by him upon compliance with statutory conditions (Merchant Shipping Act, 1894, secs. 494-498). And a like rule applies to passengers' luggage (except wearing apparel actually in use) for unpaid passage money.

A claim to general lien, though, as already stated, not regarded with favour by the courts, may be established by special or necessarily implied agreement, or by the custom of a certain trade. By virtue of accepted custom of trade or profession, wharfingers, bankers, insurance brokers and solicitors have a lien upon the property of their employers, not only for debts arising out of the particular transaction for which the property was delivered to them, but also for a general balance of account between the parties, and this rule has been held to apply to statute barred debts (*Courtenay v Williams*, 3 Hare at p. 552).

A similar principle as to general balance of account has been held applicable to the lien of calico printers and packers, and locally (by the custom of Exeter) to fullers. The right to general lien is, however, incapable of transference.

Maritime Lien differs from all other forms of lien in that it neither includes nor requires actual physical possession of the ship in respect of which it arises. It exists altogether independently of such possession and is not connected with any actual or constructive possession by the parties seeking to enforce it. Maritime lien presupposes the giving of a credit coupled with an intentional postponement of the right to enforce the claim at the time when the lien was created. Consequently the position of a creditor having a proper maritime lien differs from that of an ordinary creditor in that "unless he has forfeited the right by his own laches, he can proceed against the ship notwithstanding any change in her ownership," the lien relating back to the period when it first attached.

The principal instances in which the law recognizes maritime liens are bottomry (*q. v.*) (see mortgage of ships *see*) salvage

(*q v*), wages, master's wages, disbursements and liabilities, and damage arising from collision

Right of Sale or Transference of Lien.—Apart from statute a mere lien confers no right of sale on the party entitled to retain the chattels against the true owner, even if the detention be attended with trouble and expense (*Thames Iron Company v Patent Derrick Company*, 1860, 29 L J, Ch 714) A statutory right of sale, however, of any goods left by a guest in his custody enures, after six weeks, to an innkeeper for the amount of his bill, by virtue of the Innkeepers Act, 1878 (sec. 1) By the Merchant Shipping Act, 1894 (secs 497-498), a wharfinger or warehouseman, at the expiration of 90 days from the time when goods are placed in his custody (or a shorter time if the goods be perishable) is entitled to sell them by public auction, and sec 97 of the Railway Clauses Act, 1845, authorizes railway companies to detain and sell any goods delivered to them for carriage upon default of payment of their tolls Neither the custody of the chattel nor the accompanying lien is capable of legal transference to a third party, who is consequently, after demand and refusal, liable in trover to the true owner of the goods

The lien of an unpaid vendor for the price of the article which he has sold to an insolvent purchaser subsists until the chattel has either been actually or constructively delivered into the hands of the latter This lien for the price of specific goods is not determined by the mere delivery of the chattels to a carrier for the purpose of conveyance Consequently, if the vendor can arrest the goods at any stage of the transit before they reach the hands of the purchaser or his agent the vendor reverts to the same position as if he had not parted with the possession of the goods

The right is not de-vested by the purchaser endorsing over a bill of lading of the goods by way of security or for valuable consideration to a third party, with notice of the consignee's insolvency, or by a purchaser's sub-sale of the goods before the termination of the *transitus*, without delivery of the documents of title to an innocent third party

Waiver and Determination of Lien.—A lien may be waived, and the right to assert the claim lost, by conduct on the part of the holder of the goods obviously inconsistent with the existence of such a right A lien is determined by actual payment or tender of the full amount of the legal claim for which the goods are detained, but part payment of such demand is not sufficient, neither is a general tender or offer to discharge the claim without actual tender or what, in point of law, is equivalent thereto.

(W W P)

U.S Differences.—In the United States, speaking generally, the law relating to liens is that of England, but there are some considerable differences occasioned by three principal causes (1) Some of the Southern States, notably Louisiana, have never adopted the common law of England. When that State became one of the United States of North America it had (and still preserves) its own system of law In this respect the law is practically identical with the Code Napoleon, which, again speaking generally, substitutes privileges for liens, *z e*, gives certain claims a prior right to others against particular property. These privileges being *strictissimæ interpretationis*, cannot be extended by any principle analogous to the English doctrine of equitable liens (2) Probably in consequence of the United States and the several States composing it having had a more democratic government than Great Britain, in their earlier years at all events, certain liens have been created by statute in several States in the interest of the working classes which have no parallel in Great Britain, *e g*. in some States workmen employed in building a house or a ship have a lien upon the building or structure itself for their unpaid wages This statutory lien partakes rather of the nature of an equitable than of a common-law lien, as the property is not in the possession of the workman, and it may be doubted whether the right thus conferred is more beneficial to the workman than the priority his wages have in bankruptcy proceedings in England Some of the States have also practically extended the maritime lien to matters over which it was never contended for in England (3) By the constitution of the United States the Admiralty and inter State jurisdiction is

vested in the Federal as distinguished from the State courts and these Federal courts have not been liable to have their jurisdiction curtailed by prohibition from courts of common law, as the court of Admiralty had in England up to the time of the Judicature Acts, consequently the maritime lien in the United States extends further than it does in England, even after recent enlargements, it covers claims for necessaries and by material men, as well as collision, salvage, wages, bottomry and damage to cargo

Difficulties connected with lien occasionally arise in the Federal courts in Admiralty cases, from a conflict on the subject between the municipal law of the State where the court happens to sit and the Admiralty law; but as there is no power to prohibit the Federal court, its view of the Admiralty law based on the civil law prevails More serious difficulties arise where a Federal court has to try inter-State questions, where the two States have different laws on the subject of lien, one for example, like Louisiana, following the civil law, and the other the common law and equitable practice of Great Britain The question as to which law is to govern in such a case can hardly be said to be decided "The question whether equitable liens can exist to be enforced in Louisiana by the Federal courts, notwithstanding its restrictive law of privileges, is still an open one" (Derris, *Contracts of Pledge*, 517, and see *Burdon Sugar Refining Co v Payne*, 167 U S 127)

LIEPAJA (*Libau*), a seaport of Latvia in 56° 32' N, 23° 2' E, at the northern extremity of a narrow sandy peninsula which separates Lake Libau (12 m long and 2 m wide) from the Baltic sea Pop (1923) 77,000 There are four harbours, the Commercial, with stone quays, storehouses for merchandise and three large grain elevators, the Winter, with numerous timber yards round the quays, the Avant pier or New Harbour, north-west of the Commercial harbour, where regular passenger steamers berth, and the War harbour, with two dry docks, each 600 ft There are three entrances, but the southern one is at present closed for navigation, being blocked with sunken wrecks, the middle entrance is now comparatively clear, but some wreckage remains, marked by a gas buoy, the northern entrance is now clear Vessels drawing more than 28 ft cannot enter The port is practically open all the year round with the help of its icebreakers

The port is a coaling and oil station The chief imports are coal, iron, salt, herrings, grain, cotton, machinery, chemical manure and phosphates The exports include rye, barley, oats, wool, linseed, sleepers, deals, pit-props, pulp-wood, ply-wood, skins and hides, wheat and eggs. War conditions and the severance from Russia have much reduced its trade which is only 10 to 15% of that in 1913 Its industries before 1913 included iron and steel works and engineering yards, veneering, flour-milling, bacon-curing, tobacco manufacture, the making of vegetable oils, colours and varnishes, brewing, distilling and leather works. Many of the factories were ruined during the war and await capital for repair and development

The port of Libau, *Lyra portus*, is mentioned in 1263, when it belonged to the Livonian order or Brothers of the Sword In 1418 it was burned by the Lithuanians and in 1560 mortgaged by the grandmaster of the Teutonic order, to which it had passed to the Prussian duke Albert In 1701 it was captured by Charles XII of Sweden, and in 1795 annexed to Russia After 1873 when it was brought into railway connection with Moscow, Orel and Kharkov, Liepaja became an important port and developed rapidly The Russians constructed an extensive naval port protected by moles and breakwaters in 1893-1906 The Latvian government removed here when Riga was in German occupation in 1917-19, and Liepaja itself was occupied by German troops in 1919. Evidences of war destruction remain still, though many repairs have been carried out

LIERNE, in architecture, a small, subordinate vaulting rib, which runs between the more important structural ribs With the English tendency to sub-divide vaulting areas during the 14th century, the invention and development of the lierne was a necessary consequence Used more for decorative than for structural

ribs. Lierne ribs are especially grouped near the vault ridges where

... rich and complicated intersecting patterns... known as reticulated, or... of Gloucester (completed 1377)... of Canterbury cathedral (c... The interactions of hemes with each other or of hemes with the major ribs are usually decorated with carved, pro-

LIERRE, a town in the province of Antwerp Belgium, 9 m. SE of Antwerp. Its church of S. Gemme (completed 1557) is three times as long as given by Archduke Maximilian to celebrate the wedding of Mary of Burgundy. The cutlery industry is very important and a little silk is manufactured. Pop. (1925), 10,000.

LIESTAL, the capital of the half-canton of Baselland, Switzerland. Pop. (1920) 6,307.

LIEUTENANT, one who takes the place, office and duty of and acts on behalf of a superior or other person. The word in English preserves the form of the French original (from *lieu*, place, seat, holding, which is the equivalent of the Lat. *locum tenens*, the holding the place of another. The usual English pronunciation appears earlier, the word being frequently spelled *lieutenant*, *lyeftenant* or *lyeftenant* in the 14th and 15th centuries. The modern American pronunciation is *lieutenant*, while the German is represented by the present form of the word *Leutnant*. In French history *lieutenant* (*locum tenens regis*) was a title borne by the vicar sent with military powers to represent the king in certain provinces. With wider powers and functions, both civil as well as military, and holding authority throughout an entire province, such a representative of the king was called *lieutenant général du roi*. The first appointment of these officials dates from the reign of Philip IV. the Fair (see CONSTABLE). In the 16th century the administration of the provinces was in the hands of *gouverneurs*, to whom the *lieutenants du roi* became subordinates. The titles *lieutenant civil* or *criminel* and *lieutenant général de police* have been borne by certain judicial officers in France (see CHATELET and BAUFFRE-BAILLE). As the title of the representative of the sovereign 'Lieutenant' in English usage appears in the title of the lords lieutenant of the counties of the United Kingdom (See CONSTABLE: MILITARY *Lihtaz in England*).

The most general use of the word is as the name of a grade of naval and military officer. In Italy and Spain the first part of the word is omitted and an Italian or Spanish officer bearing this rank is called *teniente* or *teniente* respectively. In the British and most other navies the lieutenants are the commissioned officers next in rank to commanders, or second class of captains. Originally the lieutenant was a soldier who aided, and in case of need replaced, the captain who until the latter half of the 17th century, was not necessarily a seaman in any navy. At first one lieutenant was carried and only in the largest ships. The number was gradually increased and the lieutenants formed a numerous corps. Lieutenants now often qualify for special duties such as navigation, or gunnery or the management of torpedoes. In the British army a lieutenant is a subaltern officer ranking next below a captain and above a second lieutenant. In the United States of America subalterns are classified as first lieutenants and second lieutenants. In France the two grades are *lieutenant* and *sous-lieutenant*, while in Germany the *Leutnant* is the lower of the two ranks, the higher being *Ober-leutnant* (formerly *Premier-leutnant*). A "captain lieutenant" in the British army was formerly the senior subaltern who virtually commanded the colonel's company or troop and ranked as junior captain, or "puny captain," as he was called by Cromwell's soldiers.

LIFE, the kind of activity characteristic of living creatures. No doubt this activity is, in its objective aspects an integration of numerous chemical and physical processes, and there is no warrant for postulating any mysterious 'vital force'. On the other hand, it must be allowed that life is a unique kind of activity, for the formulae of matter and energy, electrons, protons and electro-magnetic radiations or ether-waves, as at present understood do not suffice to describe (a) the everyday functions of the body in their orchestration, (b) the self-preservative activities of any organism at any grade of being (c) the purposive be-

haviour of higher animals well-endowed with brains, (d) the phenomena of development and heredity or (e) the facts of evolution. Everyone allows that living is in part analysable into chemical and physical processes yet these are modified by their occurrence in the colloidal medium of the chemically very complex protoplasm. In conditions of extreme complexity, a new aspect of reality—Life—emerges. Moreover when the chemical and physical ledger is added up, it does not give a unified description of what has actually occurred when, e.g., a migrant bird makes its journey. For to describe this it is necessary to introduce concepts beyond physics and chemistry, such as emigration of the past, awareness of the present and purposiveness towards the future. In at least the higher reaches of the animal kingdom, behaviour is correlated with psychical activity, incommensurable with physical processes. Thus life is an activity of organisms which requires for its description concepts transcending those of mechanism. This view does not in any way contradict the theory that living organisms may have arisen on the earth from non-living materials. When the materials were complex enough and in an appropriate collocation, living organisms may have emerged.

Characteristics of Organisms.—(a) The self-preservative persistence of an organism is associated with the building-up and breaking-down of proteins, which have large complex molecules, representing an accumulation of potential chemical energy. Anabolic processes counterbalance the katabolic, repair counteracts waste, rejuvenescence wards off senescence. The organism is like a clock that winds itself up as it runs down. No doubt this quality is to be analysed as far as may be,—in terms, for instance, of the characteristic fermentations and their reversibility. Much depends on the fact that the proteins are always colloidal, admitting of intensity and rapidity of chemical reactions on the surface of the multitudinous ultra-microscopic particles or dioplets suspended in the liquid phase. Another feature is the chemical individuality everywhere manifest, for each distinct type of organism seems to have some distinctive protein of its own, and some characteristic rate or rhythm of metabolism. Thus under the general quality of persistence amid unceasing metabolism, there is a triad of facts: (1) the building-up that compensates for the breaking-down of proteins (2) the occurrence of these proteins in a colloidal state and (3) their specificity from type to type.

(b) A second triad of qualities includes the organism's characteristic powers of *growing*, *multiplying* and *developing*. A surplus or income over expenditure is the primal condition of organic growth. As contrasted with the growth of a crystal, an organism can grow at the expense of materials more or less different from those of the growing body; it implies active assimilation, not mere passive accretion, and it is a definitely regulated process—regulated from within. Growth naturally leads to the simplest forms of multiplication or reproduction, for persistent growth tends to bring about organic instability, which may be intracellular as in unicellular organisms and in ordinary cell-division, or localized along a line of weakness or low vitality, as in the fragmentation of some lower multicellular animals. Asexual multiplication is a regularized form of discontinuous growth, and sexual reproduction by liberated germ-cells is a secondary specialization, anticipated in the spore-formation of many of the Protozoa and Protophyta (see REPRODUCTION).

Development is the progressive attainment of full-grown complexity from comparatively undifferentiated simplicity, whether that be in stump or fragment, in leaf or bud, in spore-cell or germ-cell. It implies an expression of hereditary initiatives in appropriate nurture and often in such a way that the individual stages in the ontogeny can be correlated with great steps in the racial history or phylogeny. Development, with its central fact of progressive differentiation and integration, is particularly to be thought of in connection with the building up of the embryo, but it cannot be separated from the everyday repair of worn-out tissue, the replacement of periodically deciduous structures (like leaves and hair), and the frequent regeneration (q.v.) of lost parts, thus linking back with reproduction and growth.

(c) In the third place living creatures stand apart from non-living things in their purposive behaviour in their power of en-

registering experience, and in their capacity for giving rise to the new—a third triad. Many non-living things such as explosives, react forcefully to outside stimulus but organisms are marked by the self-preservative efficiency of their reactions. Only the higher big-brained animals can be credited with perceptual purpose, but the quality of purposiveness seems to be co-extensive with life. The organism is an agent that gets things done, at various levels of behaviour—intelligent, instinctive, tropistic, reflex, and so forth. The mental aspect may in many cases be subordinated to the bodily, but in the majority there is the bent bow of endeavour, even though the creature's awareness of that endeavour may be dim. The mental aspect seems to be struggling for expression throughout, and the organism appears as a psychophysical being, now (mind)-BODY and again (body)-MIND (see BIOLOGY)

A bar of iron is never quite the same after it has been severely jarred, a violin suffers from misbanding. But these are hardly more than vague analogies of the distinctive power that living creatures have of enregistering the results of their experience, of establishing internal rhythms, of forming conditioned reflexes and habits, and of remembering. Individual experience is built into the individual organism and influences subsequent reactions.

Finally it must be recognized as characteristic of organisms that they give origin to what is new; they have evolved in the past, and the evolution of many is still going on. Variability and evolvability must be ranked as fundamental characteristics of living beings. The organism selects stimuli from its environment and often moves from one environment to another, the organism is often experimental, moulding itself by its efforts, it tests the newness of its inheritance in its ceaseless trafficking with circumstances. The central secret of life is missed if the organism is not recognized as in some measure a struggling sub-personality.

To sum up, the characteristics of organisms are—(a) *Persistence of integrity amid ceaseless change*, there being (1) a self-preservative compensation of down-breaking by up-building, (2) a metabolism of proteins and other complex substances in a colloidal state, (3) a chemical individuality, (b) *a triad of linked capacities*, namely, (4) growth, (5) multiplication, (6) development, and (c) the crowning triad of (7) effective behaviour, (8) enregistration of experience, (9) evolvability.

Aspects of Life.—The biologist works with three co-ordinates—the organism, its functions and the environment. These are the three sides of the biological prism. At times what is observed is the insurgent organism acting on its environment, both animate and inanimate, and this may conveniently be summed up by using the first letters, $O \rightarrow f \rightarrow e$, giving the Organism a capital. But at other times and just as familiarly, the Environment closes in upon the organism, stimulating and inhibiting, fostering and weathering, warming and cooling, feeding and starving. This may be formulated again $E \rightarrow f \rightarrow o$, reversing the capitals. Thus, as Patrick

Geddes points out, living implies an ever-changing ratio $\frac{Ofe}{Efo}$.

Most animals are less in the grip of their environment than most plants, and sedentary corals more than pelagic medusae, the very young more than the resiliently mature, and the summer hedgehog more than the hibernator. In the article BIOLOGY it has been suggested that since an organism without its everyday functions is rather an empty abstraction, the term function in the $O \rightarrow f \rightarrow e$ $E \rightarrow f \rightarrow o$ formula, should rather read "functionings," i.e., the work or on-goings, the actions and reactions of the organism as a whole.

The Drama of Life.—What has been said gives too cold an impression of life, which must be envisaged as a drama on a crowded stage. (1) Whatever the secret of vital activity may be, it must be thought of as an overflowing spring. Organisms accumulate energy acceleratively and must multiply. Life is like a river that is often in flood. (2) From the ant-hill, the bee-hive, the rookery, the rabbit warren, there comes the impression of urge and endeavour. Whether the urge be vegetative, appetitive, tropistic, instinctive or intelligent, organisms are almost always after something—never satisfied. The more they get the more they want. (3) But the quality of life rises to what may be called

insurgence. Animals in particular are full of daring and adventure. As Goethe said, they are always attempting the next to the impossible and achieving it. This is well illustrated by gossamer spiders making aerial journeys, or by Arctic terns within the Antarctic Circle, but it finds many an unsensational expression. (4) Another quality, so universal that it must be called characteristic, is adaptiveness. Practically every organism is a bundle of adaptations or fitnesses. As Weismann said, "If all the adaptations are taken away from a whale, what is there left?" (5) It is perhaps an expression of this adaptiveness that so many living organisms form linkages with others. There is no aloofness in the realm of organisms, nothing lives or dies to itself. Thus animate nature is characteristically a system,—a fabric that changes in pattern and yet endures. Though the individual threads of the web are always dying, they are replaced without a discontinuity. There is wear, but no tear, except when man carelessly interferes with the loom, or when some physical violence like flood or fire, causes an inevitable rent. (6) But this leads to another characteristic of the biosphere that marks it off from the cosmosphere: there is continual sifting. A new star often appears in the sky but there is no indication of any struggle for existence or selection of the relatively more fit. But who can describe the advancement of life and leave out winnowing? There is cosmic flux and there is organic flux, but only in the latter is there discriminate elimination. (7) Another characteristic of living creatures is their beauty. All independently-living organisms are artistic entities, with protean wealth of beauty in form and colour, in pose and movement, expressing a harmonious life from which the discordant has been more or less completely eliminated. Apart from exceptions, like parasites, which prove the rule, organisms are like works of art. (8) Nothing can be said as to the mental aspect of a wood-anemone and only a little about that of a sea-anemone but a picture of life must include the fact that in organisms there is the promise and potency—and in higher animals the epiphany—of "Mind." Perceptual inference is a relatively late achievement, conceptual inference or reason is man's prerogative but throughout the animal kingdom there is a stream of inner life, of feeling and purpose, even when there is not very much in the way of intelligence. The probability is that "Life" and "Mind" are co-extensive. (9) But the crowning characteristic of life is its progressiveness. No doubt there have been eddies and stagnant pools, but on the whole there has been a flow in the stream of life, and it has been uphill! As epoch has succeeded epoch for inconceivably long ages, life has been slowly creeping—sometimes swiftly leaping—upwards, towards greater fullness and freedom. The whole process must be envisaged in the light of its outcome, organic evolution in the light of man.

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(J. A. TH.)

LIFE-BOAT AND LIFE-SAVING SERVICE. The article on DROWNING AND LIFE-SAVING (*q.v.*) deals generally with the means of saving life at sea, but under this heading it is convenient to include the appliances connected specially with the life-boat service. The ordinary open boat is unsuited for life-saving in a stormy sea, and numerous contrivances, in regard to which the lead came from England, have been made for securing the best type of life-boat.

The first experimenter in England was Lionel Lukin, a London coach-builder, later Master of the Worshipful Company of Coach-makers. Encouraged by the prince of Wales (George IV), he converted a Norway yawl into what he called an "unimmovable" boat, which he patented. Buoyancy he obtained by means of a project

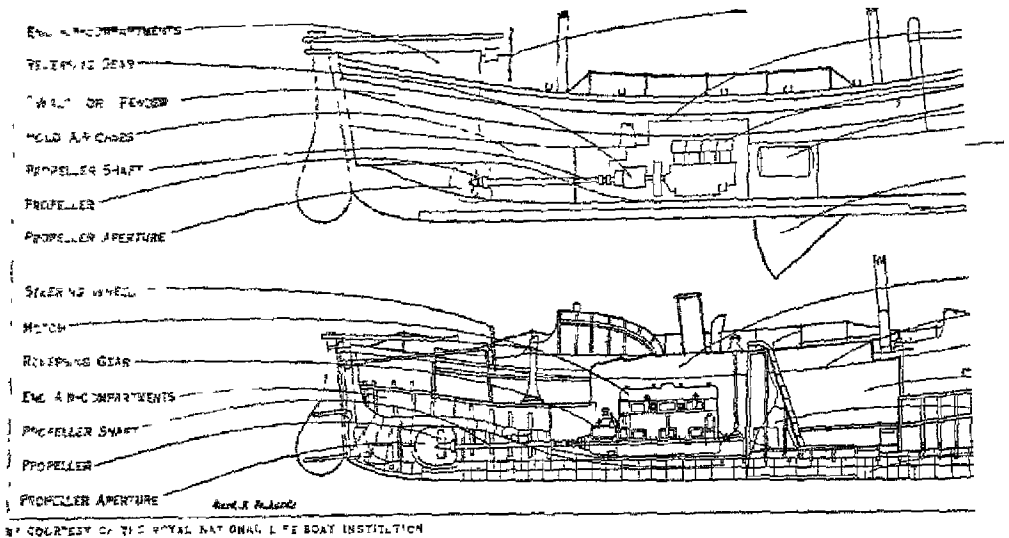


FIG 1.—TYPES OF MODERN LIFE-BOATS

Top: self-righting life-boat, 40 ft. by 10 ft. 6 in., with 40 h.p. motor, also fitted with rowlocks for oar prop motor life-boat, with 80 h.p. motor

ing a rowlock of cork and air-chambers inside—one of these being at the bow another at the stern. Stability he secured by a false iron keel. The self-righting and self-emptying principles he seems not to have thought of, at all events he did not compass them. Lukin was thinking rather of making all boats safer than of constructing a boat for the special purpose of life-saving but he was associated with the earliest known attempt at establishing a Life-Saving Service when in 1786, he converted a coble into a "safety-boat" for Archdeacon Sharp. This boat was employed for some years at Bamborough in saving life from shipwreck, the village becoming thereby the first life-boat station.

Public apathy in regard to shipwreck was temporarily swept away by the wreck of the "Adventure" of Newcastle at the mouth of the Tyne in 1789. This vessel was stranded only 300 yd from the shore, and her crew dropped, one by one, into the raging breakers in presence of thousands of spectators, none of whom dared to put off in an ordinary boat to the rescue. An excited meeting among the people of South Shields followed, a committee was formed and premiums were offered for the best models of a life-boat. This called forth a number of plans, among those who submitted them being William Wouldhave, a house painter and a teacher of singing, and Henry Greathead, a boat builder, both of South Shields. Wouldhave's model was so constructed that, if capsized, it would immediately right itself, and Wouldhave is entitled to be considered the discoverer of that principle, which is now used in more than half the life-boats round the British coasts. But the committee did not adopt this principle, nor was it entirely satisfied with Wouldhave's design. It gave him half the reward and then, from this and the other designs submitted prepared a model of its own from which Greathead built the first life-boat.

The First Life-boat.—This boat was rendered buoyant by nearly seven tons of cork, and had very raking stem and stern-posts, with great curvature of keel. The total cost was just under £150. This life-boat, the "Original," served until 1830 and rescued hundreds of lives. No other life-boat was launched till 1798, when the duke of Northumberland ordered Greathead to build him a life-boat which he endowed. This boat also did good service and its owner ordered another in 1800 for Oporto. In the same year Mr. Cathcart Dempster ordered one for St. Andrews. There, two years later, it saved twelve lives. Thus, the value of life-boats began to be recognized, and before the end of 1803 Greathead had built thirty-one boats—eighteen for England, five for Scotland and eight for foreign lands. In this work he was materially helped by Lloyds. Four years later Lukin, the coach-maker again appeared on the scene, being invited by the Suffolk Humane Society to superintend the building of the first sailing life-boat. This boat, launched at Lowestoft at the end of 1807, was the forerunner of the Norfolk and Suffolk type of life-boat

still used on that part of the

In spite of these efforts, societies acting independently life-boats was not thoroughly to the nation was made by a resident in the Isle of Man. Establishment of a national life-boat service on the stormy coasts to save no fewer than 305 thought out plan of what a life-boat to whom it should look for its work. As Sir William Hall a century ago so, in all the matter. These main features were matter for national concern dangerous work of rescue should be certain that, if they lost be provided for, that the life all in peril round the coasts, the service should be maintained. Within a year, and with the help of Mr. Thomas Wilson and founded the "Royal National Life from Shipwreck."

The Royal National Life-boat Service.—The grandest of England's charities, the "Royal National Life-boat Institution," was founded in 1824. It began its career in its first year twelve new life-boat stations, besides which thirty-two life-boats were placed on the British shores by benevolent associations over which the institution often assisted them. In its infancy the mortar apparatus of Cay provided for the wants of a shipwreck—a duty subsequently taken over by the Fishermen and Mariners' Royal Beneficial Society. The first year of the institution's second report showed that three hundred and forty-two life-boats were saved by the mortar apparatus or by other means.

In the year 1849, came a tragedy on the Tyne. The life-boat "Provide" was launched and of her double crew of 24 men, 23 were killed. Tragic though this event was, it attracted attention to the needs of the life-boat service. It was a turning point in its history. The institution's history had been a long and hard one, and the institution had never before had fallen as low as £354 an

no longer seaworthy. Public interest in it had almost ceased. The Tyne disaster helped to recall the public to the importance of their life-boat service and the need to support it. In 1850 the Prince Consort became vice patron of the institution in conjunction with the king of the Belgians, and Queen Victoria, who had been its patron since her accession, became an annual contributor to its funds. In 1851 Algernon, fourth Duke of Northumberland, became the institution's president. He was known as the "Sailor Duke." He entered the Navy in the year of Trafalgar, was now a Rear Admiral, and a little later became First Lord of the Admiralty. He brought a new spirit to the work, and from that day to this the institution has never looked back. It has gone from strength to strength and it is many years now since it was first able to say that a life-boat had been stationed at every point on the coast where it was required and where an efficient crew could be found.

In 1850 its committee undertook the immediate superintendence of all the life-boat work on the coasts with the aid of local committees. Periodical inspections, quarterly exercise of crews, fixed rates of rewards for coxswains and men, on a sliding scale according to the season of the year, and the day or night were instituted; and the duke of Northumberland, realising that the "first and most obvious step was to endeavour to introduce an improved life-boat," offered a prize of one hundred guineas for the best model, and appointed a committee of experts to report on those sent in. In reply to the offer no fewer than two hundred and eighty models were sent in not only from all parts of Great Britain but from France, Germany, Holland and the United States. The prize was gained by Mr James Beeching of Great Yarmouth, whose model, slightly modified by Mr James Peake, one of the committee of inspection, was adopted by the Institution. Mr Beeching's model embodied most of Wouldhave's ideas with improvements of which he had never dreamed, and, coming sixty-two years later, was the model for the first genuine self-righting boat ever built. This boat, with minor alterations, is practically the type of the self-righting life-boat of to-day.

The Watson Life-boat.—Another important step was taken in 1887, following on an accident at the end of 1886 to two self-righting life-boats on the Lancashire coast, in which twenty-seven out of twenty-nine of the two crews were drowned. A permanent technical sub-committee was appointed by the Institution whose object was, with the help of an eminent consulting naval architect—a new post created—and the Institution's technical officials, to give its careful attention to the improvement of the design of life-boats. The immediate result was the designing of a new type of life-boat, by Mr G. L. Watson, the famous yacht designer, who had been appointed consulting naval architect, and held that post for many years. The Watson life-boat did not self-right. It was a larger and more stable boat than the self-righter, had beautiful lines, was safe, weatherly, quick in stays and with a good turn of speed. With the design of this type a new principle was introduced, the principle on which the Institution's life-boats are still built. Broadly speaking, it is that with large life-boats intended to go well out to sea, it is better to set aside the self-righting principle and aim at great buoyancy and stability. Besides the Watson boats there are six other types of life-boat which do not self-right, in the Institution's fleet. More than half the fleet consists of self-righters, more than a quarter of Watson boats, and the remainder of these other types. The choice of boat is largely determined by the conditions of the coast on which it will be placed, but the crews are always consulted, and no crew is given a new life-boat unless it has already inspected it and expressed itself as satisfied. The first of the Watson life-boats was designed in 1890, and in the same year the first steam life-boat, named "Duke of Northumberland" was stationed at Harwich.

The Motor Life-boat—The first experiments with an internal combustion engine were made during the year 1903. With these experiments began the modern era of life-boat work. To design an engine which should comply with the stringent requirements of the service might well seem an insoluble problem. Such an engine had to be water-tight but not air-tight, and able to run under all conditions of night and storm without attention. It had to have con-

trols not only simple but easy to distinguish by touch, so that they could be worked in the darkness. It had to run and to lubricate itself with certainty at any angle. At the same time, when the capsizing point was reached it had to cut itself off automatically, for, otherwise, if the boat were of the self-righting type, she would right herself and be carried away by her engine, leaving the crew in the water. In addition to all this, the engine must interfere neither with the self-righting quality of the boat, nor with its sailing powers. The first life-boat to be converted to motor power was completed in 1904, and sent to Tynemouth. She had a 12 h.p. two-cycle motor. The Institution has now sixty-five motor life-boats in its fleet, and it is hoped in the next few years to increase this number to over a hundred. By its ability to attain a speed and to cover distances impossible for boats which depend upon sails and oars; by its power to force its way in the face of winds and seas before which rowing and sailing boats would be helpless, and, above all, by its great manoeuvring power when close to the wreck, the motor life-boat can save lives which, without it, would be beyond the reach of human aid.

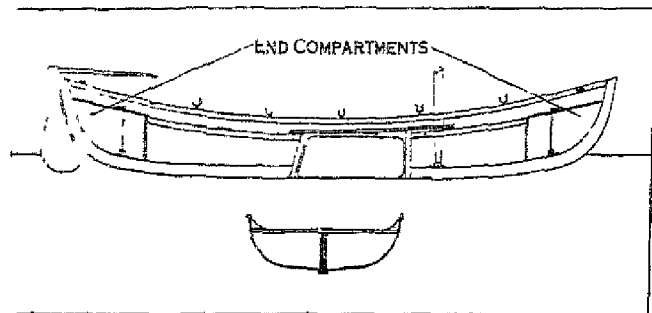
Greathead's life-boat was an open rowing boat, 30 feet long. She had no other source of buoyancy than cork could give her, no other means of ridding herself of water than by baling, no other means of propulsion than by oars. That the largest of the modern motor life-boats are twice as long as the smallest part of the difference. Instead of baling tins they have automatic valves which empty out the water as fast as the sea can pour it in. Instead of cork they have as many water-tight compartments as a modern battle-cruiser. Twenty holes might be knocked in each side, and they could still go on with their work. They are practically unsinkable. Instead of oars they have engines so designed that they can go on running when completely submerged, so long as the air-intake is above water. They have cabins, electric searchlights, line-throwing guns, with a range of 80 yards, and oil-sprays for spraying oil on heavy seas. The largest of these life-boats, the Barnett Twin Screw type, has two engines, each of 76 h.p. She has 15 main and 100 minor water-tight compartments, and two cabins with accommodation for between 50 and 60 people. In a calm sea she could take 300 people on deck. Under most conditions of bad weather she could in safety carry 150 people in addition to her crew. She carries enough petrol to be able to travel 500 miles at a cruising speed of 8 knots, and her maximum speed is 9½ knots. This may not seem a high speed, but a life-boat is not built for high speed, but so that she can maintain her speed under practically any conditions of weather.

All the Institution's engines for motor life-boats use petrol for fuel in order to obtain the greatest power for a given weight. The earliest types were adaptations of various designs of commercial engines, the most successful being an adaptation of an engine built by Messrs Tylor and Company for lorries. It was, however, soon found that a water-tight engine was essential in order that it might continue to work even when the life-boat had been holed in the engine-room. As there was no such engine on the market the Institution produced a design of its own for a six cylinder 76 h.p. engine and the first was built in 1923. This has been followed by an improved type, of which there are two variants, one being a four cylinder engine producing 40 h.p. and the other a six cylinder engine producing 60 h.p., one, or two, of these engines being installed in a life-boat, according to its size and type. A light 35 h.p. engine has also been adapted to the Institution's requirements for use in the specially light type of life-boat built for launching from the beach.

Life-boat Houses and Slipways.—The largest type of motor life-boats lie afloat, and in one or two cases the life-boats lie on the open beach, but for the most part they are kept in houses, various methods of launching being used according to the type of foreshore. The most effective, because the quickest, is down a slipway. For a slipway to be built, however, it is necessary that the shore should be steep enough to give a sufficient depth of water for launching the boat at any state of the tide. Slipways for the most part, are built of reinforced concrete, the longest at Porthumlaen, Carnarvonshire, being 351 feet in length. The usual slope is 1 in 5. The great majority of houses with slipways for

motor life-boats are provided with power winches for hauling up the boats. On flat sandy beaches life-boats are still launched off a cradle, which is taken out into the sea until a sufficient depth is reached to float the boat, and a specially light type of motor life-boats are used for such stations. Instead of horses motor caterpillar trolleys are now used at an increasing number of stations; these trolleys not only drag the life-boat down to the water's edge, but push it out into the sea.

Modern Life-Boat Equipment.—All motor life-boats are provided with a line-throwing gun specially designed for the Insti-



PROPERTY OF THE UNITED STATES COAST GUARD
FIG. 2.—PROFILE AND HULL SECTION OF 26-FT SURF BOAT

tion by the Birmingham Small Arms Company. The gun is similar to a carbine with Martini Henry breech action. The line is coiled up in a tin cylinder which fits over the barrel. One end of it is attached to a hollow steel projectile and this projectile has a rod down the centre, the rod having the diameter of the bore of the gun. The gun is loaded by slipping the projectile over the muzzle so that the rod goes inside the barrel, while the rest of the projectile fits outside it, in the space between the barrel and the cylinder holding the line. The projectile is fired with a small cordite cartridge which has a very small recoil, and as the weight of the gun, complete with projectile and line, is only 14 lb. it can be easily handled. There is no need for firing sights, and the correct angle at which the gun should be held is automatically obtained by a small plumb-bob suspended from a leaf-sight fixed at an angle of 30 degrees. The line used is $\frac{3}{16}$ in. in diameter, and can be thrown a distance of sixty to eighty-five yards, according to the conditions of the weather.

The majority of motor life-boats are provided with electric searchlights specially designed to be water-tight and simple to manipulate. They are of two kinds a portable searchlight of 100 candle-power and a mounted searchlight of 2000 candle-power, the latter being used only on the largest type of boats. The largest type of life-boat the Barnett twin-screw is provided with a net stretched amidships into which those on board the wreck can jump as the life-boat lies alongside.

The Crew.—All pulling and sailing life-boats are launched for an exercise once a quarter and all motor life-boats once a month, for testing the machinery and once a quarter for drilling the crew. A crew varies in number from 6 and 8 in the case of motor life-boats to 13 and 17 in the case of pulling and sailing life-boats.

The Life-boats in the World War.—At the beginning of the World War there were already nineteen motor life-boats on the British coast. For four and a half years all construction was suspended. Boats already begun were left unfinished until the war was over. Even the work of repairing damaged boats was sometimes impossible. But though the war came at a time of critical development in the life-boat service and delayed that development for over four years, it found the service ready for every emergency. The brief chronicle of its war-rescues is that from the outbreak of war in Aug. 1914, to the signing of peace in July 1919, the life-boats were launched 1,808 times and 5,322 lives were rescued. The boats were launched 552 times to the help of ships or aircraft of the navy or to merchant vessels wrecked or in distress on account of the war. Besides those 5,322 lives the life-boat saved 186 boats and vessels. The bulk of the crews who did such fine work in the mine-sweepers, trawlers and drifters were drawn from the fishing population which, for generations, has manned the life-boats. On one of a crew

of eighteen, twelve were over fifty years of age and two of the twelve were men of seventy-two.

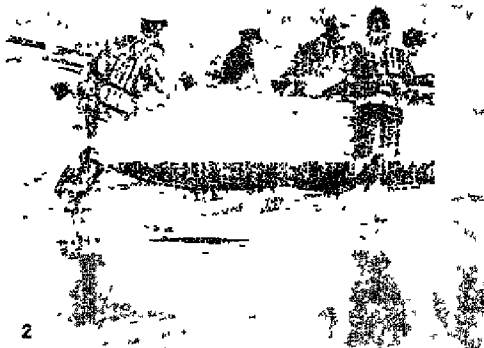
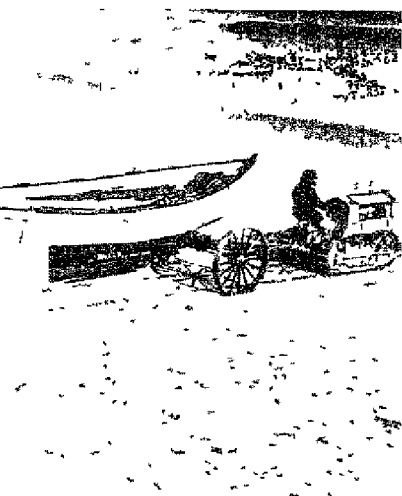
Relations with the Government.—In 1893 a representative of the Institution moved a resolution in the House of Commons that, in order to decrease the serious loss of life from shipwreck on the coast, the British Government should provide either telephonic or telegraphic communication between all the coast-guard stations and signal stations on the coast of Great Britain, and that where there are no coast-guard stations the post offices nearest to the life-boat stations should be electrically connected, the object being to give the earliest possible information to the life-boat authorities at all times, by day and night, when the life-boats are required for service, and further that a Royal Commission should be appointed to consider the desirability of electrically connecting the rock lighthouses, lightships etc., with the shore. The resolution was agreed to without a division, and though its intention has never been entirely carried out, the development of wireless should, in due course, provide a simple and efficient means by which, eventually, all lighthouses and lightships will be connected with the shore.

Finance.—When the Institution was founded, it was laid down as one of its chief objects to reward those who rescued life from shipwreck, and give relief to the widows and families of those who lost their lives in attempting to save others. In carrying out these objects the Institution has long since worked on a carefully prepared scheme of rewards and pensions. In 1893 a pension and gratuity scheme was introduced by the committee of management under which life-boat coxswains, bowmen and signalmen of long and meritorious service, retiring on account of old age, accident, ill-health or abolition of office, receive special allowances as a reward for their good services. This was followed in 1917 by a pension scheme for the widows and dependent children of life-boatmen who lose their lives as a result of rescuing or attempting to rescue life from shipwreck. For many years before that date it had been the practice of the Institution to pay a gratuity of at least £100 to the widow, and £25 for each dependent child. The financial obligation assumed by the Institution towards those who risk their own lives in attempting to rescue life from shipwreck may be summarised as follows.—It gives retaining fees to coxswains, second coxswains, etc., and wages to motor mechanics; it gives rewards for every rescue or attempted rescue from shipwreck round the coasts of Great Britain and Ireland by whomsoever performed, it compensates life-boatmen injured on service. It pays pensions or gratuities to coxswains, bowmen and signalmen of long and meritorious service, it pensions the widows and dependent children of life-boatmen who lose their lives on service.

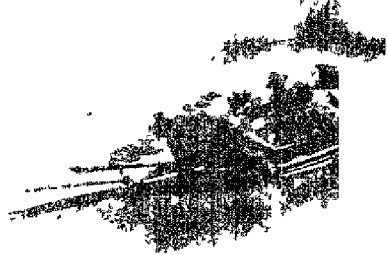
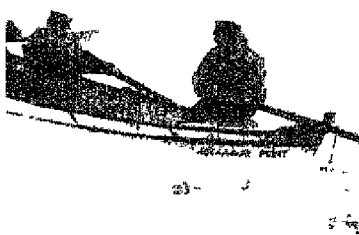
The 40 years after the duke of Northumberland reorganized the Institution were years of many experiments and immense developments. In 1851 there were only 30 life-boats on the coast, and the Institution's income was under £800. In 1890 there were 300 life-boats, and the ordinary income of the Institution was over £42,000. Unfortunately, developments outstripped the increase in income, great as this had been, and in the year 1891, the total expenditure was over 275,000, nearly double the income. Once again the life-boat service was in the greatest need of increasing public interest in its work, and it found the means in the Life-boat Saturday Fund, which was founded by Sir Charles W. Macara, Bt., in 1891. This fund was started as a result of the public interest aroused by the disaster, already mentioned, to the two life-boats on the Lancashire coast in 1886. It remained in existence until 1910, when its work and organization were taken over by the Institution, and during those 19 years it raised nearly £300,000.

The use of mechanical power wherever possible, while it has greatly increased the efficiency of the service, has necessarily increased its cost. At the end of the 19th century a thousand pounds was sufficient not only to build but to endow a life-boat, so that, out of that sum, it could be replaced in perpetuity. To-day a motor life-boat costs, to build alone, from £4,500 to £14,000 while the boat house and launching slipway cost, on an average as much as the boat. At the beginning of the century the Institution required annually to provide and maintain the service,

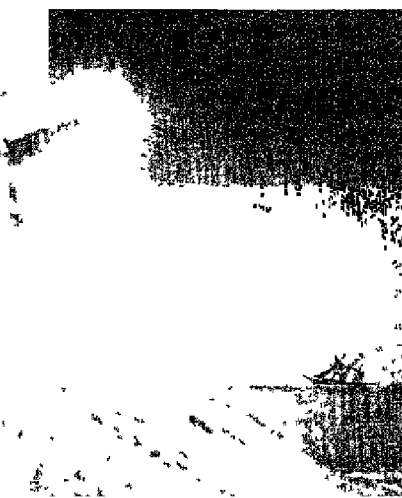
FE BOAT AND LIFE SAVING SERVICE



2



4



LARD

UNITED STATES COAST GUARDSMEN USING FLARES AND LAUNCHING LIFEBOATS FOR RESCUE WORK

abreast of wreck for launching. Boat is constructed on cradle chassis, and is hauled by a team of horses or members of the crew. The crewman (extreme left) is the last to enter the boat and the oarsmen in their places. Every man is required to wear a lifebelt. The boat is launched from a station, New York, just after launching. The men in their places and the captain on board. Skill and strength, with steady nerves are required to launch or land a boat through

- 5. Surfman, upon discovery of a vessel in distress, is answering with the Coston light or beacon signal to let the vessel know that help is at hand.
- 6. A life-saving crew burning flares to illuminate a vessel. Stations are supplied with powerful acetylene flares for this purpose, which are practically wind and water proof. They cast an intense diffused light over the entire field of vision. The hand lights are generally used only for signaling a vessel into danger, or to notify a stranded vessel that help is at hand.



£100,000 It now requires £250,000 In order to obtain this much larger sum it has greatly extended its methods of appeal In 1921 the Ladies' Life-boat Guild was formed, to unite in one body the many hundreds of women who were working for the Institution In addition to over 200 life-boat stations, the Institution has over a thousand financial branches and guilds, with thousands of voluntary workers attached to them It is one of the remarkable features of the Institution's work that, in spite of the great changes and developments which have been made in the course of over a century, it is still maintained by voluntary means

National and International Aspects.—It is still more remarkable that even those who believe in nationalization would not nationalize the life-boat service, and one of the best tributes to its success as a voluntary organization was paid by a leading exponent of socialist theory, Mr Sidney Webb, when he was president of the Board of Trade He said that "one of the Institution's glories is that it is entirely voluntary," and to that he added an interesting analysis of the reasons why the Institution has succeeded as a voluntary body "One of the advantages of voluntary organization is that it can initiate and experiment, which is very difficult for a Government department"

The British life-boat service has been the acknowledged model of the other life-boat services of the world, and of the fourteen other countries which have national services, Holland, Belgium, the United States, Germany, Denmark, Norway, Sweden, France, Russia, Spain, Japan, Portugal, Latvia and Iceland, only four are maintained by the State, those in the United States, Belgium, Denmark and Russia Four of the remaining nine—those in Germany, Norway, Sweden and Spain—were originally State-services, but they have since been handed over to voluntary organizations, or such organizations have been set up to supplement the State-service.

In 1924, by which year it had given rewards for the rescue of nearly 60,000 lives, the Institution celebrated its centenary, and those celebrations showed what a secure place it holds in the pride and affection of the British people. The King personally decorated with the Medal of the Order of the British Empire the eight men still living out of the eighty-seven who during the century had won the Institution's Gold Medal, the Victoria Cross of the Life-boat Service On its hundredth birthday, March 4, the Institution held a centenary meeting at the Mansion House Shortly afterwards an international conference was held in London, attended by delegates from eight foreign countries, while five of them sent life-boats, so that, for the first time, an international life-boat fleet lay on the Thames At this conference it was unanimously decided that an international life-boat organization, on the lines of the Red Cross Society, ought to be formed, and that it was desirable to have some organization for saving life from shipwreck in all the maritime countries of the world. This resolution was brought to the notice of the governments of all maritime countries and of the League of Nations It was discussed at a meeting of the League's sub-committee on Ports and Maritime Navigation in the following year, at which the Institution was represented by its secretary, and the sub-committee decided that it could best encourage the promotion of life-boat services by asking governments to induce their national life-boat organizations to keep in constant touch with one another For this purpose the sub-committee placed its own secretariat at their disposal Thus, a little more than a century after Sir William Hillary launched his appeal for a national life-boat service, the international value of such services, and the duty of all maritime countries to provide them for the succour of the seafarers of their own and other nations, were fully and formally recognized.

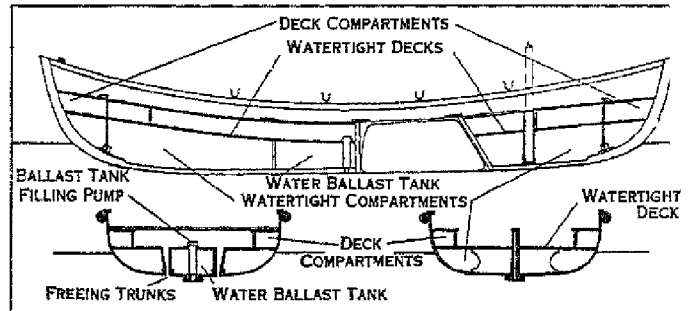
For the use of rockets in life-saving, see ROCKET AND ROCKET APPARATUS

(G F SH)

THE UNITED STATES

The Life-Saving Service of the United States was merged with the Revenue Cutter Service in 1915, the combined service taking the name of the Coast Guard (*q v*). The Life-Saving System, while an integral part of the Coast Guard retains its distinctive organization equipment and methods of operation

Extent of Operations.—In the extent of coast-line covered, the magnitude of operations, and the extraordinary success which has crowned its efforts, the Life-Saving Service of the United States is not surpassed by any other institution of its kind in the world. Notwithstanding the exposed and dangerous nature of the coasts stretching between the approaches to the principal seaports, and the immense amount of shipping concentrating upon them, the



BY COURTESY OF THE UNITED STATES COAST GUARD

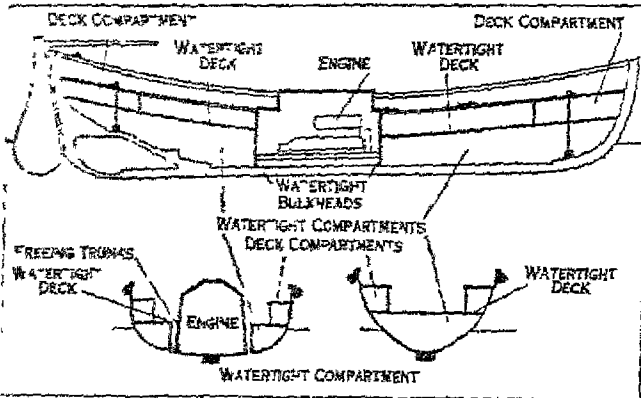
FIG. 3 — PROFILE AND TWO SECTIONS OF 25 FT 6 IN SELF-BAILING SURF BOAT (MODEL H)

loss of life, out of a total of 178,741 persons imperilled by marine casualty within the scope of operations of the service, from its organization in 1871 to June 30, 1914, was 1,455—less than 1%—and even this small total is made up largely of persons washed overboard immediately upon the striking of vessels and before any assistance from shore could possibly reach them, or lost in attempts to land in their own boats, and persons thrown into the sea by the capsizing of small craft

In the service, next in importance to the saving of life is the saving of property from marine loss. During the period named vessels and cargoes to the value of nearly \$300,000,000 were saved while considerably less than a quarter as much was lost Separate statistics of the operations of this branch of the service subsequent to its incorporation in the Coast Guard in 1915 are not available, but with the marked improvement in equipment following the perfection of motor-propelled boats, and the greatly extended radius of operation made possible thereby, the efficiency of the service has kept pace with the rapidly increasing volume of maritime commerce Brief statistics of the operations of the Coast Guard as a whole during the year ending June 30, 1927, are given in the article on the COAST GUARD The number of persons aboard vessels assisted during that year alone was 14,496, and the value of the vessels and cargoes was nearly \$40,000,000

The Massachusetts Humane Society, as early as 1789 began the erection of rude huts along the coast of Massachusetts for the shelter of any destitute persons who might escape death in the sea At first no attempt was made to provide means of rescue but in 1807 a station, equipped with a boat for use by volunteer crews, was erected at Cohasset, Mass, and additional stations were placed at exposed points along the coast from time to time The Federal Government, soon after its organization at the close of the Revolutionary War, commenced the erection of lighthouses, which were placed under the charge of the Treasury department, but it was not until 1838 that it was suggested, by two officers of the navy who had been assigned to make a general inspection of the lighthouse system, that life-boats be added to the equipment of seven of the lighthouses, and it is not recorded that this suggestion bore any immediate fruits However, on March 3, 1847, Congress appropriated the sum of \$5,000 "for furnishing the lighthouses on the Atlantic coast with means of rendering assistance to shipwrecked mariners" No steps having been taken to expend this sum, the Massachusetts Humane Society in the following year made application to the secretary of the Treasury and was granted the use thereof. The society at that time represented that it was maintaining "16 or more life-boats on the coast at the most exposed places, also a number of houses on exposed beaches During the period from 1849 to 1870 this society secured additional appropriations aggregating \$40,000 from Congress for the prosecution of its work The society today maintains twenty-one stations on the Massachusetts coast.

First Government Efforts.—The first Government life-saving stations were clam boat-houses, a few of which were erected along the coast of New Jersey in 1825, each equipped with a fisherman's net-boat, a net for firing a line across a stranded vessel, a life-raft or embryo metal boat to be hauled between the shore and wreck and a few simple accessories. In 1840 the service was extended to the coast of Long Island, and in 1850 one station was



BY COURTESY OF THE UNITED STATES COAST GUARD
 FIG. 4.—PROFILE AND TWO SECTIONS OF 26 FT. MOTOR SELF-BAILING LIFE BOAT (MODEL H)

placed on the Rhode Island coast, thus protecting the coasts converging in the principal American seaport, New York city. No provision was made for crews or even for responsible caretakers and as a result the buildings and equipment rapidly deteriorated from the ravages of the elements, and much of the equipment was stolen or destroyed. In 1854 provision was made for the appointment of port keepers for the New Jersey and Long Island stations, and a superintendent for each of these coasts, marking the beginning of an organized effective governmental life-saving service. Volunteer crews were depended upon until 1870, when Congress authorized crews at each alternate station for the three winter months.

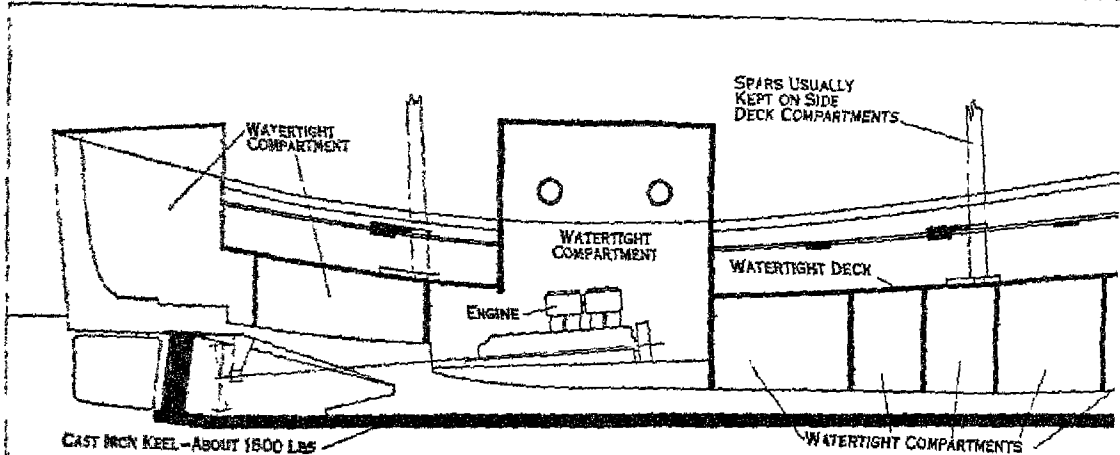
The present extensive and thoroughly organized system was inaugurated in 1871 by Sumner I. Kimball who in that year was appointed chief of the Revenue Cutter Service which, some years

pointments and promotions was inaugurated for the government of the service and were adopted and enforced. A beach patrol the hours of darkness and in thick and stormy time, for the warning of vessels standing prompt discovery of such as were cast ashore. result of this transformation was immediate end of the year not a life had been lost by service, and during the next year but one service now embraced the dangerous coast.

Establishment of Regular Service. to grow rapidly in extent and importance established the Life-Saving Service as a organization, operating under the Treasury administration was placed in the hands of appointed by the president and confirmed of office being limited only by the will of ball, who had displayed such energy and merit, was appointed to this position, when the Life-Saving Service was united with the Revenue Cutter Service in 1915, when in recognition of his distinguished service he was granted the unique distinction of being the first member of the Government outside of the judiciary.

Organization.—The service in 1928 with 277 stations of which 252 were actual points upon the sea and lake coasts. Eight and Gulf coasts contained 193 stations, 1 refuge on the coast of Florida, each in a district without crews, three districts on the Chesapeake, including one at the falls of the Potomac; and two districts on the Pacific coast including one within the Arctic circle at Sitka.

Each district is in command of a district commander, a commissioned officer of the Coast Guard who undergoes a special examination from the warrant office. The district commander has immediate supervision of the stations, the selection and enrollment of crews, the enforcement of discipline, the assignment, the enforcement of discipline of supplies and equipment, and the purchase of property. He is held responsible for the efficiency



BY COURTESY OF THE UNITED STATES COAST GUARD

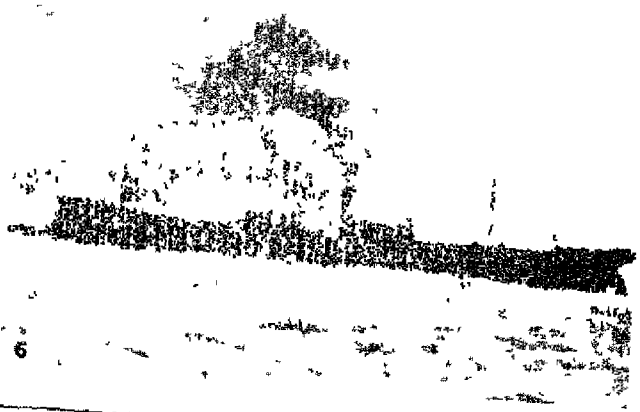
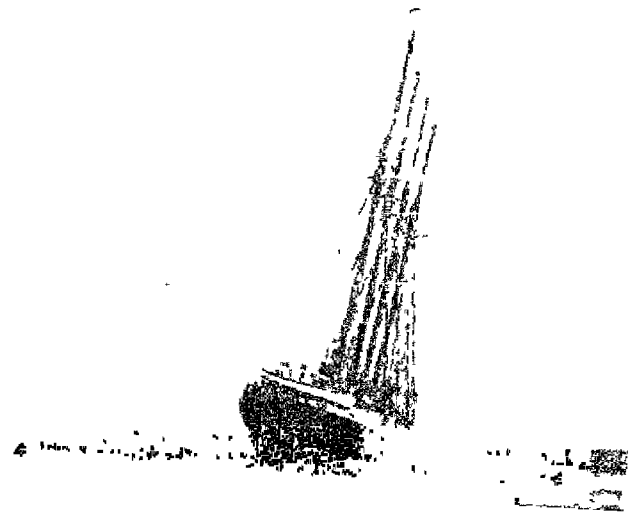
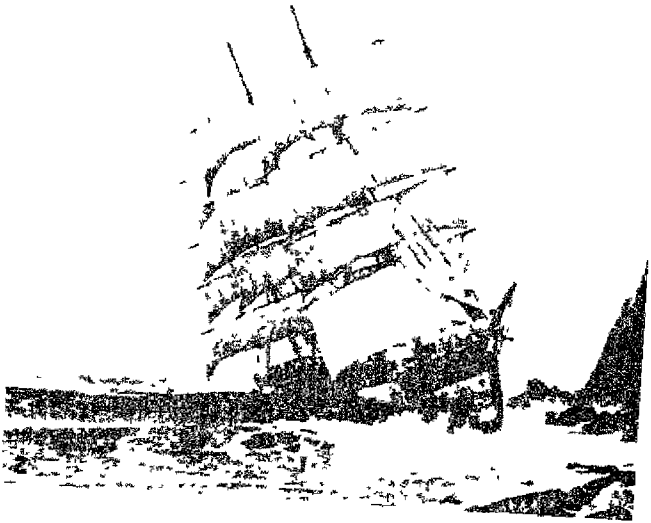
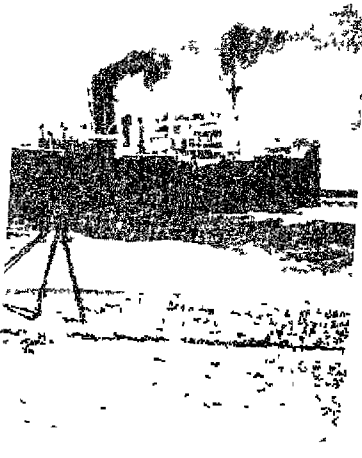
FIG. 5.—PROFILE OF 36 FT. SELF-BAILING AND SELF-RIGHTING MOTOR LIFE-BOAT

earlier, had been given charge of the embryo system. He secured from Congress an appropriation of \$200,000 and authority for the employment of crews for all stations for such periods during the year as were deemed necessary. The existing stations were thoroughly overhauled and put in condition for the housing of crews, the best available boats and equipment were provided; inefficient station keepers, who had secured appointment through political influence, were succeeded by men carefully selected for their skill and experience. Additional stations were established, and all were manned by capable surfmen; the merit system of ap-

pointment, and is a bonded disbursing officer. The district commanders are assisted in the performance of their duties by warrant officers (boatswains) selected from the crews and put in charge of stations.

The maintenance of the property, buoys, sea walls, etc., is in the hands of the district commanders, who report to headquarters in Washington, with a view to the immediate personal charge of extensive general administration of the service is in the hands of the Coast Guard with headquarters at Washington.

E BOAT AND LIFE SAVING SERVICE



IN PROGRESS AND VESSELS ASHORE AND AFIRE AFTER LIFESAVING

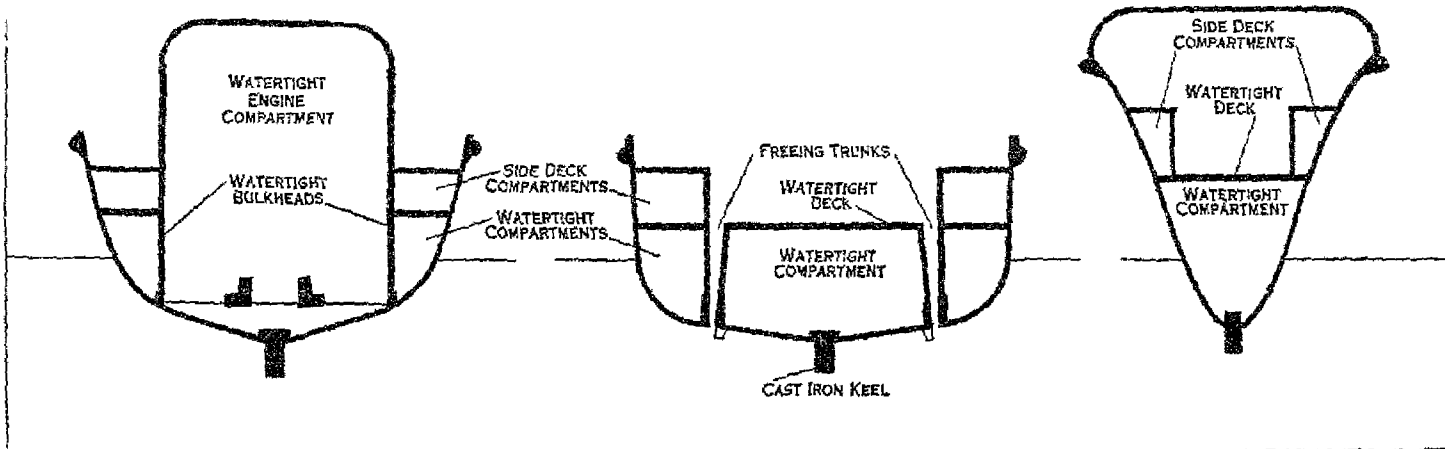
1 ashore, Peaked Hill Bar, Cape Cod, men on the beach have shot a lifeline Lytle line-throwing gun. Persons are or breeches buoy (see fig. 3)

2 "slin" ashore on Oregon coast. Many rous coasts during earlier days before ng stations. Sailing vessels were par n a lee shore because of difficulty in

3 device which travels on a hawser vessel and the shore. The buoy con-

- sists of a cork life-preserver having breeches attached. Suspended a pulley on the lifeline, the apparatus holds occupant securely. 1 to ship and shore control passage
- 4 Schooner "Annie C. Ross" stranded on sandy beach near Pens. Florida. Hull of ship rests on sand, lessening chance of breaki
- 5 A steam trawler or fishing vessel ashore resting on her port side type of vessel operates largely outside of regular ship lanes, whe danger of running ashore is increased by the absence of light
- 6 Steam freighter "Cabo Hatteras" afire at sea. Crew was rescued an ship, which had become a menace to navigation, was later su. gunfire and mines from U. S. Coast Guard Cutter "Seminole"





BY COURTESY OF THE UNITED STATES COAST GUARD

FIG 6—THREE SECTIONS OF A 36 FT SELF-BAILING, SELF-RIGHTING MOTOR LIFE-BOAT

Station crews are composed of an officer in charge holding the rank of a boatswain, and, at a majority of the stations, from six to eight surfmen, with a larger number, up to as many as fifteen at certain stations where the service is particularly arduous. The number of men in each crew is determined principally by the number and kind of boats, the extent and nature of the coastline to be served, the climatic conditions at various seasons, and the amount of shipping in the locality. Nearly all stations are now equipped with motor-powered boats. One or more of the members of the crew are trained in the care, operation and repair of these engines, those so qualified being rated motor machinists.

For this purpose there is maintained, at the ship repair and boat building yard of the service, at Baltimore, Md., a school for the special instruction of men who show an aptitude for this work. The surfmen are enlisted for periods of from one to three years, after a thorough medical examination. All stations on the ocean coasts are in commission and fully manned throughout the year. The floating station at Louisville, and a number of stations on the Great Lakes situated at harbours where shipping is in operation during the winter months are in continuous commission.

Stations—The stations contain, as a rule, suitable living quarters for the officer in charge and members of the crew, and a boat and apparatus room. Many of the stations, particularly on the Lakes, have living quarters for the family of the officer in charge. Each station has a look-out tower for the day watch, on the station building proper, or separately placed at a point of vantage. In some places the dwelling and boat-house are built separately, and a number of stations also have additional boat-houses situated at danger points distant from the main station. Those equipped with the larger life-boats have launchways or marine railways for the launching of the boats directly into deep water, with power winches and cradles for launching and hauling out. The Louisville station guards the falls of the Ohio river, where life is much endangered from accidents to vessels passing over the falls, and to small craft which are liable to be drawn into the chutes. It consists of a dwelling with look-out tower, apparatus room, and ways for small boats, the whole mounted on a scow-shaped hull. Its equipment includes several river skiffs which can be quickly launched directly from the ways at one end of the station. These skiffs are modelled much like surf-boats, designed to be rowed by one or two men.

Equipment—The equipment of the stations consists of the beach apparatus—line-throwing guns, hawsers, bretches-buoys and life-car—flag and pyrotechnic signals, heaving sticks and lines, life-preservers and life-boats, surf-boats and other special types of boats. The outfits are practically the same at all stations, but the boats are of various types, depending upon their suitability for rescue work on the different coasts. The larger life-boats are too heavy to be launched from the beach into the surf, and launching ways are provided for them where comparatively smooth water prevails—on rivers, bays and inlets. The surf-boats are

mounted on boat-wagons by which they are drawn to a point abreast of a wreck and launched directly from the beach.

Beach Patrol.—The system of beach patrols maintained at all stations is of distinctly American origin, and has proved of great value in the saving of life and property. A fixed beat or patrol is laid out in each direction along the shore varying according to the conformation of the coast with respect to inlets, headlands, etc., from one-half to two, three or four miles in length. The station crew is divided into regular watches of two men each, who during the hours from sunset to sunrise, and during thick and foggy weather in the daytime, patrol these beats, keeping a sharp look-out seaward. The usual schedule is first watch, sunset to 8 P. M., second watch, 8 P. M. to midnight, third watch, midnight to 4 A. M., fourth watch, 4 A. M. to sunrise.

Positive evidence of the integrity of the patrol and watch is required. Where stations are sufficiently close to one another to permit the entire intervening distance to be patrolled, a half-way point is established, at which point each patrol-man must deposit a brass check bearing the name of his station and his number in the crew. This is taken up on the next visit by the patrol-man from the adjacent station, who in turn leaves his check. The first patrol-man at night returns all checks of the previous night. Where the patrols do not connect the patrol-man carries a watchman's clock or time detector, in which there is a dial that can be marked only by means of a key which registers the exact time of marking. This key is secured in a safe embedded in a post at the limit of the patrol, and the patrol-man must reach that point in order to obtain the key with which to register his arrival.

In some cases telephones are placed in half-way houses or at the end of patrols, by means of which the patrol-man reports to his station. In other cases the patrol-man is provided with a small portable telephone set with which he can communicate with the station from any point along his patrol. The Coast Guard owns and operates a telephone line system consisting of 183 separate lines, with a total mileage of approximately 2,650, including nearly 500 m. of submarine cable. Practically all of its stations, 160 lighthouses, and a number of other Government agencies such as naval radio compass stations, weather bureau stations, etc., are served by these lines, which are connected with commercial exchanges for both local and long distance service.

Assistance and Rescue.—On discovering a vessel standing into danger the patrol-man burns a pyrotechnic signal which emits a brilliant red flare, to warn the vessel of her danger. The number of vessels thus warned averages over 200 annually. The extent of the loss of life and property thus averted can never be known. When a stranded vessel is discovered, the patrol-man's Coston signal apprises the crew that they are discovered and assistance is at hand. He then notifies his station, either by telephone or by an electric hand flash using the telegraphic code. When such notice is received at the station, the officer in charge determines the means by which to attempt a rescue whether by boat or beach.

If the beach apparatus is chosen, the apparatus cart is hauled to a point directly opposite the wreck by motor tractor or team of horses or by the members of the crew. The breeches-buoy gear is unloaded and while it is being set up the officer in charge fires a line over the wreck with the Lyle gun, a small bronze cannon weighing, with its 18 lb elongated iron projectile attached, slightly more than 200 lb, and having an extreme range of about 700 yd though seldom available at ranges for more than 400 yd. This gun is the invention of Col David A. Lyle retired, U.S. Army. Shotlines are of three sizes, $\frac{1}{2}$, $\frac{3}{4}$, and $\frac{1}{4}$ of an inch in diameter, designated respectively, No. 1, 2, and 3. The two larger are ordinarily used, the No. 3 only for extreme cases. A line having been fired within reach of the persons on the wreck an endless rope rove through a pulley-block is sent out by it with instructions printed in English and French on a tallyboard to make the tail fast to a mast or other elevated portion of the wreck. This done a 3 in. hawser is bent on to the whip and hauled on to the wreck, to be made fast a little above the pulley-block, after which the shore end is hauled back over a stretch by means of tackle attached to a sand anchor.

From this hawser the breeches-buoy or life-car is suspended and drawn between the ship and shore by means of the endless whip-line. The life-car can also be drawn like a boat between ship and shore without the use of a hawser. If any of the rescued persons are frozen as often happens, or injured first aid and simple remedies are furnished. Dry clothing, supplied by the Women's Nat Relief Assn, is also furnished to survivors.

Boat Equipment.—All stations are equipped with boats adapted to the special requirements of the different localities and occasions. The three principal types of life-boats used in rescue work are a self-righting and self-bailing motor life-boat, a self-bailing motor surf-boat and self-bailing pulling boat.

The motor life-boat is 26 ft in length with an overall beam of 9 ft 2 in and an approximate draft of 2 ft 3 inches. Its weight with full equipment, not including fuel and crew, is about 12,000 pounds. It is constructed of wood with $\frac{1}{2}$ in planking. It is fitted with numerous water-tight compartments and has a water-tight deck, end compartments and a house over the engine. A cast iron keel weighing 7,500 lb extends the full length of the bottom and protects the propeller and rudder from injury. A semi-tunnel for the propeller is provided in order to obtain shallow draft. This boat develops to the highest degree the self-righting and self-bailing qualities so essential to a life-boat. It is equipped with a 44 hp gasolene engine, driving a 3-bladed propeller of 22 in diameter, and 16 in pitch, and has a speed of about 9 m ph under usual service conditions. Sails and oars are also provided for auxiliary use when needed. This type of boat is used at practically all stations on the Great Lakes, and along the ocean coasts in localities where sheltered inlets are available in which it can be safely launched or moored. It is an extremely able craft and will go through practically any surf and live in any sea.

The power surf-boat has a length of 25 ft a beam of 7 ft., and is equipped with a 20 hp gasolene engine. Like the larger life-boat, this type is also provided with self-bailing features, but is not self-righting. The construction in general, follows that of the larger boat except that water-tight end compartments and a house over the motor are not fitted. A small water-tight enclosure protects the motor from spray and seas. The boat is rather lightly but strongly constructed, and a semi-tunnel and shoe provide protection for the propeller when the boat is grounding. No sails are fitted, but oars and thwarts for the crew are provided. This type of boat is used generally at stations where it can be launched into the water on a carriage. It is also issued to the larger coast guard vessels for use as a life-boat.

A third type of life-boat which is generally used is the self-bailing pulling surf-boat, 25 ft 6 in. in length, and weighing about 2,000 lb. This boat has no engine, but is manoeuvred under oars and sails only. The construction is very similar to that of the life-boat and power surf-boat already described, having water-tight compartments and deck above the load water line with free-

ing trunks, which give it the self-bailing feature. Although not self-righting it can be readily righted by means of righting lines provided along the sides, which enable the crew easily to roll it right side up, when it quickly clears itself of water through the bailing trunks. It is fitted with a water-ballast tank filled by means of a hand pump, which increases the stability and sailing qualities of the boat. This type of boat is light and handy for use in launching through the surf directly from the beach and is an exceptionally able boat when used in rescue work in broken waters. It is generally mounted on a specially built boat-wagon on which it can be quickly transported along the beach to a point abreast of a stranded vessel. Sails and centreboard are embodied in the design, and are very effective when the boat is called to a considerable distance from the station. This type of boat is also used extensively as a ship's life-boat.

Special Service Boats.—Another type of boat in general use along the New England coast is an open whaleboat commonly known as the Monomoy surf-boat. This boat is neither self-righting nor self-bailing. It is propelled by oars and sails, and is a very seaworthy craft. A number of stations are supplied with fast motorboats especially designed for law enforcement duties, as distinguished from those here described, of heavier construction and less speed, provided for rescue work under adverse conditions of weather and sea in which the paramount consideration is seaworthiness and reliability of operation. Others, situated in sheltered harbours, where the principal source of danger is from accidents to pleasure craft, are provided with light skiffs or with small motorboats designed more particularly for speed.

(A T T)

LIFE GUARDS: see GUARDS AND HOUSEHOLD TROOPS

LIFE INSURANCE, a contract insuring the payment of money on the happening of any contingency, or one of a variety of contingencies, dependent on human life; as this definition would, however, include contracts for annuities or pure endowments, it should be limited by the condition that one of the contingencies should be death (except death by accident only). The sum insured is agreed upon at the outset and may be added to from time to time, out of profits or otherwise; life insurance therefore differs in character from other forms of insurance, the essence of which is indemnity to the insured for actual loss incurred.

The word assurance is more commonly used than insurance in connection with life contracts, the latter word being applied in general to contracts of indemnity, it is not, however, incorrect to use either word in any context.

Primitive Form of Life Insurance.—The principle that groups of persons should agree to make common cause against dangers which threaten all, but are individual in operation, is an old one. Action of this nature was moreover, in its origin, dictated by the interest of the group rather than by the interests of its members. As communications became more widely organized, the character of the group granting the benefit naturally tended to become that of a class or trade union, but until what are historically known as modern times, insuring associations were associations of persons, not of capital, and insurance of members would only have been one of their reasons for existence. Modern life insurance, mainly by companies, is concerned only with the risk to be insured against, and even institutions which were in their origin, distinguished by some bond of class or calling among their members, are usually open to do business with all comers and retain but a shadow of their earlier exclusiveness.

The beginnings of true life insurance that is to say, the payment of certain benefits on death against certain periodical subscriptions, are to be found in the Roman Collegia. The guilds of mediæval times would, in many cases, make provision for the decent burial of a member, but the extent of such assistance would depend on the actual needs of the dead man's dependants and was not, therefore, life insurance in the full sense.

Marine insurance is generally believed to have an earlier origin than life insurance and it is therefore natural that the first definite contracts of life insurance, made with underwriters as a matter of business, should have been on the lives of mariners. The earliest

contract of this type recorded to have been made in England was effected in 158

The First Companies.—An important step was the foundation in England of the first insurance companies. The Amicable Society for a Perpetual Assurance was founded in 1705, but provided merely for the dividing up of certain sums between the representatives of those members who died each year. The Royal Exchange Assurance Corporation and the London Assurance Corporation, both incorporated by royal charter in 1720, were, however, true life insurance institutions, and, with the Amicable, held the field for 40 years. During this period they effected only a moderate amount of life insurance business, also the contracts were still of the simplest nature, being as a rule for a term of one year.

The period of scientific insurance began with the foundation of the Equitable society in 1762. Until that date there had been no endeavour to graduate premium rates according to the age of the person insured, despite the obvious fact that such differentiation was called for. The material for calculating rates was, however, in existence although it was imperfect. Dr Edmund Halley's tables based on the deaths in the city of Breslau in the years 1687-91, and the death rates derived from the London bills of mortality of the period were the foundation of the society's first table of premiums. It is moreover notable that in addition to differentiating rates, the society introduced the principle of making a policy renewable from year to year throughout life. The success of the new venture was soon apparent. In 1776 it made its first actuarial valuation of assets and liabilities and returned part of the premiums paid to the insured by way of bonus, this was the beginning of the with-profit system, which might have been much longer in making its appearance, had it not been for the fact that the rates charged by the Equitable were decidedly on the safe side, although in most cases substantially less than the £5 to £6 per £100 for a year's insurance which had been the general rule until 1762.

The Gambling Act.—The Life Assurance Act of 1774, usually referred to as the Gambling Act, is a highly important landmark in the history of life insurance. Speculation in the lives of other persons, particularly public men, had become something of a scandal.

The Act forbade the issue of policies in which the names of the persons interested did not appear and also prohibited the insuring of lives in which the insured had no interest, the path was thus cleared for the development of life insurance for provident purposes only—its principal function.

The Equitable had the field to itself until towards the end of the century when the Westminster society was founded. This society instituted the principle of paying commission to agents for the introduction of business.

Many offices came into existence in the first half of the 19th century—a natural concomitant of the growth of the joint stock enterprise which marked that period. Incidentally the Joint Stock Companies' Registration Act of 1844 brought in a number of recruits, but many of these were mushroom concerns and most of the leading offices had commenced business before that date.

Events Leading to Act of 1870.—There was little restraint or check on the earlier operations of the companies (the Act of 1774 was a check on the insured, not the insurer) and it is therefore not a matter of surprise that concurrently with many carefully-managed institutions, there should have grown up others whose existence was undesirable. The description given by Dickens in *Martin Chuzzlewit* of the business methods of the Anglo-Bengalee Disinterested Loan and Life Assurance Company suggests what may have been the state of affairs with certain offices, but it was not wholly a caricature. Matters were brought to a head by the disclosure of the difficulties of two companies, the Albert and the European. Both these offices had been active in absorbing lesser concerns, and, in their greed for large figures, had in many cases paid unjustifiable prices to the shareholders of the companies absorbed, without regard to the interests of the original policy-holders or those to whom they subsequently became responsible. The Albert closed its doors in 1869, and although the European did not do so for another three years, its position was

a factor in hastening much needed legislation. The provisions of the Life Assurance Companies' Act of 1870 are essentially those which have governed the business in Great Britain ever since. Like most acts of parliament, it has been subject to amendment as the result of experience and it will probably be further amended in certain important respects by the bill of 1927.

The Scottish Widows Fund Life Assurance Society, established in 1815, was the first life insurance office founded in Scotland, where the business has, in proportion to the population, acquired even greater importance than it has in England.

Development Outside the United Kingdom.—Life insurance on the Continent, and in America, developed later than in Great Britain. The first successful venture in France was made in 1819, when the *Compagnie d'Assurances Générales sur la Vie* was founded. In Germany, branches of English offices were operating before the end of the 18th century, but the first German company was not founded until 1828. As for the rest of the Continent, just as the English companies had extended branches into Germany, Holland and Scandinavia, so the French companies pushed theirs into Italy, Spain, Belgium and Switzerland, and the existence of these branches gave an impetus to the formation of companies of national origin.

In addition to being served by English and Scottish offices, most of the British dominions and colonies have developed life insurance institutions of their own and the dominion offices have also carried their operations with vigour into the mother country.

The Contract and the Policy.—The first step in the taking out of a life insurance policy is the submission to the insuring company of a written statement called a proposal, setting out particulars as to the proposer's age, health, past illnesses and family history. The proposer warrants the correctness of his statements and the contract is voidable by the insurer should any of them prove untrue. In practice it is unusual for an office to make use of this power unless there has been a deliberate intention to defraud. If there is a medical examination, the truth of the statements made to the doctor is also warranted. In legal terms, an insurance contract is *uberrimae fidei*, that is to say based on the utmost good faith between the parties, and the proposer is bound to disclose all circumstances material to the risk, not excluding any in regard to which he may not be specifically questioned. The necessity for this arises from the fact that many matters essential to the contract can be only within the private knowledge of the person desiring to be insured.

Insurable Interest.—Another condition precedent to the granting of a policy is that the person effecting it should have an interest in the life to be insured, known as an insurable interest. This arises mainly from the provisions of the Act of 1774. Every adult person has, of course, an unlimited insurable interest in his or her own life. A wife has an unlimited insurable interest in the life of her husband, and it was decided in 1909 (*Griffiths v Fleming*) that a husband has a similar interest in the life of his wife. Except in the cases named the interest must be pecuniary, e.g. the interest which a creditor has in the life of his debtor for the amount of the debt.

The proposal, the warranted statements to the doctor, and the policy, constitute the entire contract between insurer and insured.

Modern British policies are simple in form, the essential facts and figures being incorporated in a schedule. Of the many restraints formerly in vogue, the only one in common use is the restraint on suicide during the first 12 months of the policy.

Surrender Values, etc.—Under whole life and endowment assurance contracts, where the annual premium is more than sufficient in the early years to cover the yearly risk, the office will return, after, on the average, two years' cash payments, a sum known as the surrender value. As current risk and expenses have to be allowed for, this is for policies of short duration considerably less than the total of the premiums paid. An alternative is to obtain a policy for a reduced amount, free from further premiums, this is known as a paid-up policy. Offices are as a rule prepared to lend back to the insured a proportion of the surrender value, 90% to 95%, the maximum amount which can be thus lent is the loan value. Under the laws of the State of New York insurance com

Companies are bound to state in their policies the surrender value for each of the first 20 years and this is also done voluntarily by many British companies.

What are known as non-forfeiture regulations provide for the continuance in full force, for a period, without payment of premiums of policies carrying surrender values under which a certain number of years premiums have been paid. The period may be for a year or it may be for a number of years until the surrender value is exhausted, a provision of the former type is common in Great Britain while the last mentioned plan is usual in America.

Proof of age, usually by the production of a birth certificate is required and this is best done at the outset, though it may be left until the policy becomes a claim.

Extra Risk—In between those risks which an office can accept at its tabular rate of premium and those which are unacceptable as a large body of risks which can be accepted on special terms. In Great Britain these are usually dealt with: (1) by an addition to the premium, (2) by the deduction for a period of years of a level or diminishing sum from the amount insured—described as a debt. The assessment of these risks is a matter of great difficulty, but special researches into the question of over and under weight, cancer, phthisis, circulatory disease etc., are by degrees making the treatment of the problem less empirical. In America the question is usually decided by a system of numerical ratings, positive and negative marks being given for different qualities and defects, while in certain Continental countries under-coverage lives are sometimes dealt with by reinsurance companies or pools, created *ad hoc*.

Extra risk due to the surroundings or occupation of the insured, as distinct from his individual peculiarities, is of a different nature. Extra premiums are charged for certain tropical countries, removable as a rule on return to a healthy climate, and in any case after a period of years these are known as climate extras, but the portion of the world to which they apply is an ever contracting one. The additional risk for the army and navy can usually be covered by a moderate extra 5s to 10s per £100 per annum available in peace time, no further extra is then demanded on the outbreak of war. The extra to be charged for the Air Force is still in process of evolution. Other occupations regarded as extra-hazardous are the liquor trade, and to a less extent, seafaring. Formerly it was usual to charge an extra to women under 40.

A person who has no definite prospect of going abroad or engaging in a hazardous occupation is given a policy which is termed world-wide and indisputable, and no climatic or occupation extra can thereafter be charged under such a policy, no matter where the insured goes or what he does.

Different Types of Insurance.—Life insurance policies may be for a definite sum throughout, or they may share in the profits of the company, such profits being allotted in the form of cash additions to the sum insured, or reductions of the premiums. In the following brief descriptions of the principal types of policy the word assurance is employed as being that in common use.

Whole Life Assurance—If the term is used without qualification the sum insured is payable at death, and the premiums throughout life.

Whole Life Assurance by Limited Payments—The sum insured is payable at death and premiums cease at death or at the end of an agreed period.

Endowment Assurance—The sum insured is payable at death or at the end of a fixed period when premiums cease.

Double Endowment Assurance—As above, except that the sum payable on survival of the agreed period is double that payable on death.

Joint Life Assurance—The sum insured is payable when the first death arises out of a group of two or more persons. Effected by partners in a business to provide a fund on the death of either of them.

Term Assurance—The sum insured is payable only if death arises within a period agreed upon. School fees policies are term assurance for sums payable annually until the expiry of a certain period, to that of a child's education.

Options—A term assurance premium may be increased so as to allow the insured to continue the policy at the end of a certain period as a whole life or endowment assurance at normal rates, whatever may then be his or her state of health.

Deferred Assurance—Children's lives may not be insured except for small sums under industrial policies. A deferred assurance policy may, however, be effected under which premiums are returnable in the event of the child's death before age 21 and which the child can continue after 21 as a whole life or endowment assurance, irrespective of health.

Group Assurance.—Insurance for a certain sum on the life of each member of a group of employees, usually term assurance renewable yearly, the sum insured often being one year's wages.

Certain special benefits are sometimes offered concurrently with life insurance. Disability benefit involves the suspension of premium payments during permanent disability and in its most developed form, the payment in addition of a monthly sum to the insured, usually 1% of the sum insured, without prejudice to the ultimate payment of the sum insured in full. Free medical overhaul at intervals and financial assistance towards surgical treatment are further examples of special benefits offered by certain offices.

Pure endowments, payable on survival over a certain period, are not strictly life insurance, but the granting of these forms part of a life insurance company's business.

Institutions Granting Life Insurance.—*Mutual life insurance institutions* are without shareholders and all profits go to the participating policy-holders.

Proprietary life insurance institutions are nominally controlled by shareholders, who however, only receive as a rule about 5% to 10% of the profits, the remainder going to the participating policy-holders.

Composite offices are those which transact more than one kind of insurance; they are, as a rule, proprietary.

Mortality Tables.—As this subject is dealt with under the heading MORTALITY STATISTICS (*q v*), the following remarks will be confined to a brief description of the principal tables used in connection with life insurance.

Breslau Table—Used by the Equitable society for its first premium tables.

Northampton Table—Based on deaths in Northampton, 1735-80. Constructed on unsound basis, but erring on the safe side when issued in connection with insurance contracts. The standard table till 1815.

Carlisle Table.—Based on census and death records in two parishes of Carlisle, 1779-87. The standard table till 1872, and used after that for valuing reversions etc.

Seventeen Offices Table—Constructed in 1838 from the experience of insured lives, but used more in America than Great Britain.

H^m (Healthy Males) Table—Based on experience of insured lives till 1863. The standard British table for 30 years from 1872.

O^m. (Office Males) Table—Based on experience of insured lives 1863-93. The standard table from 1903 onwards.

American Experience Table—Published in 1867. Adopted as standard in several States of the U.S.A.

Thirty American Offices Table.—Based on the experience of 30 American offices and published in 1881.

American Medico-actuarial Mortality Investigation.—An investigation into the mortality of special groups, based on the experience of American and Canadian life insurance companies. Deviations due to climate, race, height and weight, and various diseases and occupations, were analysed and published in 1903 and 1912.

Among the best known Continental tables are the A.F. (France) and the Gotha (German).

Sundry tables relating to the experience of residents in the tropics, both native and European, have been compiled.

The construction of a mortality table from the crude data is a complex process, but the tabulation of particulars taken from office records is greatly facilitated by mechanical devices as the P and Hoerth calculating sorting and tabulating ma

chines Graduation, that is to say the removal or smoothing down of irregularities not inherent in the data is the next step, and the tables in use by actuaries are eventually compiled by associating the graduated rates of mortality with various rates of interest to form what are technically known as commutation functions, the shaped bricks of the actuary's stock-in-trade, the combination of which in various ways enables him to compute his rates and value his risks. Select tables, as distinct from aggregate tables, are those in which the duration of the policy as well as the age of the insured is taken into account, effect being thus given to the light mortality resulting in the earlier years of insurance from the elimination of unfit lives.

New life insurance tables are in course of preparation which will unquestionably render the O^m table obsolete.

Life Insurance Legislation.—The following are the principal British Acts relating to life insurance.—

The *Life Assurance Act, 1774*, which stopped gambling insurance.

The *Life Assurance Companies Act, 1870*, which was amended by the *Assurance Companies Act, 1909*, is to be further amended by the *Insurance Undertakings Bill, 1927* (drafted by Departmental Committee, but not yet [1928] introduced to Parliament). The essential provisions of the Act of 1909 are (1) deposit of £20,000 with the High Court (2) annual balance sheets and revenue accounts in form prescribed, (3) valuation returns in form prescribed at least once in five years (4) separate funds for life business, fire business, etc. The most noteworthy additions of the 1927 bill are (1) separation of assets of different classes of business as well as separation of funds, (2) more detail and greater uniformity in returns, (3) powers enabling the Board of Trade to initiate steps for winding up an apparently insolvent company.

The *Policies of Assurance Act, 1867*, regulates the notification of dealings with policies to the insurance company.

The *Married Woman's Property Act, 1882* (Clause 11) and the *Married Woman's Policies of Assurance (Scotland) Act, 1880* confer certain powers on married women enabling policies to be effected for their benefit on their own lives or those of their husbands.

The *Life Assurance Companies (Payment into Court) Act, 1896* enables life assurance companies to pay money, the ownership of which is doubtful or in dispute into Court in certain cases.

The principle of British legislation is freedom combined with publicity.

The legislation of most of the British dominions and colonies is modelled on the Act of 1870 and amending acts. An additional provision met with in dominion legislation is the protection of the first £1,000 to £2,000 of life insurance, unless specifically pledged, against a deceased man's creditors. Canada follows the American model. In Australia insurance is regulated by the laws of the different States, in 1928 there was still no Commonwealth legislation, but the Government had announced its intention to remedy this defect. It may be noted that New South Wales had no specific legislation regulating life insurance up to 1927.

Legislation of Europe is as a rule more restrictive than that of Great Britain; in general it imposes a basis of valuation and places limits on investments.

Premiums, Reserves and Bonus Distribution.—Although in practice his functions are much wider, the primary business of the actuary of a life insurance company is to calculate premiums, value risks, and deal with the distribution of profits. The basis of an office's tabular premiums is a pure or net premium, "loaded" to provide for expenses, and, in the case of with-profit premiums, for bonus additions also; the margin for contingencies is, from the nature of things, larger for non-profit than for with-profit premiums. The annual premium for a whole life or endowment assurance is, owing to the fact that the risk increases from year to year, larger at first than is required to meet the bare risk (*i.e.*, the policy's contribution to the claims expected in the year) and from this there arises the necessity to set aside and invest the balance, the amount so accumulated is called the reserve. The excess interest earned and the saving of mortality and

(relatively to the assumptions on which the premiums are based), provide the main profits, to these there may be added certain extraneous profits, such as those arising from non-profit business. The different methods of allotting surplus have already been described, and there are various plans for dealing with bonus which is distributed by the reversionary bonus method, that is to say by way of additions to the sum insured. The principal of these are—(1) The *simple bonus* plan, which provides additions at a given rate for each £100 of original insurance and each year (within the valuation period) of duration, (2) the *compound bonus* plan, providing additions at a given rate to the sum assured and previously declared bonuses, (3) various *contribution* plans which aim in theory at a return to the insured of the surplus actually contributed. The tendency is for the valuation period to shorten, prior to the Act of 1909 the maximum was seven years, but that Act reduced it to five, and there is a growing inclination towards triennial and yearly distributions. It is obvious that while in non-profit business the rate charged is the main consideration, with-profit rates should be judged in relation to prospective bonus results, and that a high rate for a with-profit premium is not necessarily an uneconomic one.

Finance and Investments.—The investment of the funds of a life insurance office is one of the most important duties of its administration, and it is on the successful accomplishment of this function that its bonus earning power, and, in the long run its general prosperity, depend. The primary essential is security of the capital, and, subject to this, the earning of the highest rate of interest practicable. Formerly it was held that a life insurance company should keep a small proportion of its assets in readily convertible securities, but under normal conditions this is not really necessary, as the income of a progressive company exceeds its outgo and it is moreover in a position to obtain without difficulty all the credit it is likely to require to enable it to meet an individual emergency or to take advantage of an investment opportunity. In this respect its position differs from that of a bank and also from that of a fire office, which must always be in a position to meet the loss occasioned by a big conflagration, such as the San Francisco fire of 1906. The analogy in the case of life insurance would be an epidemic comparable to the plague a negligible risk.

Mortgages are highly suitable investments and generally absorb on the average rather more than a quarter of the funds. British government securities also account (1927) for about a quarter of the funds of all companies combined, but this is largely a result of the war and the proportion is diminishing. Home railway debenture and preference stocks are much favoured and sound industrial debentures are also bought to a certain extent. There are, moreover, certain types of security which give little or no immediate yield from interest but are certain to appreciate in value, such as low yielding redeemable stocks standing at a heavy discount, and reversionary interests. These are unsuited to the private investor, but thoroughly adapted to the needs of a life insurance office. As the funds commonly run to many millions of pounds, those responsible for their investment are of course able to effect the saving which arises from being able to underwrite new issues and to take up large lines of stock on preferential terms. Ordinary stocks and shares are engaging a certain amount of attention but only figure to a modest extent in life office balance sheets.

Amalgamations—The amalgamation and transfer of British life insurance business is regulated by legislation. The tendency of recent times has been for companies not to absorb other concerns but rather to secure control of them by acquisition of shares and so to avoid the amalgamation procedure necessary under the Act of 1909. A provision of the Insurance Undertakings Bill is that investments in and loans to controlled companies must be shown separately in the balance sheet, the sanction of court must be obtained for any fresh purchases of insurance stock or shares.

Expenses.—The expenses of a life insurance company are usually measured by comparing them with the annual premium income. The percentage thus arrived at is the expense ratio and it is generally in the neighbourhood of 75%. The expense ratio

may be unduly lowered when the year's income includes a large proportion of single premiums, or where bonuses are used extensively to reduce premiums; on the other hand a high expense ratio where business is large and increasing does not necessarily indicate extravagance. To avoid misleading comparisons, allowances should therefore be made for these factors.

Life Insurance and Income Tax.—Formerly a distinction was made between the method of taxing a purely life office and that of taxing the life insurance section of a composite office, but in 1915 this was altered, and the basis is the interest earned, less expenses. Should the profits exceed this they become the basis of assessment, but this is rarely the case.

A policyholder is entitled to a rebate on the premiums paid by him on a life insurance policy. The scale of rebate depends on the date of the policy, and on insurances effected up to June 22, 1916 (inclusive) if the income does not exceed £1,000, half the standard rate; if the income exceeds £1,000 but does not exceed £2,000 three-quarters of the standard rate; if the income exceeds £2,000, the full standard rate. As regards insurance made after June 22, 1916 for all incomes subject to tax, half the standard rate. The proportion of the premium subject to rebate is limited to one-sixth of the income and 7% of the amount guaranteed by the policy to be paid at death.

Life Insurance Outside the United Kingdom.—Although life insurance owed its early development to the efforts of British companies, the extent to which it is practised in the United States and certain of the British dominions is greater than in the country of origin. In 1921, for example, it was estimated that the average amount of insurance per head of the population was £109 in the United States, £81 in Canada and £44 in Great Britain. Moreover, the aggregate funds of the American offices are from three to four times those of Great Britain. The colossal dimensions of the leading American offices may be gauged from the fact that the Metropolitan Life Insurance Company of New York had (1917) funds of nearly £500,000,000—the largest aggregate of capital in the world.

Life insurance in the Crown colonies is extending and in India insurance on the lives of natives both by British and Indian companies is on an increasing scale.

On the Continent of Europe the practice of life insurance is not so widespread as it is amongst the English-speaking peoples. Sums insured per head vary from about £15 to £30 in Holland and Scandinavia to a few pounds in Germany, France, and Italy, where other forms of thrift are favoured. It is, however, probable that the average amount insured would have been considerably larger in all of the last mentioned countries had it not been for the currency depreciation caused by the World War.

Life Insurance and the World War.—A large proportion of the policies actually in force on the lives of civilians who joined His Majesty's forces were indisputable, and British insurance offices decided to make no extra charge even in cases where they were entitled to do so. Extras for new insurances ranged from £7 7s. per £100 at the outbreak of hostilities to as much as £20 per £100 per annum, and many offices declined to undertake the risk.

There were three main sources of war loss. Mortality in excess of the pre-war ratio cost the offices about £3,000,000 a year. Excess depreciation of investments—which was partly the result of increased income tax, and partly due (e.g., Russian bonds) to actual default—accounted for approximately £4,000,000 a year. Increased income tax added £500,000 a year to the loss. These losses rather more than absorbed the normal profits of the period.

The change in the character of life office investments was marked. United States railway bonds, which were largely held before the war, were sold freely, and replaced by war issues, and the holdings of British government securities rose from about 1% to a maximum of 38% of the total funds. The geographical field for securities has of course been greatly narrowed, the United States and Canada being unsuitable on account of the relatively low yield of investments there, while other portions of the world have had to be avoided on account of the insecure conditions prevailing.

Post-War Developments.—Post-war currency depreciation proved disastrous in many Continental countries. In Germany and Austria it eventually became useless to collect premiums and the efforts of the companies were devoted to converting such assets as remained into forms which would not depreciate in proportion to the currency. After the achievement of stabilization, it was, however possible to do justice to the older policy-holders under various valorization schemes and to start building up reserves again on a sound foundation.

The recovery of the British offices from the effects of the war has been remarkable. All war losses have been dealt with, and as the companies are actually able to invest, after allowing for income tax, at a higher rate than before the war, and mortality becomes steadily lighter, bonuses are on a higher scale than at any time in life insurance history. Expenses have been brought down nearly to the pre-war level. The temporary withdrawal of the American offices from the United Kingdom has resulted in an increase of business to Canadian and British offices.

The failure of the City Life Assurance Company in 1923 (and of the City Equitable Fire Insurance Company) emphasized the fact that although the Board of Trade might be fully aware that a company was in difficulties, it could take no action of itself, and that it might be difficult in practice to get the policy-holders to do so. To remedy this and other defects in the Act of 1909 a departmental committee was appointed in 1924 and its report resulted in the Insurance Undertakings Bill, already referred to.

Group insurance, disability benefit business, and insurance without medical examination, have all developed rapidly since the war. A policy without medical examination is no longer subject to any special restrictions, and the amount of insurance which companies are prepared to grant on any given life under this plan is increasing. An extension is also taking place in insurances on the lives of women.

A notable symbol of the restoration of normal working in life insurance was the holding in London, in June 1927, of the eighth International Congress of Actuaries, the first held since 1912. These congresses had previously been held at intervals of three years. The papers read on this occasion were therefore of great interest and value, embodying, as they did, the experience of all the leading countries of the world over a period of unprecedented changes.

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UNITED STATES

The first American companies were stock companies which have since given up the insurance and annuity business and have devoted their attention exclusively to banking or to execution of trusts—the Pennsylvania Company for Insurance on Lives and Granting Annuities, organized 1809; New York Life Insurance and Trust Company, 1830 (renamed Bank of New York and Trust Company, 1922) and Girard Insurance, Annuity and Trust Company, 1836. The first mutual company was the Mutual Life Insurance Company of New York which received a charter April 1842 and began business on Feb. 1, 1843, its first premium rates were based on the Carlisle and Northampton Tables and were those used previously by the New York Life Insurance and Trust Company. The New England Mutual, though chartered as early as 1835, did not begin the issuance of policies until Dec. 1841. The Nautilus Insurance Company was chartered 1841 as a joint

stock company was changed to mutual in 1841 and was renamed New York Life Insurance Company in 1849. Other early companies were the Mutual Benefit, 1845 and Connecticut Mutual, Penn Mutual and State Mutual, all in 1847.

Growth and Institutions.—There are now (1928) over 300 companies with assets, as of Dec. 31, 1927, of over \$15,000,000,000 and insurance in force of over \$90,000,000,000; in 1927 the premium income was nearly \$3,000,000,000 and the new insurance issued about \$19,000,000,000. All but about 50 are stock companies but the list of mutual companies includes almost all the very large companies so that about \$61,500,000,000, or over two-thirds of the total insurance, is carried by these mutual organizations. In addition to the regular stock and mutual companies are fraternal associations, primarily social or fraternal in character with about \$10,000,000,000 in force and assessment associations and stipulated premium companies with relatively small amounts.

Types of Insurance.—The life insurance now in force in the regular companies is made up of (1) ordinary, (2) industrial and (3) group. "Ordinary," issued by every company, includes policies for \$1,000 or more with premiums payable annually, semi-annually or quarterly (or in rare instances, monthly). "Industrial," most of which is in three large companies, is that paid for by a weekly premium of a multiple of five cents, collected at the policy-holder's home. "Group," the greater part of which is transacted by ten companies, is that issued to an employer to cover a stated minimum number of employees on some underwriting plan precluding individual selection. The insurance in force at Dec. 31, 1927, may be roughly sub-divided into \$67,000,000,000 ordinary, \$15,000,000,000 industrial and \$8,000,000,000 group.

State Legislation and Supervision.—An outstanding feature of the life insurance business in the United States has been the growth and character of State (as distinguished from Federal) legislation and the degree of supervision implied thereby. Each State has power to prescribe the terms and conditions upon which the insurance business may be conducted in the State and as a result insurance departments and codes of laws have evolved. The administration of the insurance department and the execution of the State law are in the hands of an insurance commissioner or superintendent of insurance whose powers and duties are defined by law. The general objectives are safety and equity to policyholders and economy of operation.

Character of State Laws.—The New York Law (see leading article for salient features) is of special significance because about 90% of the insurance in force in the United States companies and 85% of their assets are in companies authorized to operate in New York. The limitations on amounts of new business and of contingency reserve are peculiar to New York. Wisconsin also has an expense limitation and some other distinctive provisions. Colorado and Oregon permit the full preliminary term method of valuation which allows a large margin for initial expenses and reduces the reserve. Illinois and several other States recognize a modified preliminary term method which produces smaller margins and larger reserves on the higher-priced policies. Texas requires companies doing business therein to invest in Texas at least 75% of the reserves on Texas business. Minnesota policies must provide that the company may defer a policy loan not more than six months from the time application is made therefor. These specimen provisions will illustrate the diversity of State laws.

Agency Methods.—The growth of life insurance in America is largely due to the development and effectiveness of the agency systems, of which there are two types, (1) general agency, under which the total field agency expense is paid to a general agent for a specified territory—city, county, State or group of States—who pays all expenses including sub-agents' compensation, the margin being his profit and (2) branch office or managerial, where under the compensation of sub-agents and all other organization expenses are paid by the company through a salaried manager.

Finances and Investments.—Investments being governed by State laws, differ widely but in general are limited to (1) real estate, (2) mortgage loans, (3) collateral loans, (4) Government, State, county and municipal bonds, (5) mortgage bonds of railway and other commercial and industrial enterprises, (6) to a limited

extent preferred stocks and, to a still more limited extent common stocks of the corporations referred to in (5) and (7) policy loans.

Taxation.—State taxes, aside from licence fees, usually consist of a tax on premiums collected in the State of from 1% to 3% (2% is used by about half the States) with varying interpretations as to what constitutes "premiums." Reciprocity usually affects the application of such laws as between States. Massachusetts is unique in levying a tax (1%) on reserves. The Federal tax is an income tax, now (1928) 12% of the total income from interest, dividends and rents after deducting tax-exempt interest, 4% of mean reserve fund for year, dividends on stocks investment expenses paid, taxes and other real estate expenses and minor items.

War and Post-War Experience.—War mortality was not serious even for the few companies with extensive foreign business. For the latter the depreciation of foreign currencies more than offset extra losses. The influenza mortality of 1918-19 was extremely severe, amounting to about \$110,000,000 in the companies doing business in New York State. Post-War developments have included an enormous expansion in volume of business, the lowest mortality ever experienced, and a progressive decline (since about 1920) in the interest rate with corresponding appreciation of security values.

BIBLIOGRAPHY.—*National Fraternal Congress Table*, based on experience of some of the largest and oldest fraternal and largely used in valuing liabilities of fraternal societies (1868). *Standard Industrial Table*, based on industrial experience of Metropolitan Life, 1896-1905, recognized by New York as the valuation standard for industrial policies (1907). *American-Canadian Mortality Investigation*, compiled by a joint committee of Actuarial Society of America, American Institute of Actuaries and National Convention of Insurance Commissioners in response to a request of the latter for a table exhibiting recent mortality among American insured lives and based on experience, 1900-15, of new and old standard business of about 60 American and Canadian companies (1918-19). Many tables were derived. (See the mortality tables listed in the article on p. 52.)

Chief repositories of both technical and general articles of current and permanent interest are *Transactions*, Actuarial Soc. of Amer.; *Record*, Amer. Inst. of Actuaries; *Proceedings*, Ass. of Life Insurance Presidents; *Proceedings*, Association of Life Insurance Medical Directors; *Proceedings*, American Life Convention. For statistical summaries—*Reports* of the insurance departments of New York, Massachusetts and Connecticut; *Life Insurance Year Book*, Spectator Company of New York. For information regarding policy forms and other details of company operations, including current dividend scales—*Handy Guide*, Spectator Company; *Unique Manual-Digest*, National Underwriter Company. For critical review of company operations—*Life Insurance Reports*, Alfred M. Best Company. For actuarial textbooks and reports: H. Mow, *Life Insurance Primer*, J. B. Maclean, *Life Insurance*, *Actuarial Studies*, reports of specialized, medico-actuarial and American-Canadian mortality investigations, Actuarial Society of America. For investments: L. W. Zartman, *Investments of Life Insurance Companies*; For insurance law: A. J. Parker, *Insurance Law of New York*, *Corpus-Juris* and *Cyclopedia of Law and Procedure*, American Law Book Company (J. S. T.)

LIFE TABLES. It has long been recognized that there are certain influences which normally affect the duration of life, and that for a large number of individuals of a homogeneous class it is practicable to frame an estimate of their mortality experience. Such estimates at first were based on conjecture rather than on the scientific analysis of observed facts. This appears to have been the case amongst the Romans who had tables for calculating the values of life interests, and no more authentic bases seem to have been discovered until towards the end of the 17th century. The first approximately accurate mortality tables were compiled by Edmund Halley, and were based on the records of baptisms and deaths in the city of Breslau in Germany. About half a century later, De Parcieux published his *Essai sur les probabilités de la Durée de la Vie Humaine* in which were incorporated several mortality tables which were for many years in general use in France. Meanwhile De Moivre had propounded his well-known theory of the law of mortality, "that the number of lives existing at any age is proportional to the number of years intercepted between the age given and the extremity of old age." As he assumed that 86 was the limiting age, according to his table the number living at any age x was $86-x$.

In 1762 the Equitable Society (London) was formed and the

Life assurance began to develop. It was not, however, until the publication in 1771 of a table prepared by Dr Price for the records of baptisms and deaths in the parish of All Saints, Northampton, and the absence of the constructor of mortality tables can be said to have been founded. A revised form of this table published in 1853 afterwards became famous as *The Northampton Table*.

A Mortality Table—This consists of two columns showing the numbers out of an assumed number of births, surviving and dying in each subsequent year or age. The term *life table* in actuarial practice designates any collection of columns of functions involving the contingencies. The two terms are however commonly used indiscriminately in either sense.

There are two main sources from which material for the construction of a mortality table is obtainable, (a) the census returns and death registers of a community, and, (b) the records of assurance companies and other bodies whose operations involve the duration of life. The statistics relating to the general population are subject to misstatement of age and other inaccuracies and it frequently happens that the information is available only in groups of ages a circumstance which necessitates the subdivision of the group figures into numbers at individual ages. For numbers both of the population and the deaths are invariably recorded according to age last birthday. On the other hand, the data obtained from assurance companies are compiled from the individual records of policy-holders who are usually required to furnish evidence of their age before the contract is completed. The numbers living at each age, known as 'the exposed to risk,' can therefore be subdivided according to nearest age, age last birthday, or any other arrangement that may be convenient.

The functions most usually included in a life table and their relations to one another are—

l_x = the number of persons surviving at exact age x ,

d_x = the deaths in the year of age x to $x+1$ among the l_x persons who enter on that year,

$p_x = \frac{l_{x+1}}{l_x}$, the probability of a person aged x living a year,

$q_x = \frac{d_x}{l_x}$ the probability of a person aged x dying in a year, or

the rate of mortality at age x .

$e_x = \frac{\sum_{t=x}^{\infty} l_t}{l_x}$, the complete expectation of life, or the total

future life-time which on the average will be passed through by a person aged exactly x .

Actuaries frequently use tables involving other decremental forces operating in conjunction with mortality, e.g. marriage, widowhood, remarriage and withdrawal.

The construction of a mortality table is carried out by obtaining from the observation of a number of persons over a limited period the rates of mortality, q_x , to which they have been subject at each age. The values of q_x having been obtained, the mortality table is formed by selecting a suitable radix, usually taken for convenience as 100,000 at the youngest age in the table, and obtaining successive values of l_x by the formulae $l_x \times q_x = d_x$, $l_{x+1} = l_x - d_x$, or, since $q_x = 1 - p_x$, by the formula $l_{x+1} = l_x \times p_x$.

The other contents of the table can then be completed by means of the appropriate formulae.

If the recorded numbers of the population and of the deaths were free from irregularities and errors, the rates of mortality directly derived from them would if plotted graphically, be capable of being represented by a smooth curve. These conditions are never fulfilled in actual experience and it is necessary to submit the data, or the rates derived from the data, to a process of adjustment, technically known as graduation.

Factors Affecting Mortality.—Various factors influence the rate of mortality. Age, of course, is a fundamental cause of variation, as the form of a mortality table implicitly indicates. At birth the rate of mortality is high, but it immediately drops, and steadily decreases until about age 10 or 11, when it is at a minimum. Thereafter it increases slowly at first, but more rapidly with advancing age.

Sex is another element to be taken into consideration. Female mortality is generally higher than that of males. Certain special classes of lives are subject to abnormal mortality rates. Race, climate, social status, occupation, degree of urbanization or density of population, housing conditions and other aspects of environment, geographical situation, types of various diseases, are also factors which affect vitality. Of the utmost importance in connection with the experience of assured lives is the variation of mortality according to duration of assurance. Before a life assurance policy is issued, the proposer is usually required to undergo a medical examination or at least to furnish satisfactory evidence of good health. At entry into insurance the policyholder is therefore a "select" life. Select rates of mortality vary according to age at entry and duration of contract, and a "select table" is arranged in a form showing the select rates converging towards and finally running into the "ultimate" rates which vary only with age. When the effects of selection are ignored and all the data irrespective of duration are combined in one mortality experience, the table is designated an "aggregate" table.

Separate tables have sometimes been constructed by excluding the first five years' experience from the data obtained for the aggregate tables, and are called "truncated aggregate" tables.

When it is desired to compare the results of different investigations of mortality experience several criteria may be adopted, e.g. (a) the rates of mortality at selected ages throughout the table (b) the number of survivors at selected ages, (c) the probability of surviving a specified term of years from the attainment of selected ages, and (d) the expectation of life at selected ages. Of these criteria (c) is, perhaps, most generally satisfactory.

One feature which has been disclosed by successive investigations of the mortality experience of lives of the same class is the progressive improvement in vitality, the later investigations almost invariably revealing the lighter rates of mortality at all ages. There are no indications of any retardation in this tendency, and in several instances endeavours have been made to forecast its effects in the one case by a definite modification of the rates of mortality directly deduced from the experience, and in the other by a suitable adjustment of the annuity values.

Standard Tables.—Brief reference may now be made to the principal mortality tables.

The *Northampton Table* was constructed by a method which gave unduly heavy rates of mortality, particularly at the higher ages. It was however, the only authoritative measure of mortality available for many years and the assurance companies which performed had to adopt it as the basis of their scales of premium. The Government adopted it in 1808 for the grant of annuities, and thereby incurred a loss estimated at two million pounds before discarding it 20 years later. It was gradually superseded by the *Carlisle Table*, formed by Joshua Milne. This table was a great improvement on previous ones, and the extensive monetary tables which were based upon it are even now referred to.

The compulsory registration of births, marriages and deaths was introduced into England and Wales in 1837. The statistics which have thus become available, taken in conjunction with the successive decennial censuses, have led to the publication of a most valuable series of *English Life Tables*. The earliest tables were prepared by Dr William Farr, whose services in the development of the science of vital statistics are pre-eminent.

Simultaneously with the publication of the national tables various sectional tables have usually been prepared, e.g. the three successive *Healthy English Life Tables*, derived from the experience of the districts showing a low death rate. The most recent national table is the *English Life Table No 9*, based on the 1921 Census and the deaths in the years 1920, 1921 and 1922.

In the United States of America the first important tables prepared by the Government were based on the 1910 Census and the deaths in 1909, 1910 and 1911 in certain States situated mainly in the north-eastern section of the country. Numerous tables have been prepared from the records of life assurance companies, the earliest being those of Griffith Davies based on

experiences of the Equitable Society of London. Tables in general use have however been compiled from the combined experience of a number of Life Offices. The first table of this nature was the *Seventeen Offices, or Actuaries' Table*. The date of the close of the observations was Dec 31, 1837. It was a weakness of this table that it was based on contracts a large proportion of which were of short duration.

A more extensive investigation, that of the combined experience of 20 British Offices up to the end of 1863, was carried out by the *Institute of Actuaries*. Two very important tables were obtained from this investigation, those relating to healthy male lives, the aggregate $H^{(m)}$ table, and the truncated aggregate $H^{(m)50}$ table. Dr. Thomas Bond Sprague later prepared a select table, the $H^{(m)}$, based on the assumption that the experience of the first five years of assurance could be linked up with the $H^{(m)50}$ experience. Assurance business in Great Britain was for many years conducted on the basis of these tables.

The most recent investigation of the experience of assured lives in Great Britain is that known as the *British Offices Experience*, compiled from the experience of 60 British Offices during the period 1863-93. This investigation was carried out on a most elaborate and comprehensive scale, and the volume describing "*The Principles and Methods*" adopted is an indispensable handbook for all students of life tables. The principal tables were the $O^{(m)}$ select and the $O^{(a)}$ and $O^{(m)}$ aggregate tables, and the $O^{(m)}$ select and aggregate tables, based on the experience of participating and non-participating policies respectively. The mortality of other types of policies was also investigated, and indicated that generally the contracts with the lowest rates of premium showed the highest rates of mortality.

The mortality of annuitant lives was also examined, and the results published in the $O^{(m)}$ and $O^{(a)}$ tables, which displaced the tables derived from the earlier *Government Life Annuitant* investigations as the authoritative standard for annuity contracts. These tables are, in turn, being superseded by the *Life Office Annuitants 1900-1920 Tables A^(m) and A^(a)*, and those based on the contemporaneous mortality experience of Government Life Annuitants. In the United States the most recent authoritative table for annuitants is the "American Annuitants" table, compiled from the experience of 20 companies carried down to the year 1918. (See ANNUITY.)

In the United States the table which in addition to the *Seventeen Offices or Actuaries Table* is used as a standard mortality table is the *American Experience Table, 1868*, compiled by Mr. Sheppard Homans. It was intended to represent the death rate among insured lives in America after the effects of medical selection were eliminated, and has been universally employed for valuation purposes.

The most recent American investigation produced in 1918 the *American Men Mortality Table*, derived from the experience of 59 companies during the period 1900-1915, which has already had a great influence on the operations of American insurance companies.

BIBLIOGRAPHY—*The Institute of Actuaries, Text Book, Part II*, by Mr. George King has for nearly half a century been recognized throughout the world as the standard work on life contingencies. *Life Contingencies*, by Mr. E. F. Spurgeon, is a more recent textbook, published by the Institute of Actuaries as the successor to Mr. King's work. There are numerous papers in the *Journal of the Institute of Actuaries*, and in the *Transactions of the Faculty of Actuaries*. *The Theory of the Construction of Tables of Mortality*, by the late Sir G. F. Hardy, deals particularly with graduation. *The Principles and Methods* volume gives an account of the British Offices experience and in *Mortality of Annuitants, 1900-1920*, selection and future improvement in vitality are discussed. All these as well as numerous volumes of life tables are published by C. and E. Layton, London. A useful non-technical work, "*The Construction of Mortality and Sickness Tables—a Primer*," by W. P. Elderton and R. C. Fippard, is published by A. and C. Black, London. The English Life Tables are contained in successive *Decennial Supplements* to the Reports of the Registrar General, published by the Stationery Office. The English Life Table No. 9, together with a *Report on Life Tables*, by Sir Alfred W. Watson, K.C.B., the Government Actuary, is contained in Part I of the 1921 Decennial Supplement. *The Mortality of Government Life Annuitants, 1900-1920*, is also a Stationery Office publication. The Actuarial Society of America has published a number of

volumes on the investigation of mortality experience, and the *Transactions* of the Society include many important papers. Other works on life tables are included in the publications of the Spectator Company of New York. (P. G. B.)

LIFT: see ELEVATORS

LIGAMENT, anything which binds or connects two or more parts, in anatomy a piece of tissue connecting different parts of an organism (see CONNECTIVE TISSUES, JOINTS AND LIGAMENTS)

LIGAO, a municipality (with administration centre and 17 barrios or districts), near the centre of the province of Albay, Luzon, Philippine Islands. It is situated on the railway running to Albay. To the east is the Mayon volcano, which has the most perfect cone known and which in June 1928 was once more in a state of eruption. The rich volcanic soil produces great quantities of abaca, rice and coconuts. In 1918, it had three manufacturing establishments, five rice mills and 50 household industry establishments with outputs valued at 37,000, 125,500 and 30,500 pesos. Of the four schools, three were public. The language spoken is Bikol. Pop. (1918), 21,467.

LIGGETT, HUNTER (1857-), American soldier, was born at Reading, Pa., on March 21, 1857. He graduated from the U.S. Military Academy in 1879, and saw service in the west against the Indians. In the Spanish-American war in 1898 he served on the staff of the adjutant general, and later was in the Philippines where, as major of volunteers he served for three years. In 1902 he was appointed a major in the regular army and spent several years with the department of the lakes and at Fort Leavenworth. In 1909 he attended the War college, and on being graduated in 1910 was appointed a director there and in 1913 president, becoming brigadier general in the same year. From 1915 to 1917 he was again in the Philippines, being for one year commander of the department. In 1917 he was made major general and commander of the western department, but in September went to France as commander of the 41st Division of the American Expeditionary Force. He was at the second battle of the Marne, at St. Mihiel and in the Argonne, commanding the I Army Corps and later the I Army, and commanded the III Army of Occupation on the Rhine. In 1919 he was commander of the Western Division, and in 1920 commander of the IX. Corps area, retiring on March 21, 1921, with the rank of major general.

LIGHT, subjectively, the sense impression formed in the eye (See VISION.) The present article deals with it purely objectively and is concerned with the more fundamental characteristics of light and optical instruments. For the more practical applications, which are not here discussed in detail, see OPTICS, TELESCOPE; MICROSCOPE, INTERFEROMETER, PHOTOMETRY. The subject is conveniently still further subdivided according as to whether we are more interested in how the light originates or how it behaves after it has been emitted. The first subject is treated under RADIATION, THEORY OF; and SPECTROSCOPY; the present article is chiefly concerned with the behaviour of light after it has been emitted, a branch of the subject often called Physical Optics, dealing almost entirely with the Wave Theory of Light.

INTRODUCTION

It might perhaps be expected that we should begin by saying what light "really" is, and should then develop its characters from such a starting point; but this procedure is not possible, since light is essentially more primitive than any of the things in terms of which we might try to explain it. The nature of light is only describable by enumerating its properties and founding them on the simplest possible principles. As these principles transcend our ordinary experiences they must be cast in a purely logical, that is to say mathematical, form. But that is never enough, for, though logic tells us what deductions must be right, it does not tell us what will be interesting and so gives no guidance as to the direction the theory will take. In choosing this direction much help is derived from analogies and models, which are often loose and incomplete, but without which no proper understanding of the subject can be acquired. We shall therefore describe, largely by means of analogies, the behaviour of light, and this is the "real" nature of light.

Types of Radiation.—Light would be taken strictly speaking

It has been seen that it is customary to include in the term 'light' a wide range of radiations, because though they differ in many respects their behaviour is similar. These are the ultra-violet and infra-red radiations which are the most extreme and most remote, or the ends of the spectrum of the X-rays, α-Röntgen rays, γ-rays (see RADIO-ACTIVITY) and the extremely penetrating cosmic rays; while on the other end of the spectrum we have the electromagnetic vibrations of the visible spectrum. All these radiations have one property in common, namely, the speed of propagation. The most accurate measurement of the velocity of light (see VELOCITY OF LIGHT) assigns to it the value $299,792,458$ cm per sec. The distinction between the various kinds of radiation depends on wave-length and frequency, and the following table shows roughly their wave-lengths measured in centimetres.

Ultra-violet rays	1×10^{-4}
Shortest X-rays	5×10^{-4}
Shortest cosmic waves	2×10^{-2}
Infra-red rays	
Longest heat waves	3×10^{-1}
Longest 'heat-rays'	1×10^{-2}
Average 'heat-rays'	5×10^{-3}
Longest sound to	7×10^{-5}
Visible Light	
Limit of red	7.2×10^{-5}
Yellow	5.8×10^{-5}
Green	5.0×10^{-5}
Blue	4.5×10^{-5}
Limit of violet	4.0×10^{-5}
Ultra-violet rays	
Limit of transparency of glass	3.5×10^{-5}
Limit of transparency of quartz	1.8×10^{-5}
Infra-red region	1×10^{-3}
Heat-rays	
Longest X-rays	1×10^{-1}
Average X-rays	1×10^{-2}
Shortest X-rays	1×10^{-4}
γ-rays	1×10^{-10}
Cosmic rays	4×10^{-11}

It is not convenient to use the same units throughout such an enormous range. It is customary to measure wireless waves in metres. The 'heat-rays' are often measured in units called μ , the thousandth of a millimetre, but for light the unit universally used is the Angstrom Unit (A.U.) which is 10^{-7} cm. This is also most frequently used for X-rays, though in precision work X-units of 10^{-8} cm. have been introduced. Much of what we shall say here applies to the whole range but it is not unnatural that there should be differences, and when these occur we shall restrict ourselves to the case of light, visible ultra-violet and infra-red.

The Appearance of Ordinary Things.—In many branches of science, though we start with familiar and crude observations, we very soon find it necessary to discuss much more recondite questions and this leads to an elaboration of the theory, until the most important things in it are quite different from what is familiar to us. This is very emphatically true of light. For example, the most familiar thing about light is that it goes in straight lines, and hardly any of our ordinary experiences disagree with this fact. But by more refined experiments it is easy to exhibit that light is sometimes bent (diffracted) and such cases prove more important to the theory than the commonplace observations. Almost the only example of these phenomena, diffraction and interference, which is a matter of common experience, is the iridescent colours that appear on soap-bubbles and on the surface of greasy water.

So it comes about that the theory of light is not much concerned with the appearance of ordinary things, and as we shall later have very little to say about them, we may consider them briefly here. In things we see we may distinguish between the luminous and the non-luminous—in day-light between the sun and everything else. The non-luminous objects are only visible by light reflected from some luminous source, the sun or a lamp, and their different appearances are solely due to the different ways in which they reflect light. Thus a black object is one which does

not reflect at all. A coloured object is one which reflects some colours but not others. This is easily proved by illuminating a piece of red paper by light passed through a green glass, when it will appear black because there was no red light for it to reflect. White being a mixture of all the colours, a white object is one which reflects all colours about equally, and so it looks coloured if lit by a coloured light. When two pigments are mixed together the resulting colour will be that which they are both capable of reflecting and may be quite different from the colour seen when the light of two coloured lamps is projected together on to a white screen. For example if the light from red and green lamps is compounded in this way the result is a brilliant yellow, but red and green paints when mixed give a dark muddy colour because there is little light which they can both reflect (see COLOUR).

Many substances are really nearly transparent, but appear opaque because they are not homogeneous, so that the entering light is reflected and refracted many times until it is completely scattered. The most obvious example of this is ground glass, but the same is largely true of paper and white wood. An easy test of whether a substance is opaque in this way or by an inherent opacity to light is to see whether it is of the same colour for reflected and transmitted light. A sheet of red paper looks red whether we look at it or through it at a light because in both cases what we see is light which has got tangled in the fibres, and at each reflexion has lost a little of the green and blue light by absorption, so that only the red emerges on both sides. On the other hand if a substance is truly opaque the colours on the two sides will be quite different. For example the yellow colour of gold is due to the fact that it reflects the yellow light more effectively than other colours and, by a paradox which we shall explain later, this means that it absorbs the yellow more strongly. If then we take a very thin sheet of gold, the yellow light will not penetrate it so easily and transmitted light will be bluish green.

HISTORY

The ancients were acquainted with mirrors and with the burning glass, but their theories of optics were rather of the metaphysical character so much more congenial than experiment to the Greek temperament. The Pythagoreans believed in an emission theory, supposing that the seen object emitted particles which bombarded the eye, but the Platonists complicated the matter by supposing that vision was produced by a triple interaction between rays emitted by the sun, the object viewed and the eye itself. Among these speculations we can only distinguish the discovery of one real scientific law, enunciated by Hero of Alexandria who saw that the equality of the angles of incidence and reflection at a mirror could be expressed by saying that the ray took the shortest possible course between object and eye. This law is the first statement of the general "principle of least action," a principle which now dominates not only geometrical optics but also dynamics.

We may omit the other speculations of the Greeks, Romans and Arabs and come to the revival of learning. The earliest developments were practical, such as the invention of spectacles and later of the telescope, with which we shall not be concerned here. The first great theoretical discovery was the law of refraction discovered by Snell in 1621, but not published until after his death by Descartes. This law asserts that when a ray of light passes from one medium to another, the plane of the two rays contains the normal to the surface and the sines of the angles of incidence and refraction are in a constant ratio, the refractive index. Descartes was led by a metaphysical argument to maintain that light was some sort of pressure in a medium (in a very indefinite way something like the present wave theory), and thought that the velocity of light must be greater in a denser medium. This view was combated by Fermat, also on metaphysical grounds, and modern theory supports Fermat though not his reasoning. It seems to be the rule rather than the exception that correct results are first obtained from quite incorrect arguments. Fermat asserted that nature performs its operations always by the most direct path, and that therefore a ray of light between two places must take the shortest possible time. The rectilinear propagation of

light and the law of reflection conform to the principle and therefore refraction must do so too. Snell's law then implies that the velocity of light in a medium is inversely proportional to its refractive index. Fermat's "principle of least time" is the natural extension of that of Hero of Alexandria, and was later erected by Hamilton into a general method of great beauty for dealing with optical systems.

The Age of Newton and Huygens.—The first great era in the theory of light is the second half of the 17th century. Grimaldi discovered (and named) the phenomenon of *diffraction*, that light going through a fine slit cannot be prevented from spreading on the further side and that no matter how small the source of light, the edge of a shadow cannot be perfectly sharp. Hooke independently discovered the same thing, and offered a theory approaching closely to the wave theory in that he had the idea of *wave-fronts* and of light being some sort of oscillation, but it was more than a century before it was seen that the strongest possible argument for this theory lay in the discovery of diffraction. During the same era Roemer measured the velocity of light for the first time, by a comparison of the calculated and observed times of the eclipses of Jupiter's satellites.

Of all the founders of the theory of light undoubtedly the greatest were Newton and Huygens. Newton discovered the theory of the spectrum. By passing a fine beam of sunlight through a glass prism he resolved it into its component colours.—red, orange, yellow, green, blue, indigo, violet. It had already been known that white light was resolved into colours on passing through glass or water (for example the rainbow had been explained), but it was supposed that the glass had produced a definite alteration in the light. Newton showed that, if the light passed through a second prism reversed the coloured lights would recombine into white, but that if a single colour were selected from the spectrum, no subsequent treatment could change it in any way. He was thus led to the correct explanation of white light as a compound of all the colours, but the further details of this question would lead us into physiological optics (see VISION).

Newton also investigated the colours of thin plates such as soap bubbles. He placed a slightly convex lens on a flat piece of glass and observed the light reflected. At the centre the surfaces are in contact and nothing is reflected, but round this point, where they are very close, though not in contact, there appears a succession of brilliantly coloured rings, the succession of colours being black, faint blue, strong white, orange, red, dark purple, violet, blue, faint green, vivid yellow, etc. The rings become narrower and fainter as we go outwards and soon become invisible. These are not the colours of the spectrum, and their origin is better appreciated by considering the case where the illumination is by monochromatic instead of white light. There is then a dark centre surrounded by a large number of rings of the colour used (See Plate, fig 1.) The sizes of the rings depend on the colour of the light, they are closer together for blue than for red. If then we illuminate simultaneously with red and blue light there will be places where the rings fall together so that we get alternately purple and dark, and other places where they fall apart and we get alternate rings of red and blue. Plate, fig 2 is a photograph of this type, as the camera is unequally affected by the two colours, in some regions the rings look blurred, in others sharp. The rings in white light can be explained in the same way as due to a superposition of all the colours, and at no great distance from the centre so many of the coloured rings overlap that they become invisible.

Newton was very cautious in making theories and he did not really succeed in explaining his rings, but he attributed them to certain "fits" of reflection and transmission which later were seen to be very like the *phases* of the wave theory. As to the general theory of light he was also very non-committal, but he criticized the wave theory as being unable to explain rectilinear propagation and his followers, interpreting his views in a much narrower way than he intended, adopted a complete corpuscular theory of light which held the field for more than a century. This theory supposed that light consists of minute particles, or cor-

puscles shot out from the luminous body, and attempted to explain all the phenomena by suitably modifying the properties of these corpuscles. The theory implies that the velocity of light must be proportional to the refractive index, not inversely proportional as in Fermat's principle and the wave theory and this was later to provide a critical test which condemned it.

Huygens is the real founder of the wave theory of light. He based his belief in it primarily on the fact that, if a beam of light

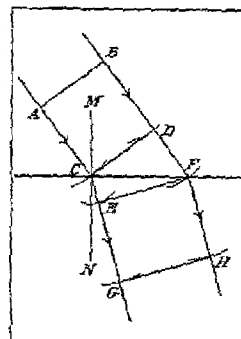


FIG 1—HUYGENS' CONSTRUCTION FOR REFRACTION

were like a flight of arrows, then when two beams cross these should be collisions between the arrows. He succeeded in explaining reflection and refraction, and we may consider his construction as it lies at the foundation of modern methods. The general idea is that light is a disturbance in a medium but it need not be specified what is the character of the disturbance; for purposes of rough visualisation we may think of the medium as a jelly which is distorted so that its particles move out of their usual places. Any disturbance then acts as a centre causing the propagation of a wave of disturbance to go out at a constant speed, so that at any subsequent time the effects of the initial disturbance will be found on a sphere surrounding it. When the initial disturbance is not confined to a single point, each point of it is to be regarded as a source, and the subsequent disturbance is the geometrical envelope of the spheres surrounding all these sources. Refraction is explained by supposing that the velocity of light is different in different media. Consider light obliquely incident on a flat surface, say of water (see fig 1). The velocity of propagation outside is c the velocity of light, in the water it is v a slower velocity. The advancing disturbance is at one moment spread as a pulse over the surface AB . Each point of AB gives out a spherical pulse and, to reconstruct the wave later we draw spheres of equal radius round all the points of AB . Obviously one such set of spheres will give the line CD as their envelope, and this shows that the light goes in the direction AC outside the water. But if we repeat the construction starting at CD we have to allow for the fact that the velocity is less in water than in free space. Thus corresponding to the sphere of radius DF about D , we draw round C a sphere of radius $CE = v/cDF$, and it is evident that EF will be bent round more nearly parallel to the face than was CD . After this both spheres are in the water and the propagation goes straight again on to GH . This construction immediately gives Snell's law of refraction, for $\sin ACM / \sin GCN = DF/CE = c/v$, and the refractive index is simply the ratio of velocities. The construction fails in the case of very oblique incidence if v is greater than c , for then the circle round C may have radius actually greater than CF itself. Refraction is then impossible and all the light is reflected. This is the phenomenon of total internal reflection which we shall discuss later. A simpler construction than that we have given applies for reflection, and the same principle also explains diffraction, but Huygens did not find this out.

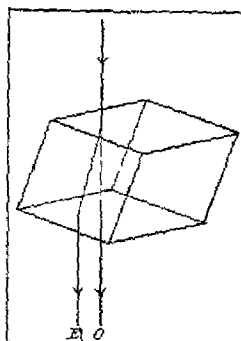


FIG 2—DOUBLE REFRACTION, SHOWING TWO RAYS EMERGING WHEN A LIGHT RAY STRIKES A CALCITE CRYSTAL PERPENDICULARLY

Huygens' other great investigation is connected with *double refraction*. Certain crystals of calcium carbonate, from Iceland, called calcite or Iceland spar, have the extraordinary property that objects viewed through them appear double. To reduce the matter to simpler terms it can be expressed thus, a crystal of calcite resembles a cube that has been compressed along one of its diagonals. Suppose that a narrow beam of light is incident on one face perpendicularly. If the crystal were glass the beam would emerge from the opposite face in the same line. Actually two beams emerge, one in the same way as for glass but the

... through in a direction parallel to the first (see fig 3). These are called the ordinary and extraordinary rays. Huygens successfully applied his wave construction to explain double refraction by showing that two surfaces must be constructed round each point of a sphere which would give the ordinary ray, but the other a spheroid with its axis of revolution determined by the crystal axis (and is by the shortened diagonal of the cube) for the extraordinary ray. This is illustrated in fig 3. Round the point C and D we draw not only a sphere but also a spheroid, which is such that the two surfaces touch at the points that lie in the direction of the crystal axis (the point K in fig 3). The envelope of the spheres is the plane EF which shows the path of the ordinary ray, while the plane GH is the envelope of the spheroids and shows the path of the extraordinary ray. Observe that the latter ray is not perpendicular to the wave front.

Huygens also discovered though he did not explain, the phenomenon of polarization. If we rotate our crystal about an axis in the direction of the beam and observe the projections of the two rays on a screen the ordinary ray will stay fixed, and the extraordinary which will be equally bright will rotate round it. But now suppose that we rotate the ordinary ray and pass it in the same way through a second crystal. In general it will give rise to two rays ordinary and extraordinary, but this time they will usually be of unequal brightness. If the two crystal axes are parallel the extraordinary ray will be absent altogether but as the second crystal is turned it will gradually grow in brightness at the expense of the ordinary until when the crystal has turned through a right angle the ordinary ray will be entirely extinguished. Rotation through a further right angle will restore the ordinary ray and destroy the extraordinary. A similar rule applies for the extraordinary ray from the first crystal, it usually gives both types, but only an extraordinary ray when the crystals have their axes parallel. Newton recognised the essential features of the matter in saying that a ray of light may have sides, in fact that this light differs from ordinary light as a thin leaf differs from a round stick. The idea of transverse vibrations had not yet been formulated, so that no further advance could be made at this stage.

We may here remark that the Huygens wave construction explains what some may regard as a philosophic difficulty in Fermat's principle. According to this principle the rays of light between two points A and B adopt that path which takes the shortest time and though the only way we have ordinarily of determining a minimum is to try a number of paths and see which is quickest, yet the ray appears to adopt the right course without any alternative trials. The wave construction explains why it does so for it shows that the wave is, so to speak, all the time trying alternative routes and is adopting the shortest because the waves in other paths cancel out.

In spite of these great advances the state of knowledge at the end of the 17th century was really insufficient to give a decision between the two theories, and moreover there was hardly the beginning of a mathematical wave theory as yet, so it is perhaps not surprising that the corpuscular theory of light gained the upper hand. The 18th century was singularly barren in optics and the only first-class discovery appeared strongly to support this theory. This was the discovery of stellar aberration, by Bradley (see ABERRATION OF LIGHT) which for corpuscles is immediately explained by the idea of relative motion, whereas with waves, though a crude explanation is not hard, the final solution was only obtained in the 20th century with the advent of relativity.

The Age of Fresnel.—The second great period of discovery coincided with the beginning of the 19th century and the first

successes fell to Young. He adopted the wave principle of Huygens, but extended its application. Thus Huygens had only considered waves of the form that we should now call pulses, but Young made use of continuous periodic waves, and so was enabled to explain Newton's rings in a manner we shall discuss later. He clearly stated the general principle of *superposition*, that "when two undulations from different origins coincide, either perfectly or very nearly in direction, their joint effect is a combination of the motions belonging to each." This principle is quite general but Young perceived that interesting results would only follow when the two sources are *coherent*, that is to say when two beams from the same source are brought to superposition, for only so could the irregularities in the process of emission be the same for both. He therefore set up what has proved to be one of the classical experiments of optical theory.

Two holes are made close together in a screen, and light from a distant point passes through them and illuminates another screen. If the holes are large there will be merely two patches of light on the screen, but when the holes are made smaller diffraction occurs, so that the rays of light spread and the patches are larger instead of smaller as might be expected at first sight. When the holes are very small the patches will overlap and it is then observed that they are crossed by a number of fine bands. To understand this let us suppose the light to be monochromatic (of a single wave-length) so that the vibrations of the light-wave are in the form of a travelling sine-curve. The source of light is equidistant from the two holes A and B (fig 4), so that at those points the waves are in the same phase (shown diagrammatically in the figure). On passing through the small hole each beam emerges as a spherical wave. At the central point O of the screen the distances to A and B are equal so the phases agree at every moment, the effect from the two holes will reinforce one another and O will be illuminated. Consider however a point P which is half a wave-length nearer to A than B. Here the waves from A and B are at every time in opposite phases (in the diagram when one wave is at the top the other is at the bottom, etc.) and so cancel, with darkness as the result. At the point Q, which is a whole wave-length nearer to A than B, the waves will reinforce each other again, because one wave is exactly a wave-length behind the other, and there will be light. Proceeding in this way the whole field is seen to be covered by alternate bright and dark bands. In the case of white light there will be a few coloured bands in the middle and the rest will look white, the colours can be worked out in just the same way as with Newton's rings. Young's interference pattern is by no means easy to observe, as it requires very careful adjustments on account of the exceedingly short wave-length of visible light. To give an idea of its magnitude, if the holes are 1 mm. apart and the screen is at a distance of 1 metre, then for red light the bright bands are a distance 0.6 mm. apart.

The investigation of polarization at this epoch received a great impetus by the discovery of Malus that, when sunlight is reflected from glass, the reflected ray may be polarized. Brewster studied the matter and found the rule that the reflected light was completely polarized when the reflected and refracted rays were perpendicular to one another. In the course of this work he discovered experimentally the formulae for the intensity of the two polarized components of light reflected from a transparent substance. If i is the angle of incidence and r that of refraction, the fraction reflected is $\sin^2(i-r)/\sin^2(i+r)$ or $\tan^2(i-r)/\tan^2(i+r)$, according to the direction of polarization. These expressions are usually called Fresnel's sine and tangent formulae, and have played a part in the history of optics. In the special case where $i+r=90^\circ$ the tangent formula vanishes and, as the other does not, the reflected light is completely polarized. Brewster also made the important discovery that some crystals exhibit double refraction of a different type from that of Huygens. In these crystals there are two directions instead of only one for which the light does not become polarized. We may also here mention the discovery by Arago of *gyration* (formerly called "optical activity"). When a beam of polarized light is sent through a quartz crystal along the axis, or through a sugar solution it is observed that on

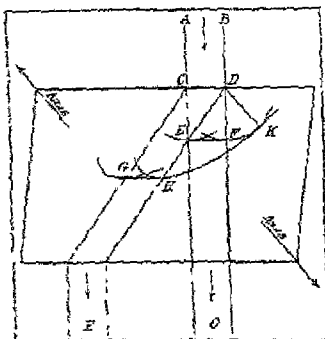
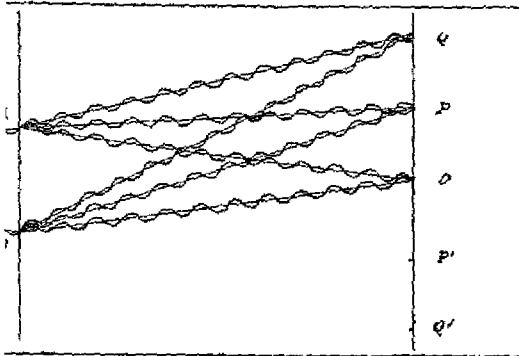


FIG 3.—HUYGENS' CONSTRUCTION FOR DOUBLE REFRACTION

Each point of C and D sends out a sphere and spheroid wave. The spheres give the ordinary ray through EF, the spheroids the extraordinary ray through GH.

beam the plane of polarization has rotated by an amount equal to the angle of the path that has traversed all these matters in detail later. The investigator of this period was Fresnel, and in his theory attained the outline which it has kept to this day. We shall have to deal with his work in detail when we mention his discoveries without explaining them.



4—YOUNG'S INTERFERENCE EXPERIMENT
 It falls on the two holes A, B. Point O is equidistant from the waves reinforces each other, P is $\frac{1}{2}$ a wave-length, so that the waves cancel out, while Q is a whole wave-length they reinforce again. Bright bands will appear at O, at P, P'.

Huygens' construction to explain diffraction, established the superiority of the wave theory over Newton's corpuscular theory. In the course of this work he demonstrated that there is a bright spot exactly in the centre of a circular screen. Like Young he also made attempts to exhibit the interference of two beams of light. He turned his attention to the optical effects of the motion of the earth and worked out all the principles, this important work had a connection with relativity theory, but is outside the scope of this book. Next he made the discovery (with Arago) that beams of light are differently polarized even if they come from the same source, it is impossible to make them vibrate in the same plane. The vibrations of light were thought to be transverse, so that there seemed to be no room for a corpuscular theory, but Young hit on the solution that light vibrations are transverse, so that a wave of light may have a plane of vibration perpendicular to the direction of propagation. Fresnel next turned his attention to the problem of reflection and completely solved the whole problem, including the motion of the earth and worked out all the principles, this important work had a connection with relativity theory, but is outside the scope of this book. Next he made the discovery (with Arago) that beams of light are differently polarized even if they come from the same source, it is impossible to make them vibrate in the same plane. The vibrations of light were thought to be transverse, so that there seemed to be no room for a corpuscular theory, but Young hit on the solution that light vibrations are transverse, so that a wave of light may have a plane of vibration perpendicular to the direction of propagation. Fresnel next turned his attention to the problem of reflection and completely solved the whole problem, including the motion of the earth and worked out all the principles, this important work had a connection with relativity theory, but is outside the scope of this book.

Classical Theories of the 19th Century.—With the wave theory of light, the more geometrical part of the wave theory was practically complete; but it was still necessary to have a dynamical formulation and this was the chief object of the theorists during most of the 19th century. It was necessary to make a model of some sort of matter which could be the optical medium. The most obvious model was that of an elastic solid, and, with the help of this, many and others had considerable success in explaining phenomena for a single medium, but the theories got into difficulties when it came to the passage of light from one medium to another. Only by highly artificial hypotheses was it possible to derive the sine and tangent formulæ.

Green on the propagation of waves in elastic bodies was the beginning of the modern mathematical theory of the propagation of waves in solid matter. It can be strained (altered in form) in three ways. It may be compressed without other parts being compressed or it may be sheared so that a square becomes a

rhombus or without changing its shape it may be rotated in position. The third type of strain can take place without the necessity of forces, but the first two require the action of forces in order that they may occur. The solid will possess two elastic constants corresponding to these forces (we are thinking of an isotropic body, not a crystal which may possess 2μ), and can propagate two types of wave, a longitudinal corresponding to compression and a transverse corresponding to shear. Green showed that when a transverse elastic wave passed from one medium to another it could not help giving rise to a longitudinal wave, and for this there is no room in the theory of light. Though his result was thus mainly negative Green's calculus firmly established what conditions a valid theory must satisfy. Under the inspiration of Green's methods Stokes gave a rigorous solution of the problem of diffraction in place of Fresnel's approximate geometrical method.

A valid formulation for the dynamical theory of light was first made by MacCullagh, who assumed that the aether was a new kind of material which opposed no resistance to compression or shear, but which resisted rotation. Such a material satisfies all the necessary conditions but it suffers from the objection that there is no known kind of matter which has the property, and for this reason it was regarded with great suspicion and its importance was not appreciated till long afterwards. During the middle of the 19th century there were many attempts, especially by Lord Kelvin (then W. Thomson), to invent a substance which should satisfy all the necessary conditions, but they were mostly very artificial. The modern theory was finally formulated by Clerk Maxwell, about 1860, who showed that electric oscillations must involve emitted waves which would have the same transverse character and would travel with the same velocity as light. He therefore identified light with electric waves, and gave the complete system of equations (then seen to be identical with MacCullagh's) which determine the behaviour of light. This theory has firmly held the field ever since, and Maxwell's name ranks as high as any among the contributors to optical theory. The completeness of his theory, and perhaps the familiarity that grows with the lapse of time, has overcome the objection that no known matter conforms to the same rules of vibration as the aether.

The Experimental Discoveries of the 19th Century.—During the period of these great theoretical investigations the experimental side had of course not been neglected, and many important discoveries had been made and instruments invented. Fraunhofer studied diffraction in a rather different way from Fresnel, and constructed gratings by winding wire between two fine screws and by ruling lines with a diamond on glass. With these he analysed the solar spectrum, and his work is thus the origin, both in subject matter and in method, of the modern science of spectroscopy. The invention of Nicol's prism (usually called the Nicol) made it easy to produce polarized light, and this has ever since been the standard instrument in the study of polarization. Stokes began the study of ultra-violet light, rendering its effect visible by means of the property of fluorescence; it is now more usually investigated by photography. Faraday discovered the theoretically very important phenomenon of magnetic gyration,—that, when a transparent substance is in a strong magnetic field, a beam of polarized light passing through it along the direction of the field has its direction of polarization rotated. This was the earliest connection discovered between light and electricity. Fizeau and Foucault developed methods of measuring the velocity of light accurately, and among other things showed that light really does go slower in water than in air, as is demanded by the wave theory (see FLUORESCENCE AND PHOSPHORESCENCE).

We must also mention the slow development of the theory of dispersion, i.e., the dependence of the refractive index on the wave length. Fresnel and Cauchy propounded a theory which attributed it to the coarse-grainedness of the refracting medium, from which it followed that the refractive index could be expanded in powers of the inverse square of the wave-length. This is often possible, but its inadequacy was seen when Leroux discovered the phenomenon of "anomalous dispersion" (which is

... that substances exist which refract ... A part of the modern theory was ... Fresnel had suc- ... difficulties remained with regard to the move- ... Stellar aberration suggested a ... but then it seemed ... terrestrial experiments this motion ought to ... On account of the great velocity of light none ... but all gave negative results; ... experiment of Michelson ... though it depended ... the ratio of the earth's velocity to that of ... the negative. The mathematical ... Lorentz to deal with this ... interpretation, given to it by ... Lorentz led to the promulgation of the theory of relativity ...

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At the close of the 19th century optical theory had attained a completeness and perfection which left hardly room for further development and it is with this classical theory that we shall here be concerned. During the 20th century one most important branch has been added to it by the discovery of the interference of X-rays but for the most part the centre of interest has shifted. The study of the conditions under which light is emitted has revealed fundamental difficulties in all our mechanical conceptions. This has led to the body of doctrine called the quantum theory (q) which is antagonistic to the older classical system. Each in its own field covers a large number of phenomena but the reconciliation is not yet complete, though it is already possible to rewrite the theory of dispersion in the new language. We shall not do this here, but shall treat it together with the rest of the subject by purely classical methods.

WAVES AND INTERFERENCE

The most familiar form of waves is of course the surface waves of water but the term is extended to cover any vibratory effect propagated through a medium. For example if we take a long stretched string and strike it near one end, a small hump will form and will travel without change of shape down the string. Though the portion of the string humped is changing all the time, the geometrical form is unchanging and so we can endow this form with individuality and say that the wave goes at a certain speed. If x denotes the distance of any point on the string from the point of reference, or the origin, and ϕ the displacement of the string at that point, the motion is described by the differential equation

$$\frac{\partial^2 \phi}{\partial x^2} = \frac{1}{c^2} \frac{\partial^2 \phi}{\partial t^2}$$

the solution of which is $\phi = f(x - ct)$. This expresses the fact that whatever the initial form the form at time t is the same with the origin shifted a distance ct .

General Characteristics of Waves.—The vibration of a string is specially simple, because the wave undergoes no change of form but in most cases, such as water-waves, that is not so, for as the wave travels it alters shape and so it is no longer possible to speak of a definite velocity. It is therefore necessary to analyse the waves into definite types which can be studied separately, and the type which is incomparably the most useful is the sine-curve. That such an analysis is useful is a consequence of the principle of superposition enunciated by Young mathematically this principle follows from the fact that the differential equations of wave motion are linear, so that if we have two solutions of a wave problem we can derive a third by taking their sum. Thus any problem

can be solved by expressing the initial state as a sum, or more usually an integral, of sine-curves of various wave-lengths then solving the motion for each of these separately and finally recombining them. This is the only method available for water-waves and though plane waves of light are propagated in free space without change of form any obstacle or refractive medium destroys this simplicity and makes the analysis necessary.

In discussing the general characteristics of waves we may conveniently think of a stretched string, but when the appropriate name is given to the dependent variable ϕ everything we shall say applies equally well to water-waves, sound, or light. Thus, ϕ in the string means the displacement of the string sideways, in water-waves the elevation of the surface above its average height, and for sound it might mean the variable part of the air pressure; for light we shall later specialize it rather more and identify it with the electric force. In all these cases the typical solution is

$$\phi = A \cos[2\pi(\nu t - x/\lambda) - \epsilon]$$

First considering the motion of a particle of the string, we keep x constant and see how ϕ depends on t . It is a pure harmonic vibration of amplitude A and frequency ν , frequency meaning the total number of vibrations described in a second. The expression $2\pi(\nu t - x/\lambda) - \epsilon$, regarded as an angle is the phase at the time t at the distance x from the origin. It can be interpreted very simply by the consideration that, when a point describes a circle at uniform speed, its projection on a diameter describes a harmonic motion; then the angle between this diameter and the radius through the point is the phase-angle. The term phase, though quite precise, is often used in a looser sense, because its absolute value does not matter, whereas differences in phase are of the very greatest importance in deciding the character of a wave. We next examine the shape of the string at any instant of time and see that it is a sine curve of wave-length λ . The amplitude, frequency, wave-length and phase are the four quantities characteristic of any wave.

The wave is progressive because of the phase relations between the various points of the string. If at any instant we compare the phases at x and $x + a$, we see that the latter is an angle $2\pi a/\lambda$ behind, and that at a time $a/\lambda\nu$ later it will have arrived at the phase which was at x initially. We therefore take $\lambda\nu = V$ as the wave-velocity or phase-velocity, it is the rate at which the crests move. Though phase velocity plays a most important part in wave theory it is misleading to think of it as a real velocity. For example, it is a general principle that no effect of any kind can be propagated with a speed greater than c , the velocity of light in vacuo, but it is not very rare to find substances in which the phase-velocity of light is considerably higher. When we say that no effect can travel quicker than c , we are thinking of the rate at which waves advance into a region previously undisturbed, but phase-velocity only has a meaning in connection with a sine-curve, and a sine-curve extends indefinitely in both directions, so that there is no undisturbed region to which the principle can apply.

In the case of water waves, and perhaps of electric waves of very long period we can observe the crests and so can see directly the wave-velocity and measure the amplitude, but in general it is impossible to do this. Usually we only observe some dynamical effect, such as that which occurs when the rays of light impinge on the retina of the eye. The exact form of this effect is special to each type of wave, but it is a general principle that it depends on the energy of the waves and this is proportional to the average value of the square of the amplitude of the wave-variable ϕ . This quantity is the intensity; it is often quite unnecessary to know the factor of proportionality associated with it. It is important to observe that the amplitude can be deduced from the intensity, but that nothing can be said about the phase, this is a consequence of the dynamical fact that only by altering the phase can the wave medium do work on the observing instrument, so that only by spoiling the phase can we observe the wave.

The case of waves in three dimensions is of course more complicated than that of one. In thinking about them the most important idea is that of the wave-front which is any continuous surface over which the phases are all the same. For mathematical

treatment such waves are sometimes resolved into sets of plane waves going in all directions but it is more often convenient to make use of spherical waves. It can be shown that, if a three-dimensional medium propagates plane waves according to the rule

$$\phi = A \cos[2\pi(\nu t - r/\lambda) - \epsilon],$$

then it can propagate a spherical wave of the form

$$\phi = A \cos[2\pi(\nu t - r/\lambda) - \epsilon]/r,$$

where r is the distance from the origin. The wave-fronts are spheres round the origin as centre, and the wave represents an emission from a point source at the origin. The amplitude decreases as the wave spreads out, and is always proportional to the inverse distance. The intensity is therefore proportional to the inverse square of the distance and this is the fundamental law of photometry (*see* PHOTOMETRY). This type of wave suffices for the discussion of a great many phenomena in optics, but it may be mentioned that it will require some unessential modifications when we come to discuss polarization and electromagnetic waves.

The Velocity of a Group of Waves.—Much of optical theory can be developed by the consideration of pure monochromatic waves, and indeed it may be said that experimental methods have tended to move in directions for which these suffice. The monochromatic wave, however, gives a very incomplete account of events, because it ranges over an infinite extent of time and space, whereas we usually want to know about events in some limited region. We saw, for instance, in Huygens' construction for double refraction, that the extraordinary wave has its front parallel to the ordinary, but yet that the rays go in a different direction. Even in the simpler case of plane waves of unlimited breadth there is a similar complication when the wave-velocity depends on the wave-length, as is the case in refracting media. Let us take a group of approximately monochromatic waves of limited length, and find the group-velocity with which it travels as a whole. To construct such a group we take a sine-curve multiplied by a factor such that the waves are not of uniform height, but fall away gradually to zero on both sides of the centre. The solution then shows that, though the crests travel forward with the wave-velocity appropriate to the wave-length, yet they alter in height as they go, so that after a time the crest which was highest at first will have become quite inconspicuous, while another wave originally quite small will have grown up and taken its place as highest crest. Thus the group as a whole moves with a different velocity from its component waves. The group-velocity U is derived from the wave-velocity V by the formula $d(kV)/dk$, where k is the reciprocal of the wave-length. The phenomenon of group-velocity is easily observed from the deck of a ship, for after a very short time a large wave under observation becomes quite small while another behind it has grown at its expense. For water the wave-velocity is proportional to the square root of the wave-length, and our formula then shows that the group-velocity is half the wave-velocity. For other types of waves it may be greater than the wave-velocity, and there is nothing to prevent it even being in the opposite direction, though no case of this is known. Only in the case where the wave-velocity is independent of the wave-length is it equal to the group-velocity; in this case any wave can be propagated without change of form.

The most important application of the idea of group-velocity to optics arises in the measurement of the velocity of light. Every type of measure depends in some way on interrupting the light and thus gives the group-velocity. In free space the wave-velocity of light does not depend on the wave-length and so is the same as the group-velocity, but this is not so in other cases. The superiority of the wave theory of light over the corpuscular theory was held proved when Foucault showed directly that light goes slower through water than air, but he did not in fact prove it, for the refractive index depends on wave-velocity, and his work dealt with group-velocity. However, since either can be deduced from the other, it is easy to verify the correctness of his result indirectly. In much of optics these considerations do not arise, and so they are frequently forgotten. Nevertheless they are indispensable for a full understanding of waves, and many difficulties have been

caused in the past through neglecting them.

The Pressure of Light.—In the course of his theoretical investigations Maxwell discovered the pressure of light. He derived this from the electromagnetic theory, but as a matter of fact it can be shown to follow from any wave-theory, and was foreseen in the 18th century by Euler. If plane waves fall perpendicularly on a surface it may be shown that they exert a pressure on it of a magnitude equal to the density of energy in the wave. This result is exceedingly difficult to observe, as the pressure is very small in practical cases. The first attempt led to the invention of the radiometer by Crookes. In this instrument freely moving vanes are coated with black on one side and are polished on the other. The side which is black absorbs the radiation while the reflecting side sends it back, so there is more energy in the space in front of the reflecting side and therefore a greater pressure. When the radiometer is illuminated it does go round, but the wrong way! This is due to a rather complicated effect depending on the heating of the residual gas in the vessel, and in order to observe the pressure of radiation much more delicate means are required. It was eventually measured by Lebedev by so improving the radiometer that the effect of the gas was eliminated. There are also indirect methods by which the pressure of light can be verified, chief among which is the thermodynamic law for the emission of radiation (*see* HEAT). Light pressure plays scarcely any part in our common experience, but grows to enormous values in the hot interiors of stars and plays a dominating part in controlling their state.

The Doppler Effect.—When monochromatic light passes through any fixed optical system there is one property that is always conserved, the frequency of the vibrations, but this frequency can be changed if the light is reflected by a moving mirror, or if there is a difference in the motions of source and observer. This change of frequency is called the Doppler effect after its discoverer, and is easily explained by the wave theory. Consider a fixed source emitting light of frequency ν , and sending it to an observer who is receding at velocity v . On account of his motion the successive crests of the light-waves will reach him at longer intervals than if he were at rest and a simple calculation shows that he will receive them with a frequency $\nu(1-v/c)$, the light will appear to him redder than it really is. If he is approaching, it will appear bluer, and if his motion is oblique to the direction of the source the change of frequency will depend on the component of his velocity in the line of sight. In the case where light is reflected from a receding mirror it has to traverse the increasing distance twice over and so the effect is doubled, and the frequency of the reflected light is $\nu(1-2v/c)$. It should be said that these values are not quite precise when v is large. The Doppler effect plays a very important practical part in astronomy, for by its means it is possible to discover the velocity of stars in the line of sight, and thus for example to calculate the motion of the components of a double star which are so close together that they cannot be seen separate. It is also vital in the theoretical investigation of the distribution of energy in the spectrum. A further consequence arises in practical spectroscopy. In a hot gas some of the atoms will be approaching the spectroscope and so will give light bluer than the average, while others will give a redder light in consequence of their recession and thus the light will never be purely monochromatic. In some experiments it is necessary to minimise this effect by cooling the gas with liquid air.

The Colours of Thin Plates.—There is no essential difference between the phenomena of diffraction and interference, but only a difference in emphasis. Thus the term diffraction is used for phenomena connected with the spreading of waves on passing through a slit, shadow formation, etc., while interference arises, as in Young's experiment when two waves from separate but coherent sources are superposed. We shall now discuss some important cases of interference, including the explanation of Newton's rings.

We have already described Huygens' construction for reflection and refraction. When a beam of light falls on a surface part is directly reflected and part is refracted. Consider now a thin plate, say a soap-film, under the action of an incident beam of a mono-

The beam refracted at the first surface is now second and part emerges while the rest is reflected back. This is the case for as back to the first face and part of it is reflected while the rest is again reflected. Thus if we want to know the total amount reflected, we have to consider the compounded effects of all the waves coming from direct reflection and any number of internal reflections. Now in order to explain the process,

we shall consider it as though the rays AP, CQ, ER, etc. were separate from one another but only with reference to the fact that they are supposed to be in phase. The reflected beams will therefore be in phase and this is a case like Young's experiment in which we have to consider the phases of the various waves. If these phases agree we shall have a reflection; otherwise it will be feeble. We shall see that the phases only agree for one colour at a time and so the film looks coloured though it is illuminated by white light. In order

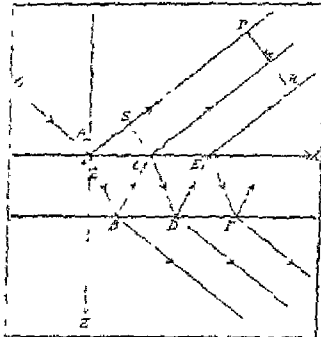


FIG 5—COLOURS OF THIN PLATES
The total amount of light reflected will depend on the phase differences of AP, CQ, ER, and these will vary with the colour and inclination of the light.

to see the colour of this we must examine the process of refraction some what more closely.

We first consider a single interface illuminated obliquely by a plane wave of light K (see fig 6). This will be broken into a reflected wave L and a refracted wave M. The strengths of these can be calculated exactly in the detailed theory (they give Fresnel's sine and tangent formulae), but we do not require their values here. Let us say that if K has unit amplitude then L has amplitude r and M has amplitude t . We shall assume (from the more detailed theory) that there is no change of phase at the interface. We also require to consider the effect of a beam coming to the surface from the other side. Let us suppose that the reversed wave M would give a transmitted wave along K of amplitude t' and a reflected wave along N of amplitude r' . Now there is an important and very general mechanical principle, that, if all the parts of a system are simultaneously reversed in their motions the system will retrace its course to the point from which it started. Thus if we take a wave r along L reversed and simultaneously t' along M reversed, they will give rise to unit amplitude along K reversed and no wave along N. The wave r from L and t' from M gives t' along K and r along N. We thus have the two equations $r^2 + t'^2 = 1$, $t - r' = 0$. The last implies that r' must be equal to r , but that there is a change of phase of 180° at the interface; we can allow for it completely by simply writing $-r$ for r' .

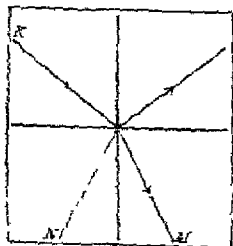


FIG 6—REFRACTION AT AN INTERFACE

We now return to the film of fig 5. The reflected ray AP has amplitude r , the ray AB has t . Of this a fraction r' is reflected at B, so that $t'r'$ arrives at C and CQ has amplitude $t'r'^2$, while CD has $t'r'^2$. Similarly ER will have $t'r'^2$ and so on. On the other side the waves emergent at B, D, F will have amplitudes t' , $t'r'$, $t'r'^2$ etc. We must now compare the various phases of the paths OAP, OABCQ, etc. Let us suppose that θ is the angle of incidence and θ' that of refraction, and that μ is the refractive index. Allowing for the difference of the wave velocity in the film, the phase difference for a single pair of internal reflections

will be $\frac{2\pi}{\lambda} (\mu \cdot ABC - AS)$, where S is the foot of the perpendicular from C on AP. This is equal to $2 \cdot \frac{2\pi}{\lambda} \mu n \cos \theta'$. If b is the

thickness of the film; we shall denote it by $2b$. Thus if the phase at P is ϵ , that at Q is $\epsilon - 2\delta$ and therefore that at R is $\epsilon - 4\delta$ and so on. The whole reflected wave thus has amplitude

$$r \cos \epsilon + t t' r' \cos(\epsilon - 2\delta) + t t' r'^2 \cos(\epsilon - 4\delta) + \dots$$

This series is now summed and reduces, with the help of the relations between $r, r',$ etc. to

$$\frac{2r \sin \delta}{1 - 2r^2 \cos 2\delta + r^4} \{ -\sin(\epsilon - \delta) + r^2 \sin(\epsilon + \delta) \},$$

and the resulting intensity follows by squaring and averaging over all values of ϵ . The fraction of the incident wave reflected is

$$4r^2 \sin^2 \delta / \{ (1 - r^2)^2 + 4r^2 \sin^2 \delta \}$$

It can be shown similarly that the fraction transmitted is

$$(1 - r^2)^2 / \{ (1 - r^2)^2 + 4r^2 \sin^2 \delta \}$$

For a soap-film the coefficient r is not very large. The chief effect is when $\sin \delta$ vanishes, that is, when $2\mu n \cos \theta'$ is any multiple of half a wave-length, for at such an angle of incidence there will be no reflection at all. Hence, when a film is lit by white light, some of the colours will be absent from the reflection, and the film will show the complementary colours. More detailed consideration than we can give here shows that these colours will not be seen well without the help of a telescope, unless the thickness of the film is very roughly of the order of twice the wave-length of ordinary light. The case of Newton's rings is very similar. The film is of air between the two glass surfaces, and the distance between these surfaces increases outwards from the point where the glasses touch so that b passes progressively through values where there is no reflection for each colour in turn.

The Fabry and Pérot Interferometer.—The same principle of multiple reflection has been put to very important use in an instrument, the interferometer of Fabry and Perot. Two sheets of very flat glass are set up accurately parallel, and from 1 to 5 cms apart. The plate producing the interferences is the air between them. The characteristic of the instrument is a slight silencing of the inner surfaces of the glass, so that at each incidence nearly all the light is reflected. Now, if in our formula for reflection r is near unity there is hardly any transmitted light at all, except when the light is very nearly incident at an angle such that $\sin \delta = 0$. Divergent monochromatic light falls on one side of the plate, and only the component waves at certain definite angles can get through. A system of narrow brilliant rings will be seen with the aid of a telescope, and their radii can be used to determine the angles at which $\sin \delta = 0$. An example is shown in Plate, fig 3 and, if this is compared with Plate, figs 1 and 2, it will be seen how much sharper the rings are in fig 3.

The instrument has two different uses. Firstly, to measure wave-lengths absolutely, or rather to determine the length of the standard metre in terms of a more unvarying measure, the wave-length of a suitable spectral line. For this purpose the glass plates are set up several centimetres apart (it may be troublesome to get them parallel), and this distance is compared with that of the standard metre. Next it is necessary to measure the distance between the plates in terms of wave-length. The cadmium arc is the standard source of light as it gives three conveniently coloured monochromatic lines. The light from the arc traverses a prism, so that the lines are separated out, and one of them is allowed to fall on the interferometer. If the distances between the plates happens to be an exact multiple of half a wave-length, there will be a bright spot, in the middle of the telescope, surrounded by rings. More usually there will be a small ring in the middle, and by measuring its angular radius, we can find directly the fractional part of the ratio of the plate distance to the wave-length. At first sight it would appear much more troublesome to determine the integral part as this may be as great as 700,000, but that is not so, for a relatively rough preliminary knowledge of the distance between the plates and of the wave-length can be made to yield it; and the final result is a determination of the absolute wave-length correct to 6 or 7 places of decimals.

The other use of the instrument is as a spectroscope. If a spectrum contains two lines very close together, each ring will appear doubled. The method is one of tremendous power but suffers from the disadvantage that if the two lines are not very close together one ring of the first line may fall near a different ring of the

second and it may not be easy to disentangle the meaning of what is observed. One ingenious use to which the phenomenon has been put is to fix the wave-length of the green auroral line which is given by the night sky. This is so faint that no ordinary spectro-scope can be used, but its wave-length was determined with a very high degree of accuracy by means of an interferometer, the plates of which were covered with gold instead of silver, for gold specially favours the passage of green light, and so prevents the fogging of the photographic plate by the general illumination during the long exposure.

The Michelson interferometer is another instrument that can be used for the same purposes. Here a beam is divided into two by being half reflected in a slightly silvered glass plate at 45°. The two beams then go to mirrors, one of which is at an adjustable distance, and are then reflected straight back and reunited at the half-reflecting mirror. There is no multiple reflection and the fringes are therefore broad as in Newton's rings. The instrument was the first to be used in measuring the standard metre. It has another important use, for by its means it is possible to measure directly how nearly any spectral line is truly monochromatic. If the wave emitted by an atom were literally a sine-curve this would imply that, like that curve, it started at minus infinity and continued to plus infinity (so the mere fact of switching off the light ensures that it is not one), but in fact the train of waves given out by each atom has a distinctly limited length and this can be measured by seeing how great may be the difference of paths in the two arms of the interferometer, before the interference fringes disappear. It is usually found impossible to see any fringes if this difference is more than about 70 cm., and this implies that after the atom has emitted about a million vibrations, it changes its phase arbitrarily before emitting again.

Another instrument of the same general character is the Lummer plate, in which light travels, being internally reflected, very obliquely, along the length of a glass plate silvered on both sides. All these instruments can be used for the most refined work in spectroscopy, but they all suffer from the difficulty that a single line produces a number of fringes rather close together, so that, when several spectral lines are photographed simultaneously, their fringes get mixed up in a way that is often hard to disentangle. There now exist diffraction gratings of nearly as high resolving power, which have not this complication, and the modern tendency is to use gratings for even the most accurate spectroscopic work, and to reserve the interferometer for the purposes for which it alone is suitable. (See INTERFEROMETER.)

DIFFRACTION

When we described Young's experiment, we regarded the two holes in the screen as themselves secondary sources of light emitting spherical waves. A similar construction was applied in Huygen's description of refraction, and may also be used in free space. We shall do this as a preliminary to describing the formation of shadows.

Fresnel's Construction.—In fig 7 we have a plane wave with front at *AB* progressing towards *P*. We know of course that at *P*

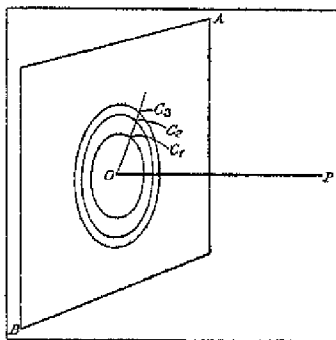


FIG 7.—FRESNEL'S ZONES
A wave is advancing from plane *AB* to *P*. The circle round *O* is the first zone, and the rings outside, the succeeding ones. Zones give nearly the same effect at *P*, but with alternating signs.

it will in fact be a plane wave too, with phase $\frac{2\pi}{\lambda} OP$ behind that at *O*, but we are now supposing that we can take every point in the plane *AB* as the source of secondary waves, and that the wave at *P* is due to the superposition of all these waves. In the plane *AB* describe circles round *O* of radii *OC*₁, *OC*₂ etc., such that

$$PC_1 - PO = \frac{1}{2}\lambda, PC_2 - PO = \lambda, PC_3 - PO = \frac{3}{2}\lambda, \text{ etc}$$

The central circle and the ring-spaces round it are called Fresnel

zones and are all of the same area. Each point is supposed to emit light and this light will arrive at *P* with a phase depending on the distance *OP*. The phases of the waves arriving at *P* from a single Fresnel zone are all the same within half a wave-length. If we take the moment when the phase arriving from *O* is just 90°, then all the phases from points in the central zone will lie between 90° and -90°, and they will all make a positive contribution. Those from the second zone will all make a negative contribution, from the third positive and so on. We may represent the total effect as due to the sum of the effects of all the zones and write it as

$$m_1 - m_2 + m_3 - m_4 + \dots$$

Each of these quantities is nearly the same because the areas of the zones are equal but they slowly diminish because the amplitude of a spherical wave varies inversely as the distance and the outer zones are further from *P* than the central ones. To allow for this decrease we sum the zones in the form

$$\frac{1}{2}m_1 + (\frac{1}{2}m_1 - m_2 + \frac{1}{2}m_3) + (\frac{1}{2}m_3 - m_4 + \frac{1}{2}m_5) + \dots$$

and then, the decrease in the *m*'s being at a constant rate, all the bracketed terms cancel, and the effect at *P* is equal to half that of the first zone. This argument is of course not a proof, but the full proof requires deeper mathematics than can be given here, for the same reason we shall not check what value must be assigned to the emission of a small area in order to give the amplitude of the reconstructed wave.

In spite of its incompleteness our argument brings out two very important facts. First, as each point of *AB* has been supposed to give out a complete spherical wave, we should expect the absurd result that there would be emission in the backwards direction towards the image point of *P* in the plane *AB*. The full solution shows that the amplitude of the secondary wave emitted at angle θ to the primary wave-front involves a factor $1 + \cos\theta$, and this vanishes in the backwards direction. Secondly we should expect the phase of the wave at *P* to correspond to the average of all the phases in the first Fresnel zone, whereas we know that in fact it corresponds to that of the point *O*. To put this right (and the full theory of course proves it) we make the rule that the secondary waves are to have their phases advanced 90°, or a quarter wave-length, in front of the primary wave causing them. These rules may be regarded merely as artifices to avoid a deeper enquiry, but they have important consequences; for, when we have a thin sheet of matter in the plane *AB*, its particles will scatter the incident light in much the same way as we have been considering, but in this case neither of the two effects will come in. There will be light scattered backwards, which constitutes the reflected wave, and the light scattered forwards will be a quarter wave-length behind the primary wave, and this is the most primitive description of refraction.

The construction of the Fresnel zones explains the bright spot in the centre of the shadow of a circular disk. For, if the screen cuts out the first *n* zones, the wave at *P* will now be $m_{n+1} - m_{n+2} + \dots$, and the sum will be $\frac{1}{2}m_{n+1}$. In order to exhibit this effect the circle has to be cut with great accuracy, for if half of it is as little as a single zone wrong the amplitude at *P* will vanish. The same idea has been carried further in the construction of zone-plates. If we make a screen which cuts out every alternative zone, we shall get an effect proportional to $m_1 + m_3 + m_5 + \dots$ which will be enormously greater than the effect without screen. Zone-plates have been made by drawing them in black on paper and then photographing down to a small scale. A brilliant spot will then be found at a point on the axis. The zone-plate illustrates wave principles admirably, but has not found any practical application.

The Formation of Shadows.—We may apply the same wave construction to explain the formation of shadows. In fig 8 *AC* is a screen with straight edge at *C*, and we consider the light falling on different points of the screen *MN*. The wave front is supposed parallel to *ACB*, and the screen blocks out the part *AC*, so that we only have to consider the secondary waves emitted by the part *CB*. First take *P*, the geometrical edge of the shadow. If we draw the Fresnel zones for this point, they will

Each zone gives half the effect of the whole zone, and the amplitude at P will be just half as great as if P were any other point. The corresponding intensity is thus quarter as great. For a point Q we make the Fresnel construction starting at C as Q moves on, from P the sizes of the zones diminish steadily and we therefore conclude that the intensity falls steadily from P to zero. For a point R outside the shadow we make the construction in the way we did before for the edge P . There will then be a circle cut off by the line C but the remaining C cuts off the rest in such a way that the zones are unaltered. Suppose AC is just $\frac{1}{2}$ far from P that the central circle is complete but is touched by the line C . Then the central zone gives its full contribution but the second gives less than its full contribution as do all the later ones. Consequently there is less to subtract than from the central zone and the light at R will be actually brighter than if there were no screen. Similarly if the circle and the first ring are complete but the second ring is cut by the line C , the second ring will give a diminished positive contribution and the light will be fainter again. Thus outside the shadow there are a series of alternating maxima and minima of intensity gradually fading into uniform illumination at a distance from the shadow. These light and dark bands are known as diffraction fringes.

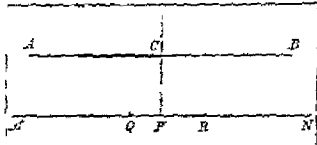


FIG 8—THE FORMATION OF SHADOWS

AC is the edge of the light from part of the screen MN , P is the geometrical edge of the shadow, and the actual illumination in its neighbourhood is shown in fig 9

The scale of the phenomenon depends on both the wave-length of the light and on the distance CP . The intensity at a point R will depend on the numerical value of $PR \sqrt{CP}$. For example if CP is 1 metre and $\lambda \approx 5 \times 10^{-7}$ cm. for yellow light, the first maximum and first minimum will occur at distances 0.061 cm. and 0.094 cm. outside the geometrical edge, and will have 1.37 and 0.08 of the intensity of the incident wave. Fig 9 shows how the intensity changes near the edge of the shadow. When the incident light is white the corresponding effect can be calculated by the superposition of all the colours; at the point of geometrical shadow the light will again be white and of quarter intensity and outside this there will first be a blue fringe. A similar process can be applied to work out the illumination due to a slit. If the slit is many wave-lengths wide it can be regarded merely as two straight edges while if it is only a small fraction of a wave-length there will be no shadow at all, but a uniform illumination. For intermediate cases there will be a rather complicated succession of fringes depending on the ratios of the three quantities, wave-length breadth of slit and distance of screen. In any given case the results are easily calculable.

FIG 9—THE EDGE OF A SHADOW
Showing how illuminative intensity rises from 0 inside to unity outside

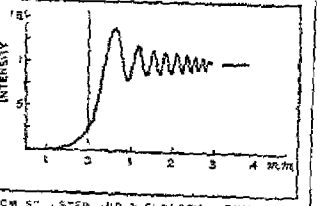


FIG 9—THE EDGE OF A SHADOW

The Fraunhofer Diffraction Phenomena.—There is another way, due to Fraunhofer, in which diffraction may be studied; this is in fact more important than Fresnel's in the theory of optical instruments. In this method parallel light again falls on a slit or hole but, instead of observing the illumination on a screen, the light is now observed in a telescope focussed for infinity. The essential purpose of a telescope is that it brings all the rays going in a given direction into focus at a point; at this point a photographic plate may be placed, or alternatively the real image may be viewed with the help of a magnifying lens. The function of the telescope is thus to convert a direction into a point and incidentally to magnify the scale. (Apart from this magnification it would be possible to see the Fraunhofer diffraction by looking at the slit with the naked eye; but the eye must be focussed for infinity and not for the slit, and this is not easy.) We must therefore find the intensities of the waves passing through a slit in various directions.

In fig 10, AB is a slit, and w goes at angle θ into the direction of the slit into secondary waves. The distance $PR = AP \sin \theta$ further

of the wave from A is ϵ , that from

For a slit of breadth l the whole

$$\int_0^l \cos \left[\epsilon - \right]$$

If this is integrated and then sq intensity proportional to

$$\left[\sin \left(\frac{\pi}{\lambda} l \sin \theta \right) \right]$$

The form of the curve $y = \sin^2$ to deduct what will be seen in

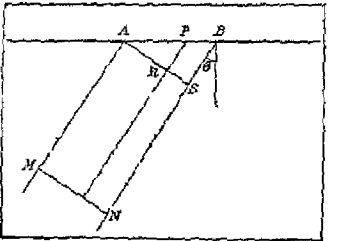


FIG 10—DIFFRACTION BY A SLIT

is any multiple of the wave-length these directions of no light the are much weaker than the cent. $\frac{1}{2}$ of it. When the slit is broad close together. We must also, slit is exactly one wave-length b in any case nothing beyond that (two wave-lengths broad, the first and there will be a secondary about 50°).

A similar construction can be slit. Plate fig 5 shows the diff rectangular hole. The pattern if the hole is narrow and vice versa the pattern consists of a bright fainter rings, as shown in Plate and the telescope focal length f , a dark ring of radius $0.61 \lambda \sqrt{f}$ inside it. The first bright ring brightest point the intensity is at the centre of the central spot. This hole is of great importance in telescopes.

The Diffraction Grating. made by spacing a large number at regular intervals. The general understood. When monochromatic out a wave on the further side from the second slit will be exact from the first and will reinforce other slits. If a is the distance centre to centre), this reinforces $\sin \theta = \lambda/a$. This is called the spectrum of the second order and on slit is two wave-lengths behind is given by $\sin \theta = 2\lambda/a$. A 5 orders also.

In order to discuss the grating breadth l . Their combined effect way as for a single slit by taking to $a+l$ or to $2a+l$, etc., and expression has been summed and found to be as expressed page

$$I = \left[\frac{\sin\left(\frac{\pi a}{\lambda} \sin\theta\right)}{\frac{\pi a}{\lambda} \sin\theta} \right]^2 \left[\sin\left(\frac{\pi b}{\lambda} \sin\theta\right) \right]^2$$

The first factor is exactly that which we found for a single slit diffraction, a is usually small, so that this factor does not vary with the angle θ . The second factor is the important one especially when b is a large number. The curve

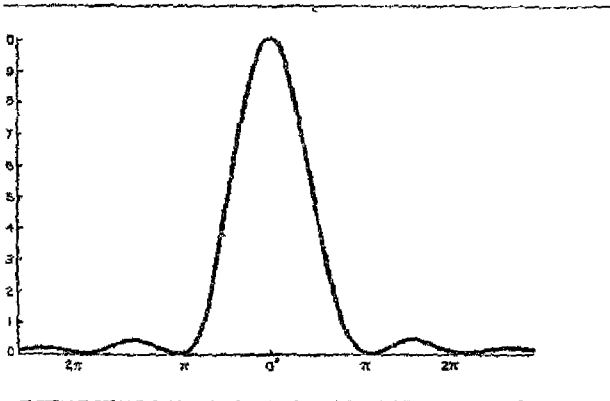
$$y = \sin^2 p \tau / \sin^2 a$$

represents usually of the magnitude of about unity, but has principal maxima of height p^2 at the values $\tau = 0, \pm\pi, \pm 2\pi, \dots$. The grating gives maxima at $\sin\theta = 0, \pm\lambda/a, \pm 2\lambda/a, \dots$. The spectra of the various orders. In the neighbourhood of these the form of the curve is the same. Considering the zero order, we can replace $\sin a$ in the denominator approximately by a so have the curve of fig 11. Thus each spectrum will be a pattern composed of a brilliant centre, and then feeble secondary maxima separated by darkness. The first darkness then $\tau = \pi/p$, and this implies that in the spectrum of

order the first zero is at angular distance $\frac{\tau}{np} \tan\theta$ from the

center. Since the second factor in I is the same for all orders the intensity of the different spectra will depend on the first factor. It may happen that this factor will entirely extinguish some orders, thus, if $b = \frac{1}{2}a$ there will be no even orders at all. In a reflection grating, the grating is the most important of the instruments. In a transmission grating, lines are ruled on a diamond. They are very fine and may be as close as 5,000 to the centimetre. The cuts in the glass do not actually make it opaque, so that the grating is not really a slit, but they give it a periodic character which is all that is needed. The second factor in I holds, but the first is invalid, entirely the intensities in the different orders may vary and in a way often unpredictable, as they depend on the cutting edge of the diamond. It has even been possible to prepare gratings in which nearly all the intensity goes into one spectrum.

Suppose that we send a mixture of colours through the grating. Each colour in the light will produce its own set of spectra. In the zero order the rays are not bent, whatever the colour, or $\theta = 0$, the mixture will be unaltered. Turning to the



11—CHART SHOWING FRAUNHOFER DIFFRACTION BY A SLIT. The y ordinate measures the intensity of light at where $\sin \theta$ is proportional to x .

we shall first see the violet of the first order, then blue, yellow and red, and then darkness, for the second order of violet (4000 Å U) falls further out than the first order of red (7000 Å U). This isolation is true only of the first order (then only by not considering ultra-violet light), the second order red is overlapped considerably by the third order violet. In the higher orders the spectra overlap one another. To eliminate this difficulty special devices have to be used. As a rough preliminary sorting of the spectrum with a prism or else a prism can be set with edge perpendicular to the

grating lines so that it shifts the blue lines to a different level from the red. The overlapping of the spectra has been put to use in comparing wave-lengths with accuracy. Thus, if a spectrum contained a blue and a red line such that the third order blue fell exactly on the second order of the red, we should know that the wave-lengths were exactly in the ratio 2:3. If they fall fairly close the ratio can still be fixed with accuracy, without a very precise knowledge of the grating constant. In this way a set of standard wave-lengths throughout the spectrum were first determined, but later the interferometer replaced the method.

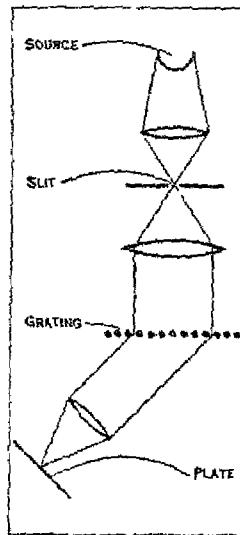


FIG. 12.—DIAGRAMMATIC VIEW OF A SIMPLE GRATING SPECTROSCOPE.

For the installation of a grating spectrograph (see fig 12) we require parallel light. Since most sources of light cover some area it is usual to focus the source on to a fine slit and use this slit as a secondary source. The light diverges from the slit and is passed through a collimating lens. Such a lens would turn the light from a point source into parallel light. For a slit the emergent rays will all lie in planes through the line of the slit and, if the lines of the grating are parallel to the slit, the obliquity of the parallel wave front comes to the grating and is diffracted. A lens is set at a suitable angle to catch the desired part of one of the spectra and the wave is focussed on to a photographic plate. When monochromatic light

is used a narrow line will appear, which will correspond in breadth to the breadth of the slit plus the breadth of the diffraction pattern that would be produced by an infinitely narrow slit.

In practical work of the highest class much complication is saved by having the grating ruled directly on a concave mirror, for this focusses the slit straight on the plate without the intervention of any lenses. It will readily be believed that the making of large gratings on this principle is a very difficult matter; it was most successfully overcome by Rowland who made a number which even now remain the most useful instruments in spectroscopy. The manufacture depends chiefly on the construction of a long screw of very regular pitch, to shift the diamond a definite distance after each line has been ruled. If the diamond should break, it is exceedingly difficult to recover the line with a new one, and all the work is wasted. A troublesome complication arises with some gratings if the screw has a systematic irregularity. Suppose for example that it rules every tenth line a little out of place. Then the true periodicity of the grating is the group of ten lines, and what we call the first order is really the tenth though in view of the approximate regularity it will be far more brilliant than the first nine. Nevertheless in the study of a spectrum it may be that some of the strongest lines give a perceptible image corresponding to one of these lower orders and such an image might be mistaken for a real line. Images of this type are called "ghosts" and in accurate spectroscopic work it is very necessary to know what ghosts may be possessed by the grating in use.

The Nature of White Light—It has been customary since the time of Newton to say that white light is compounded out of all the colours, but the diffraction grating suggests quite another point of view. Let us imagine that the incident light is a plane wave consisting of a single thin pulse. Each slit of the grating diffracts this pulse into all directions, and, if we observe from a given direction, we shall receive in turn the pulses which have come through each slit. They will be evenly spaced and further apart, the broader the angle from which we observe. At each position θ there will be something very like a monochromatic wave, more precisely it is a periodic wave composed of wave-lengths $a \sin\theta$ and all its submultiples, i.e., out of the superposition of light of the first, second and higher orders appropriate to the angle θ . Regarding the matter in this way, we have a perfect right to say that the coloured light has been created by the spectrograph. Thus

of the other. We saw that the first zero falls at $\lambda/\delta\lambda$ from the centre of diffraction, so that $\lambda/\delta\lambda$ must be equal to the dispersion of the two lines, so that $\lambda/\delta\lambda = \lambda/\delta\lambda$. The resolving power is usually defined as $\lambda/\delta\lambda$, which is the difference of wave-length of two lines that can just be resolved. We see that it is equal to $n\phi$. The important point is that it in no way depends on the dispersion, but, for a given order of spectrum only on the number of lines, no matter what their spacing. For example, if we want to separate the sodium lines in the first order we must have 1,000 lines, if in the second, 500. If the grating is coarse the lines may fall very close together, but a powerful telescope can still separate them, if there are fewer than 1,000 lines the telescope will merely magnify a blurred image.

We may compare this with the resolution of the Fabry-Pérot interferometer. The plate being of air, we take the refractive index as unity, and, as the incidence is nearly perpendicular, we can replace $\cos\theta'$ by $1 - \frac{1}{2}\theta'^2$. If $s\lambda = 2b$ for one of the lines where s is a (large) integer, there will be a bright spot in the centre and the next ring will have angular radius $\sqrt{\lambda/b}$. If there is another line of wave-length $\lambda + \delta\lambda$, its innermost ring will have radius $\sqrt{s\delta\lambda/b}$. Though the fringes are fairly sharp, the opacity of the silvering of the plates sets a limit to their sharpness, and we shall not resolve the lines unless the radius of the innermost ring of the second line is a fairly large fraction, say a tenth, of that of the second ring of the first line. This shows that the resolving power should be about ten times as great as s ; if the plates are 5 cm apart it will be about 1,000,000 for visible light.

It is also interesting to consider the resolving power of a prism spectroscope (see fig 13). This instrument separates lines by means of the difference in the refractive index of the glass for different colours. By an argument from geometrical optics, which we shall not give it may be shown that the angular separation of the two lines is $dn/l/b$, where dn is the difference of their refractive indices, b is PP' the breadth of the beam, and l is BC the base of the prism. The lens will focus a beam of breadth $QQ' = b$ to a line of breadth λ/b , and the two lines will therefore be resolved if $l > \lambda/dn$. Thus, to obtain good resolution the most important factor is a great thickness of glass, and this severely limits the use of prism spectroscopes. Taking the value of dn for typical glass we can calculate that 1 cm will resolve the sodium lines, but if we require to resolve two lines for which $\lambda/\delta\lambda$ is half a million as is possible with an interferometer or with a grating of half a million lines, we should require 5 metres of glass, and even if it were otherwise practicable such a thickness would be far too great to let any light through.

The Resolving Power of Telescopes.—The principal of the lens is usually discussed by geometrical methods (see Optics) but it is quite simple to work it out with the wave theory. In fig 14 plane waves fall perpendicularly on the lens in the beam, PA, QC . The central ray through BE is retarded in the glass, but not so the extreme rays at A and C . The focus F is the point where all the secondary waves from AEC are in phase, the retardation of the central ray is balanced by the longer path of the extreme ones. The waves at AB are in phase, and the phase changes from there to F are given respectively by AF and $nBE + EF$, where n is the refractive index. Let BE be d , AB be r and EF be f , supposed much larger then we have

$$d(n-1) + f = \sqrt{f^2 + r^2},$$

whence, approximately, $f = \frac{r^2}{2d} \frac{1}{n-1}$, which determines the focal

length of a plano-convex lens in terms of its curvature. If another set of waves at a small angle θ falls on the lens, their focus F' can be found by the consideration that the waves from A and C must be in phase, while F' is near F in a plane at right angles to the axis of the lens. We thus find that $FF' = f \sin\theta$, a familiar result in geometrical optics.

Supposing that the two waves are from stars, we enquire under what conditions they will be resolved. The image of the first star at F is of course not a point because of diffraction. We can roughly

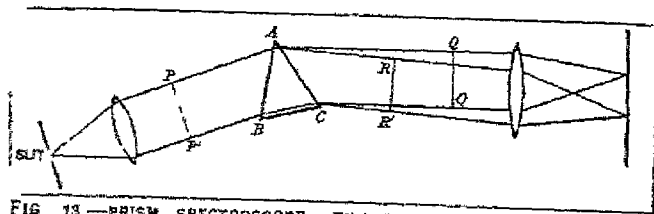


FIG 13.—PRISM SPECTROSCOPE. THE POWER OF RESOLVING TWO SPECTRAL LINES DEPENDS ON THE LENGTH BC

separated. In the n th order spectrum they appear at positions $\sin\theta = n\lambda/a$ and $\sin(\theta + \delta\theta) = n(\lambda + \delta\lambda)/a$, so that, approximately,

$$\delta\theta = \pi\delta\lambda/a \cos\theta.$$

This is the dispersion of the lines, i.e., the distance between the centres of the lines. Now if the diffraction patterns of the lines are such that each main peak (of fig. 11) falls separate from the other we can certainly distinguish that there are two lines. We could probably do so if they were a good deal closer and overlapping, but not if they were as little apart as one-tenth of the breadth of the peak. All that we require is a rough measure, and we shall take the condition that one peak falls on the first zero

estimate its size by the consideration that there will be points near F for which the waves from A and C and all intermediate points, though not perfectly in phase, are so little out of phase, that there will be still a marked intensity. This is a question of the diffraction image of a circular hole and the radius of the central spot is $0.61\lambda/r$. If the centre of the image of the second star is much closer than this, we shall only have one bright spot and shall not distinguish that there were two stars. Thus the angular distance that can be resolved is $0.61\lambda/r$. Taking visible light and measuring the radius of the telescope in millimetres this gives

$$\left(\frac{1.17}{r}\right)'$$

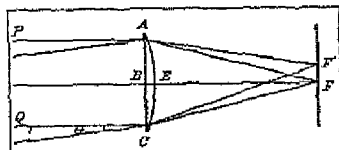


FIG 14 —THE FOCUS OF A LENS
The power of resolving the images F and F' depends on the size of the lens AC and not on the focal length BF

The important thing to notice is that the resolving power in no way depends on the magnification, but only on the diameter of the object glass. If the telescope has a short focal length the magnification will be small; but as long as the diameter is large the resolution will be good, and the small magnification can be overcome by the use of a stronger eye piece. This result requires one qualification, for we have assumed that the whole object glass is operative in bringing rays to the eye. When the magnification is not very great it may happen that the pupil of the eye is the effective limitation and not the object glass, and in such cases the resolving power will depend on the diameter of that part of the object glass from which light enters the pupil.

The tendency to make larger and larger telescopes is to be attributed partly to the fact that they collect more light, but much more to the increased resolving power. An extreme example is given by the measurement of the diameters of stars. Stars are all so distant that no existing telescope could hope to resolve the separate parts of their surface, and the disc seen is never perceptibly larger than that which would be produced by a geometrical point. But if we could have a telescope 50 ft in diameter the resolving power should be sufficient to show the disc of a large star in the same way as an ordinary telescope does for a planet. It is not of course practicable to make such a telescope, but it is also not necessary, all that is required is two little pieces of such a telescope at the points A and C in fig 14. In principle this is the way in which it has been found possible to measure the diameter of Betelgeuse and a few other stars.

The eye is an instrument similar to the telescope. Taking the pupil as 2 mm., the same calculation shows that its resolving power should be $0.42'$. The actual limit, about $1'$, is not very different, and is no doubt affected by the structure of the retina. A similar limit would apply for any eye constructed on the same principle as man's, but insects' eyes are compound, being composed of a very large number of very small independent facets. There can be no phase relations between the separate facets, so that the resolving power can only depend on the size of each separately. It thus seems improbable that an insect can discriminate between objects less than some degrees apart.

The resolving power of the microscope presents a different problem from that of the telescope, because in the microscope we observe non-luminous objects illuminated usually by parallel or not very convergent light. The discussion of the theory will be found under MICROSCOPE, and we here only give the result. If the lens can receive light from the object over a range of 180° (and for a good microscope it very nearly does), then some rough impression of form can be detected for an object of the size of half a wave-length. By immersing the object in a refractive medium the wave-length is shortened and the resolution improved, and it may be further improved by the use of ultra-violet light.

POLARIZATION AND ELECTROMAGNETIC THEORY

In our review of the history of optics we described some of the earlier work on polarization, and we must now make its character clearer. The phenomena of interference and diffraction were all explained by regarding the light as a wave, leaving it entirely open what it is that vibrates and how it does it. In fact all that

we have so far said would with suitable changes of scale, be just as true for sound as for light. But when we come to the phenomena of double refraction, this is not so, they are only explicable if the vibrations are transverse. Though we saw that, in spite of many attempts, no material model could be found which would carry waves in the way that aether does light, still it is quite possible to visualize polarization. A string stretched horizontally may vibrate in a vertical or horizontal plane or simultaneously in both, at any instant a point of the string is displaced from its position of rest in a direction perpendicular to the line of the wire, and this position can be indicated by drawing a line in the direction and of the length of the displacement. When a light-wave is travelling through space, we can also represent it at any point and time by drawing a line in a definite direction and of a definite length. It should be explained that, unlike the case of the string, here the length is only diagrammatic and can be represented on any scale, as long as we are consistent and adopt the same scale for other points. This line is called the light-vector, and the wave is said to be transverse, because the light-vector is always found to be at right-angles to the direction of the wave, that is to say it lies somewhere in the plane of the wave-front. The reason for this will appear when we come to the electromagnetic theory, we shall first describe the main properties of polarization without justifying them.

Types of Polarized Light—Suppose that we have a wave of plane monochromatic light advancing perpendicular to the paper. At any point in the paper we draw the light-vector, and it will go through a series of changes, returning to its original value in the period of the waves. We can represent any motion by giving the x, y co-ordinates of the end of the light-vector, and for monochromatic light these must be sine-functions of the time. If ν is the frequency we therefore take

$$X = A \cos(2\pi\nu t - \alpha), \quad Y = B \cos(2\pi\nu t - \beta)$$

as the general description of the light. We first consider a few special cases. If $B=0$ we have a vibration in which the vector always lies in the direction of x and ranges between the values $\pm A$. This we call *plane polarized* in the direction x . Similarly if $A=0$ we have light plane polarized in the direction y . If we have $\alpha=\beta$, we see that at any time $Y/X=B/A$, so that again we have plane polarized light, in direction $\arctan B/A$ and with amplitude $\sqrt{A^2+B^2}$. Next consider the case $B=A, \beta=\alpha+\frac{\pi}{2}$

Then $X^2+Y^2=A^2$, so that the vector describes a circle; this is therefore called *circularly polarized* light. In the general case we can find the locus of the light-vector by eliminating t and get

$$\frac{X^2}{A^2} + \frac{Y^2}{B^2} - 2\frac{XY}{AB}\cos(\alpha-\beta) = \sin^2(\alpha-\beta)$$

This is an ellipse of which the axes are determined as to position and magnitude by A, B and $\alpha-\beta$. The most general type of light is therefore called *elliptically polarized*, and we recognize our previous types as degenerate ellipses.

We next consider the propagation of such waves, that is to say, the phase relations of the light-vectors for different positions of the wave-front. Our wave is now written as

$$X = A \cos[2\pi\nu(t - z/c) - \alpha], \quad Y = B \cos[2\pi\nu(t - z/c) - \beta],$$

and the character of the polarization is the same for all values of z , as it will depend on A, B and

$$(2\pi\nu z/c + \alpha) - (2\pi\nu z/c + \beta) = \alpha - \beta$$

Next we take t as fixed and consider the way the light-vector is arranged for various values of z . We may liken it to the stretched string. If $B=0$ it will be in the shape of a sine-curve in the plane of xz with wave-length c/ν , and similarly whenever

$\alpha=\beta$, though for a different plane. If $\beta=\alpha+\frac{\pi}{2}$ and $B=A$, the locus is a screw, or helix, of radius A and pitch equal to the wave-length c/ν . If the axes are right-handed (so that a man standing with his head towards z has x to his right and y to his left), then the screw may be seen to be left-handed. This is therefore

called (oblique or slant) polarized light. If we take $\beta = \alpha - \frac{\pi}{2}$

instead, we should get a right-handed screw. The distinction between right and left-handed circularly polarized light is physically very important, as it plays a leading part in the phenomenon of gyration. In the case of elliptically polarized light the locus of light-vectors may be described as a flattened screw.

It may be either right- or left-handed, but the question is not so important physically. This suffices to describe the form of the waves, and it only remains to derive the intensity. At any point this is proportional to the average value of the square of the light-vector in the cases we have considered is the average of $X^2 + Y^2$. When the waves are traveling in an arbitrary direction, instead of along z , we may have three components of the light-vector, and in such a case $X^2 + Y^2 + Z^2$ is to be averaged over the time.

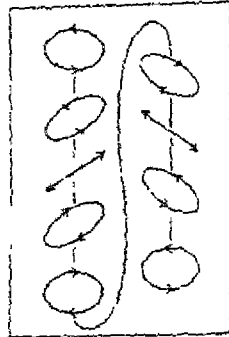


FIG 15 — ELLIPTICALLY POLARIZED LIGHT

We must also consider the nature of ordinary unpolarized light. This has no 'sides' and is symmetrical about the direction of propagation, and in this it is like circularly polarized light, but we shall see that circularly polarized light can easily be converted into plane polarized, whereas for ordinary light this is not possible, so the explanation of its symmetry must be found in another way. If the light is rigorously monochromatic, the phases of the components of the light-vector are maintained for ever, and such light must therefore be polarized either plane, circularly or elliptically. In nature however no light is rigorously monochromatic, for the Michelson interferometer fails to show interference for differences of more than a million wave-lengths, and this enables us to explain unpolarized light as being polarized light of which the direction is changed frequently. We suppose each atom to emit a polarized monochromatic wave which lasts for a time corresponding to a million wave-lengths, and then changes and emits one of a different polarization. The length of time of each separate type is so short that we cannot distinguish them, but merely get an average of all the different types and this average will be symmetrical about the direction of propagation.

In describing plane polarized light we have said that it is polarized in the direction x when the light-vector vibrates along x . Unhappily there is some confusion in the terminology used. When polarization was first discovered the convention was adopted that the light of the ordinary ray in double refraction is polarized in the plane through the axis of the crystal and the direction of propagation. It later appeared that the light-vector must be perpendicular to this plane, so that the old convention would have described the light as polarized in the plane of yz , which we call polarized in the direction x and it was even sometimes loosely referred to the direction y alone. For most optical effects the behaviour is determined by the direction of the vector and not by the direction of propagation of the wave, so that it is practically inconvenient to mention two directions when one would do. The modern tendency which we shall adopt, is to describe plane polarized light by the direction of the light-vector, thus, in double refraction we shall say that the ordinary ray is polarized at right angles to the crystal axis. Some confusion is unavoidable because the term plane polarized (instead of line polarized) is too deeply implanted to be changed, but we can avoid ambiguity by saying that light is plane polarized in some direction, instead of in some plane, and the direction is then the normal to the plane which was formerly used.

Double refraction is not the only way in which polarization is produced, and we shall discuss its other occurrences in detail later. Chief among them is reflection at a transparent surface set at a suitable angle. At other angles there is an incomplete polarization, which is sometimes very troublesome in experiments; for as light passes through any system of lenses or mirrors, it is almost impossible to prevent its becoming polarized and this may easily ob-

scure the study of its original polarization of scattered light sky. Again in the diffraction of light, the theory we have given holds rather differently at different angles and we shall not consider it required. Perhaps the most interesting effect (gyration) is here displaced and split when the atom and the split components are produced from which much information is obtained of the atom.

The Analysis of Polarized Light though by no means exclusively, double refraction in crystals will here suffice to say that when a light-vector is resolved in two directions and perpendicular to the direction of propagation in these directions have components that we have a plate with parallel sides through it along z , while the two components such a plate the light-vector will

$$Y = A \cos[2\pi\nu(t - z/a) - \alpha],$$

where a and b are the wave-velocities. If the incident light is plane polarized, it goes through unchanged, but if it is elliptically polarized, on entering the plate at $z=0$ we have $B = C \sin \gamma$. If the plate is of thickness l the farther side as

$$X = C \cos \gamma \cos[2\pi\nu(t - l/a) - \alpha],$$

and so X and Y are no longer in phase and the light is now elliptically polarized. Fig 16 shows this transformation comes about. If the incident light is elliptically polarized, the emergent light is elliptically polarized, but in a different direction. It might become plane polarized if the plate is a quarter-wave plate. A quarter-wave plate is one so that $2\pi\nu l/a - 2\pi\nu l/b = 90^\circ$ and the light is plane polarized, with the axes of the ellipse at right angles to the original axes. We write it as

$$X = A \cos(2\pi\nu t - \alpha),$$

After passing through the quarter-wave plate the light will be

$$X = A \cos(2\pi\nu t - \alpha')$$

and it is now plane polarized. A quarter-wave plate is one so that the incident light is circularly polarized at 45 degrees to the direction of propagation. The handedness will be indicated according to the direction between x and $+y$ or x and $-y$. A wave, entering from the left, is easily cut to exhibit a rather weak double refraction.

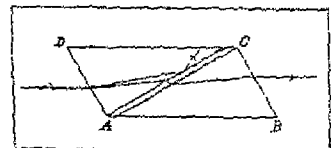


FIG 16 — THE NICOL PRISM

into plane polarized, and it remains unpolarized. The standard instrument is a rhomb of calcite, which is always cut across the line AC , and its two faces are cemented together. The ends AD and BC are also cut to form a rhomb of 72° . A wave, entering from the left, is easily cut to exhibit a rather weak double refraction.

ve index n ermediate between binary waves and as the order it becomes totally reflected and weakened so as to absorb it. The through, and so the emergent all polarize light over a certain limits are set by the condition cted at AC and lost, and on the under favourable conditions the pical experiment with polarized s. The simplest example is the

The first produces polarized , the second is placed with its it is twisted round through 90°. dinary wave in the first nicol is ed. This device has been used r rotates his nicol through 90°, mp appears to burn steadily, if will go out

rization of elliptically polarized plane polarized light by some nicol. There will always be two e light has two parameters, the l their position. There are two ce plate may be rotated until it it renders the light plane po- gushed by a nicol. The position ie axes of the ellipse, and the es the ratio of the axes. Thus ve already know the axes of the portant experiments, in other wo adjustments is troublesome d the compensator. In this the lar directions, instead of along sure the relative lengths of the those two directions and their t of the compensator consists of is a rather weakly doubly re- so that the crystal axis lies in a ther so that it is at right angles , where the lines and dots indi- cident light will be broken into lge, of which one will have a ring the second this will change e exactly equal as at the centre use. Thus, incident plane polar- ized at A. At any other point ie light will have gone further i the other. If elliptically pol- ll be places where it is plane alyzing nicol set at the proper

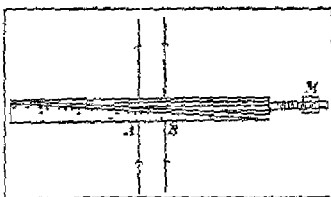


FIG 17 —THE COMPENSATOR

The dots indicate the crystal axes of the two quartz wedges, and M is the micrometer screw

ie light vector along and across er amplitudes is given by the

NETIC EQUATIONS

reat discovery that the equations ic waves are equally applicable formulation for the whole the- ion. For the derivation of the icle ELECTRICITY; we shall here

take as given and show how t applies for light

Consider first the case of free space. At every point there may be an electric force **E** and a magnetic force **H**. Each has both direction and magnitude and they can be most conveniently described by the components E_x, E_y, E_z and H_x, H_y, H_z along the directions x, y, z . The vector notation is well adapted to expressing their relations. In this notation

$$\frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y} + \frac{\partial E_z}{\partial z}$$

is written $\text{div } \mathbf{E}$ and called the divergence, while the three quantities

$$\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z}, \frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x}, \frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y},$$

are the components of $\text{curl } \mathbf{E}$. A vector equation involving curl is thus three equations, when written in terms of the components.

The equations are

$$\frac{1}{c} \frac{\partial \mathbf{E}}{\partial t} = \text{curl } \mathbf{H}, \text{div } \mathbf{E} = 0,$$

$$-\frac{1}{c} \frac{\partial \mathbf{H}}{\partial t} = \text{curl } \mathbf{E}, \text{div } \mathbf{H} = 0.$$

In these equations c is originally a rather abstruse quantity, the ratio of the electromagnetic to the electrostatic units. It is a velocity and one of the strongest evidences for the electromagnetic theory of light is that, when purely electric methods are used to determine the ratio, it is found to be the same as the velocity of light. We shall give a few examples of solutions, but before doing so must complete the theory by giving the rule for intensity. In our previous account of intensity we left a factor of proportionality undetermined and this was right because we had then no other physical phenomenon to link with light, so that there was no way of fixing the absolute values. Now however, we have a much more precise formulation, because we can imagine that we might measure (very ideally of course) the electric force in the light by means of an electrometer, and we can therefore make our definition absolute. Electrical theory assigns a value to the flux of energy, $i \cdot e$, to the rate at which energy is carried across unit area in unit time, and this is a suitable measure for intensity. It is called the "Poynting vector," after its discoverer, and is $\frac{c}{4\pi} [\mathbf{E}, \mathbf{H}]$ where $[\mathbf{E}, \mathbf{H}]$ is a vector product with component $E_y H_z - E_z H_y$, along x , etc.

We now consider some solutions of the electromagnetic equations. One such solution may be verified to be

$$E_x = A \cos \frac{2\pi}{\lambda} (ct - z), E_y = 0, E_z = 0;$$

$$H_x = 0, H_y = A \cos \frac{2\pi}{\lambda} (ct - z), H_z = 0$$

We see in the first place that we have a wave travelling along z with velocity c , and purely electrical experiments have shown c to be equal to the velocity of light. Secondly we see that it is a transverse wave, but it is ambiguous whether the electric or magnetic force is the light-vector. A similar solution is

$$E_x = 0, E_y = B \cos \frac{2\pi}{\lambda} (ct - z), E_z = 0;$$

$$H_x = -B \cos \frac{2\pi}{\lambda} (ct - z), H_y = 0, H_z = 0;$$

and this evidently represents the other polarized component. A third solution can be formed by superposing these two, or by superposing them with a phase difference between E_x and E_y

The intensity in such a case would be $\frac{c}{8\pi} (A^2 + B^2)$

We must now consider whether the electric or magnetic force is the light-vector. Since both always occur in the wave a theory could be constructed in which either was so taken, and it is a matter of convenience which we choose. A number of phenomena

... reflected straight back, the incident ... waves interfere with one another and produce a system of stationary waves. These may be described by

$$E_z = A \cos \frac{2\pi}{\lambda} (x - z) - A \cos \frac{2\pi}{\lambda} (x + z) = -2A \cos \frac{2\pi}{\lambda} x \cos \frac{2\pi}{\lambda} z$$

$$H_y = A \cos \frac{2\pi}{\lambda} (x - z) + A \cos \frac{2\pi}{\lambda} (x + z) = 2A \cos \frac{2\pi}{\lambda} x \cos \frac{2\pi}{\lambda} z$$

We see that at points where z is any multiple of half a wave-length E vanishes all the time whereas H_y vanishes all the time at points where z is an odd multiple of quarter of a wave-length. Suppose that our mirror is coated with a nearly transparent photochromic film, of some depth which is afterwards developed and examined in section. Then we shall find places where it is fogged in the direction of the light-vector, and others where it is unaffected and the positions of these tell us that it is the electric force that is effective and not the magnetic. From this and similar cases we conclude that it is best to take the electric force as the light-vector.

... one medium and the electric force ... through a ... and ... equal to the tangential components of the corresponding forces just on the other side. (See ELECTRICITY.)

Refraction in Transparent Media—In a non-conducting isotropic medium, the equations assume the form

$$\epsilon \frac{\partial \mathbf{E}}{\partial t} = \text{curl } \mathbf{H}, \quad -\frac{1}{c} \frac{\partial \mathbf{H}}{\partial t} = \text{curl } \mathbf{E}$$

It is easy to verify that these are satisfied by

$$E_x = A \cos \frac{2\pi}{\lambda} \left(\frac{c}{v} t - z \right), \quad E_y = 0, \quad E_z = 0,$$

$$H_x = 0, \quad H_y = A \sqrt{\epsilon} \cos \frac{2\pi}{\lambda} \left(\frac{c}{v} t - z \right), \quad H_z = 0$$

The electric force is transverse to the waves and the wave-velocity is $c/\sqrt{\epsilon}$, so that the medium has refractive index $\sqrt{\epsilon}$. An apparent difficulty at once arises for our result seems to imply that the refractive index should not depend on the colour of the light. This will be explained when we come to the atomic theory where it will appear that the dielectric constant depends on the frequency of the inducing electric force.

We next consider the passage of light from one medium to another. Suppose that they have refractive indices n and n' , and first suppose n to be the lesser, in the case of free space it will be unity. To find the formulae for refraction and reflection we take a given incident wave, and assume that there are reflected and refracted waves but without making any assumptions about their wave-lengths or directions. The boundary conditions then require that the sum of the tangential components of incident and reflected forces at the boundary in the first medium are everywhere and at every time equal to the corresponding forces in the refracted wave on the other side of the boundary. These conditions lead in the first place to the law that the frequencies of all three waves must be equal, so that the wave-length of the refracted wave is $\lambda n/n'$, and then to the law that the angle of reflection is equal to the angle of incidence θ , while the angle of refraction θ' is given by $n \sin \theta = n' \sin \theta'$. These rules can be deduced merely from the fact that there are boundary conditions and would be the same whatever the form of those conditions. Next with the special conditions of the electrical theory, we can find the amplitudes of the reflected and refracted waves. Taking the component in which the electric force is polarized perpendicular to the plane of incidence we find as amplitude of the reflected wave $\sin(\theta - \theta')/\sin(\theta + \theta')$, while the component polarized in the plane of incidence gives $\tan(\theta - \theta')/\tan(\theta + \theta')$. These are Fresnel's sine and tangent formulae, their squares give the intensities of reflection. The intensities of the refracted wave may also be given, but are not so important.

We may now consider how the reflection varies with the angle of incidence. Take the sine formula first. For perpendicular incidence the formula becomes ambiguous but may be replaced by $(n' - n)/(n' + n)$. For water the refractive index is about $1\frac{1}{3}$ and so when light falls perpendicularly on water the amplitude of the reflected wave is $\frac{1}{4}$ of that of the incident, and therefore the intensity is only about 2 per cent. With increasing angle of incidence, the reflection increases somewhat (for incidence on water at 45° it becomes about 5 per cent), and, as the incidence approaches grazing, it increases rapidly up to unity, which means perfect reflection. The phase of the reflected light is always the same as that of the incident. The tangent formula behaves quite differently. For perpendicular incidence it has the same value but it starts diminishing and finally vanishes at the polarizing angle, when $\tan \theta = n'/n$, at which angle the reflected and refracted waves are perpendicular to one another. For water the angle of incidence is about 54° . After this it increases again and reaches unity at grazing incidence. The phase is the same as that of the incident light up to the polarizing angle and from

REFRACTION AND DOUBLE REFRACTION

We have already made much use of the idea that the optical effect of a transparent medium can be represented by a refractive index. This is not of course an explanation of refraction, for that we shall have to consider atomic processes, but without doing this we can discuss many of its features and can describe the experiments which have been used in its investigation. We shall be content for the most part with the description of results to work them out in detail would involve rather elaborate mathematics.

The Electromagnetic Equations for Refracting Media.—The natural starting point for the discussion is the extension of the electromagnetic theory to cover electrical waves propagated through matter. When a static electric force acts on matter it may produce two effects. If the matter is a conductor a current will flow according to Ohm's law, this is expressed by defining a *current density* \mathbf{j} (a vector with components j_x, j_y, j_z) which is given by $\mathbf{j} = \sigma \mathbf{E}$ where σ is the specific conductivity of the medium. If the matter is an insulator the electric force displaces the electricity in the atoms in a way that may be compared to the compression of a spring, and a new quantity has to be introduced to express this, which is called the *dielectric displacement*. In isotropic media, such as water or glass, the dielectric displacement bears a constant ratio to the electric force. We write $\mathbf{D} = \epsilon \mathbf{E}$ and call ϵ the *dielectric constant*. General electromagnetic theory then shows that the equations for free space must be altered so as to accommodate either or both of these properties of matter. We now write

$$\frac{1}{c} \frac{\partial \mathbf{D}}{\partial t} + \frac{4\pi}{c} \sigma \mathbf{j} = \text{curl } \mathbf{H}, \quad \text{div } \mathbf{D} = \rho$$

Matter also has magnetic properties and this suggests that the other equations should be changed as well. It is found however to be unnecessary for the alternations of force in light are so rapid that the magnetic properties have no time to take effect. So we adhere to the equations

$$-\frac{1}{c} \frac{\partial \mathbf{H}}{\partial t} = \text{curl } \mathbf{E}, \quad \text{div } \mathbf{H} = 0.$$

These equations together determine the behaviour of light in most types of matter, but we must remember that we always have to make observations outside, and therefore require to know

here onwards differs from it by 180°

These phenomena have been much studied experimentally. The behaviour of a transparent medium depends only on its refractive index, which is most accurately determined by the refractometer (essentially, a prism of the substance), so that experiments on reflection do not provide new information, but serve as a very valuable check on the theory. Suppose, for example, that we illuminate a glass surface obliquely with light polarized in some direction neither in nor perpendicular to the plane of incidence. To find the reflection this light must be resolved into two components, one of which obeys the sine and the other the tangent formula. They will be unequally reflected, but in neither case is the phase changed at the reflection (or only through 180° , which does not matter) and so the reflected light will again be plane polarized, but in a new direction. If the light is incident at the polarizing angle the reflected light will contain only the component polarized in the direction at right-angles to the plane of incidence. If ordinary light is incident the same is true, and this process is often used for obtaining polarized light. The most refined experiments have revealed the fact that the polarization is never perfect, but the unwanted component can usually be attributed to the presence of grease on the surface. If elaborate precautions are taken to remove this grease the effect becomes very small but it never quite vanishes. This is probably to be attributed to the fact that the surface atoms are necessarily in a different state from those inside, so that it is not possible for a medium to remain truly homogeneous up to the boundary.

We have described what happens when the incident light is in the medium of lower refractive index. In the contrary case the intensity of reflection follows similar rules for the two components but with one very important difference. In this case the angle of refraction is larger than the angle of incidence and the reflection becomes complete for both polarized components when the refracted ray is at 90° , at which point the inclination of the incident ray is given by $\sin\theta = n'/n$. For greater angles of incidence the phenomenon of total internal reflection supervenes, and this we must now consider.

When $\sin\theta > n'/n$ there is no angle θ' for which the equation $n \sin\theta = n' \sin\theta'$ can be satisfied, and so there can be no progressive wave in the second medium. The appropriate solution involves instead a real exponential factor. If the boundary is the x plane, and if the incident wave is at angle θ , its phase will be given by

$$\cos \frac{2\pi}{\lambda} \left(\frac{ct}{n} - x \sin\theta - z \cos\theta \right),$$

and the appropriate solution in the second medium is $e^{-(2\pi/\lambda)z\sqrt{(n^2 \sin^2\theta - n'^2/n^2)}} \cos \frac{2\pi}{\lambda} \left(\frac{c}{n}t - x \sin\theta - z \right)$ which

evidently fits the boundary condition and may be verified to satisfy the wave equations. The real exponential implies that the disturbance only penetrates a very short distance into the second medium, roughly not much more than a wave-length. When the amplitudes are worked out, the reflected wave is found to have amplitude equal to the incident, but with a changed phase, and the change is unequal for the two polarizations. Thus, if incident plane polarized light is totally reflected, the emergent light is polarized elliptically. Working on this principle Fresnel devised an instrument which turns plane into circularly polarized light.

For water and air the angle of total reflection is about 49° . Thus, when the surface of a glass of water is viewed obliquely from below, it looks like mercury. Total reflection has a curious effect on the field of view of a fish, for however close it is to the surface, everything outside the water must be crowded into a cone of angle 49° , the edge of which will represent the horizon; while, on account of the total reflection, the fish will be able to see the bottom, except for parts nearly underneath, quite as well reflected in the surface as directly. Total internal reflection is much used in optical instruments, as it provides more perfect reflection than any silvering. In many types of binocular the rays are internally reflected no less than four times between the two lenses of each telescope (see BINOCULAR INSTRUMENTS).

Refraction in Absorbing Media To discuss the passage of light through materials we take both a dielectric constant and a conduction current and by Ohm's law the latter will be proportional to the electric force. The first electromagnetic equation is now

$$\epsilon \frac{\partial \mathbf{E}}{\partial t} + \frac{4\pi\sigma}{c} \mathbf{E} = \text{curl } \mathbf{H},$$

while the remainder are unchanged. The presence of the conduction term has an effect something like what we found in total internal reflection, for it compels us to introduce a real exponential. For a wave of frequency ν going along z a solution can be found in which

$$E_x = e^{-z\sqrt{\nu^2\kappa^2/c^2}} \cos 2\pi\nu(t - nz/c),$$

provided that n and κ satisfy the equations

$$n^2 - \kappa^2 = \epsilon, \quad n\kappa = \sigma/\nu,$$

n is the refractive index, and κ is called the absorption coefficient. Considered at a given instant of time, the wave is a damped sine-curve of wave-length $c/n\nu$ and the amplitude decreases to a fraction $e^{-\kappa z/n}$ of itself for each successive crest. For actual metals κ/n is quite large, so that the light can only penetrate a very short distance. The value of n could be determined experimentally from the deflection of light by a prism, if one could be made so thin as to transmit light, and κ could be determined by finding how much the light is attenuated in passing through a plate; but in view of the extreme opacity of metals such methods are very troublesome, and it is more convenient to deduce n and κ from experiments on reflection.

The principle of reflection is just the same as for transparent media, but the details are very different on account of the real exponential in the internal wave. There is a change of phase in the reflected wave and it is different for the two polarizations. Consequently, if plane polarized light is reflected, it becomes elliptic, and the study of this ellipticity is the most powerful method of evaluating n and κ . In the case of perpendicular incidence it can be shown that the intensity reflected is $(n^2 + \kappa^2 + 1 - 2n)/(n^2 + \kappa^2 + 1 + 2n)$. For all metals κ is considerably larger than n , and so the reflection is not far from complete. We see how it comes about that strong absorption, or large κ , means strong reflection. The refractive indices of metals vary over a much wider range than those of transparent substances. Thus, while the latter range roughly speaking between 1 and 2.4, silver has refractive index 0.18, associated with absorption coefficient 3.67. More remarkable still is sodium, which, if it can be used un tarnished, is an even better reflector than silver. Here $n = 0.005$ and $\kappa = 2.61$, and 99.7 per cent of the light is reflected at perpendicular incidence. In so far as wave-velocity has a meaning in such a substance, the wave-velocity is two hundred times the velocity of light.

It is hardly too much to say that there is no theory of the optics of metals. There is a general resemblance between their optical and electrical qualities in that the best conductors are the best absorbers, and therefore the best reflectors. But in all cases κ is greater than n , and this implies that the dielectric constant ϵ is negative, which has no meaning in electrical theory.

Other substances are opaque besides metals, quite apart from the opacity due to the repeated scattering of light. Indeed ordinary transparent substances are always opaque for light of some part of the spectrum, and for such light they behave much like metals. In particular, light which is strongly absorbed will be strongly reflected. Rubens took advantage of this fact in his study of "rest-rays," which consist of light in the extreme infrared. For example rock-salt absorbs light of wave-lengths round 50μ , and so reflects it strongly, although it is transparent to other wave-lengths. If then the light from a lamp emitting all wave-lengths is reflected to and fro several times by rock-salt mirrors, the other wave-lengths will be eliminated, and the reflected light will be nearly pure. After the last reflection its wave-length is determined by means of a grating. Unlike the case of metals here the process of absorption has been farry

Double Refraction. Double refraction is called to be that in regular matter and for ordinary purposes that the velocity of light is different in different directions. Consequently the refractive index of the crystal will differ for different directions and it is said to be anisotropic. The geometrical theory of crystallography is a part of crystallography and these crystals are distinguished by the types of symmetry they possess. For the purpose of the present work it is not necessary to know the way in which the atoms are packed, but the relation between electric force and polarization is important. It can be shown that in general the polarization lies in the same direction as the force but in some cases there may be three mutually perpendicular directions in the crystal for which they are in the same direction. We take these directions for the axes and have

$$D_x = \epsilon_x E_x, \quad D_y = \epsilon_y E_y, \quad D_z = \epsilon_z E_z$$

But the crystal symmetry may make a further restriction. Thus in the regular system of crystals, the three mutually perpendicular axes are equivalent to one another, so that all physical properties in these three directions must be the same and therefore $\epsilon_x = \epsilon_y = \epsilon_z$ must be equal. For electrical and optical purposes therefore though not for others the regular system is isotropic. In the hexagonal, tetragonal and trigonal systems there is an axis of 6-, 4- or 3-fold symmetry and if this is taken as the z-axis it follows that $\epsilon_x = \epsilon_y$, though they need not equal ϵ_z . Calcite and quartz both belong to this type. In all other crystal classes all three ϵ 's may be different. We thus have three types of crystal, the regular, the uniaxial and the biaxial. The regular behaves for light as though it were isotropic and we shall deal with the uniaxial as a special case of the biaxial (see CRYSTALLIZATION).

For a transparent crystal the electromagnetic equations assume the form

$$\frac{1}{c} \frac{\partial \mathbf{D}}{\partial t} = \text{curl } \mathbf{H}, \quad \text{div } \mathbf{D} = 0,$$

$$-\frac{1}{c} \frac{\partial \mathbf{H}}{\partial t} = \text{curl } \mathbf{E}, \quad \text{div } \mathbf{H} = 0,$$

together with $D_x = \epsilon_x E_x, D_y = \epsilon_y E_y, D_z = \epsilon_z E_z$. The whole question can be discussed with either E, H or D as the primitive quantity, and of course exactly the same results would emerge, but it is most convenient to take D . This is the light-vector used by Fresnel in his original theory, before it was given an electrical meaning. The process of solution consists first in eliminating E and H in terms of D and then fitting a plane wave of arbitrary direction so as to satisfy the equations for D . If l, m, n are the direction cosines of the wave front and L, M, N those of the light-vector and if the wave-velocity is V , the wave will be of the form

$$D_x = LS, \quad D_y = MS, \quad D_z = NS$$

where
$$S = A \cos \frac{2\pi}{\lambda} (Vt - lx - my - nz)$$

In giving the results of the substitution we shall write $\alpha^2, \beta^2, \gamma^2$ for $\epsilon_x, \epsilon_y, \epsilon_z$ respectively. Then it is found that the wave-velocity V must satisfy the equation

$$\frac{l^2}{V^2 - \alpha^2} + \frac{m^2}{V^2 - \beta^2} + \frac{n^2}{V^2 - \gamma^2} = 0$$

This is a quadratic equation in V^2 , and we conclude that for a given direction of the wave-front there are two wave-velocities associated with each of these values there are definite values of L, M, N , and these determine the polarizations of the two waves. They are at right-angles to one another and to the direction of the wave. A simple example is given by a wave going along the direction of z , where the two velocities are α and β and the directions of polarization x and y . Another example is given by a uniaxial crystal where $\alpha = \beta$. The wave-velocities are then given by

$$V = \alpha \text{ and } V^2 = \alpha^2 n^2 + \gamma^2 (l^2 + m^2)$$

and depend on the direction: the ordinary wave and its light-vector lies in the plane perpendicular to the axis. The other the extraordinary wave, is polarized in a direction contained by the axis and the wave direction and its velocity depends on the wave direction and ranges between γ and α .

The values of the wave velocities for different directions can be best appreciated by constructing the normal surface. This is a two-sheeted surface constructed by laying off in every direction from an origin two radii proportional to the two wave velocities. Its general form can be seen from fig. 18 which shows a perspective drawing of a portion of it which is repeated by reflection in the principal planes. The figure is drawn on the assumption that

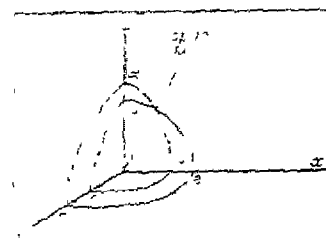


FIG. 18.—NORMAL SURFACE REPEATED BY REFLECTION IN THE OTHER QUADRANTS

that the two sheets meet in four conical points one in each quadrant of the plane of xy , that is in the plane perpendicular to the intermediate axis. Waves going in the directions of these conical points will have the same velocity whatever their polarization, and so for these directions light will not be polarized. These are the two optic axes which give rise to the name biaxial. Uniaxial crystals may be regarded as a degenerate case in which the two optic axes have approached one another, the normal surface becomes a sphere and an oval surface, which touch along the direction of the axis. The normal surface does not show how the waves corresponding to the two sheets are polarized and for this Fresnel gave a very convenient construction. The ovaloid is an oval surface obtained by laying off a radius in each direction l, m, n according to the rule

$$r^2 = \alpha^2 l^2 + \beta^2 m^2 + \lambda n^2.$$

When this surface is cut by a plane parallel to the wave front the longest and shortest radii of the section give the two values of the wave-velocity, and their directions give the polarizations. This construction shows among other things that the wave-velocity is fixed when the polarization is given, without reference to the direction of the wave-front.

The phenomena we have so far described suffice to explain many of the features of crystal optics, in particular they are all that is required to understand the action of quarter-wave plates, nicols and other polarizing instruments, but they do not explain the fundamental fact that things seen through a crystal look double. To understand this we have to consider rays not plane waves of indefinite breadth. In making Huygens' construction it would be wrong to draw the normal surface round each point and base the construction of fig. 3 on this, for the normal surface is only a diagram describing how plane waves can go, and does not represent the front of a wave emitted from a point. To find the form of this wave-front, we imagine that at every point of the normal surface a plane is drawn perpendicular to the radius-vector. All these planes will envelop a surface of two sheets, and this we call the ray surface. In general shape it resembles the normal surface, and has four conical points lying in the same plane, but now at different angles: these are called the ray axes. Huygens' construction is done with the ray surface not the normal surface. For uniaxial crystals the ray surface degenerates to a sphere and a spheroid touching the sphere at the ends of the axis.

It will be readily believed that double refraction involves much complicated geometry, and the complete conquest of the subject by Fresnel is one of the greatest feats ever performed in physics. Effects can be obtained by illuminating crystals with suitably polarized light. Plate fig. 4 shows the effect obtained in the case of a uniaxial crystal, cut at right angles to the crystal axis; and fig. 5 that in the case of a biaxial crystal, cut at right angles to the bisector of the angle between the optic axes. We must omit their explanation, which requires a detailed discussion. We can only refer to the curious phenomenon of conical refraction which was discovered theoretically by Hamilton and after

ward viewed. When a narrow beam is sent along the axis of a crystal the direction for the beam becomes indeterminate so that it can be anywhere on a certain cone. On emergence at the other side this cone is made into a cylinder by the surface refraction, and if this falls on a screen we get a ring of light.

Double refraction is invariably present in crystals which are not of the regular system, but is often quite small. Even in a strongly doubly refracting crystal like calcite the two principal indices are 1.66 and 1.49 so that their difference is considerably less than the refractive effect of either (which may be represented by its difference from unity). In uniaxial crystals and in biaxial of the orthorhombic system the axes are fixed by the crystal symmetry, though the principal wave-velocities may vary with the colour. In biaxial crystals of the monoclinic and triclinic systems the principal axes may vary in position as well, and the most complicated colour patterns may be produced. Some crystals such as tourmaline, show a selective absorption, so that one of the two polarized waves cannot penetrate far into the crystal, and the light emerges from the other side plane polarized.

Double refraction also occurs when an isotropic solid is in a state of strain, and indeed the chance strains in badly annealed glass are sometimes a cause of trouble in experiments with polarized light. On the other hand advantage has been taken of the effect, for by making a transparent model say of a girder it is possible to find the strains set up in it by the appropriate forces in cases where the shape is too complicated for direct calculation. Another occurrence of double refraction is the Kerr effect,—an ambiguous name, as there is a second effect of magnetic type, also named after this investigator. When light is sent through the glass of a charged electric condenser double refraction occurs, so that the component polarized in the direction of the electric force has wave-velocity slightly different from that transversely polarized, the effect is proportional to the square of the electric force across the condenser. Yet another case, predicted and discovered by Voigt is a very small double refraction when light traverses matter placed in a strong magnetic field at right angles; this is associated with magnetic gyration which we shall discuss later.

Natural Optical Gyration.—Double refraction is not the only optical effect exerted by crystals. The symmetrical properties of a crystal are of two different kinds, corresponding to rotation and reflection respectively. Most crystals have some symmetry elements of both types, but there are some which only have rotations, so that the crystal is not identical with its mirror image. The simplest geometrical form possessing this peculiarity is the screw, which cannot be superposed on its mirror image, and we therefore liken this type of crystal to a screw. Quartz is such a substance, and there exist two types of quartz crystals, which we may call right- and left-handed. Now circularly polarized light has the same quality of a screw and we should therefore expect that a right-handed quartz crystal would react differently to right- and left-handed circularly polarized light respectively. It is in fact found that the wave-velocities are different, and this is the basis of the theory of optical gyration.

Let us suppose that n_r and n_l are the refractive indices for the two types of circularly polarized light of frequency ν . Then the right-handed wave will be

$$E_x = A \cos 2\pi\nu(t - n_r z/c), \quad E_y = -A \sin 2\pi\nu(t - n_r z/c),$$

and the left-handed

$$E_x = A \cos 2\pi\nu(t - n_l z/c), \quad E_y = +A \sin 2\pi\nu(t - n_l z/c)$$

Suppose that at the plane $z=0$ we have light polarized along the direction x . This is given by simply adding these two solutions together, and then at any value of z we shall have

$$E_x = 2A \cos 2\pi\nu \left[t - \frac{n_r + n_l}{2} \frac{z}{c} \right] \cos \pi\nu(n_l - n_r)z/c,$$

$$E_y = 2A \cos 2\pi\nu \left[t - \frac{n_r + n_l}{2} \frac{z}{c} \right] \sin \pi\nu(n_l - n_r)z/c.$$

This means that at the point z we can regard the light as plane polarized in a direction inclined to x at angle $\pi\nu(n_l - n_r)z/c$. The phenomenon is actually observed by sending plane polarized

light through Iceland spar and seeing how an analyzing nicol must be placed in order to extinguish the light. The gyration constant is the rotation produced by a thickness of 1 cm of the substance.

In quartz the gyration is very strong being 217° per cm for yellow light, but is complicated by double refraction of the uniaxial type, and it is only for light going very nearly along the crystal axis that it can be observed. There are also crystals of the regular system which exhibit the effect, for example sodium chlorate, and here it is present for all directions. It is also shown by liquids when their molecules contain a chemically asymmetric atom, such a liquid is isotropic in that all directions are equivalent, but is not molecularly speaking, identical with its mirror image, and so it can and does refract the two types of circularly polarized light differently. Since many sugars contain an asymmetric carbon atom, measurement of the gyration is a very convenient method of estimating the strength of a sugar solution, and great practical use is made of it.

THE ATOMIC THEORY OF REFRACTION

We have so far treated refraction as an effect of matter in bulk without enquiry as to how it comes about. The gross effect must be a superposition of the effects of the separate atoms and molecules, and we shall now consider how this superposition takes place. The light arising from an atom may have a great variety of characters, but whatever these are it must have one feature, that the wave is a spherical wave with the atom in its centre. We shall therefore first investigate what types of spherical wave are possible. In discussing diffraction we described a spherical wave emerging from a point source with amplitude inversely proportional to the distance. Though that sufficed to give the outline of the theory, it took no account of polarization, and it must be further refined for our present purpose. We naturally build the complete theory by considering what types of electromagnetic waves can emerge from a point.

Types of Spherical Waves.—The transverse nature of light makes it impossible to have a wave going out uniformly in all directions. We give the mathematical form of the simplest possible wave. Let

$$S = A \cos \frac{2\pi}{\lambda}(ct - r)/r, \text{ where } r = \sqrt{x^2 + y^2 + z^2}$$

and A is a constant. Then the electric and magnetic forces are given by

$$E_x = \left(\frac{1}{c^2} \frac{\partial^2}{\partial t^2} - \frac{\partial^2}{\partial x^2} \right) S, \quad E_y = -\frac{\partial^2}{\partial x \partial y} S, \quad E_z = -\frac{\partial^2}{\partial x \partial z} S,$$

$$H_x = 0, \quad H_y = -\frac{1}{c} \frac{\partial^2}{\partial t \partial z} S, \quad H_z = \frac{1}{c} \frac{\partial^2}{\partial t \partial y} S$$

If these are worked out they lead to expressions which are rather complicated in general, but simpler for points at a great distance from the source, and it will suffice to discuss the latter case. Consider a large globe, surrounding the source, marked with circles of latitude and longitude, the pole being the axis of x . The observer is on this sphere at angular distance θ from the pole. Then the wave that reaches him will have its electric force polarized so as to vibrate in the north and south direction, and the magnetic force will be east and west and equal in magnitude. The electric force is inversely proportional to the radius of the globe and to the square of the wave-length, but, most important of all, it varies as $\sin \theta$, vanishing at the pole and having its maximum at the equator. The actual value is

$$E = \left(\frac{2\pi}{\lambda} \right)^2 A \sin \theta \cos \frac{2\pi}{\lambda}(ct - r)/r.$$

In fig. 19 (a) the observer takes up various positions on the globe (marked by his co-latitude), and looks towards the centre; then the diagram shows the vibration of the electric force that will reach him.

In the classical electromagnetic theory this is the wave which would be emitted by an electron of charge e vibrating with fre-

waves as proper time to travel in the same direction as the apparent motion of the electron. It is very convenient to have a name for this type of wave, including the complete distribution in all directions, and the sense and direction of the motion of the electron. We shall call it a *screw-wave*.

In the ordinary case of a line-wave, the electric force is perpendicular to the direction of propagation. In the case of a screw-wave, the electric force is perpendicular to the direction of propagation and to the direction of rotation. The magnetic force is perpendicular to the direction of propagation and to the direction of rotation. The electric force is perpendicular to the direction of propagation and to the direction of rotation. The magnetic force is perpendicular to the direction of propagation and to the direction of rotation.

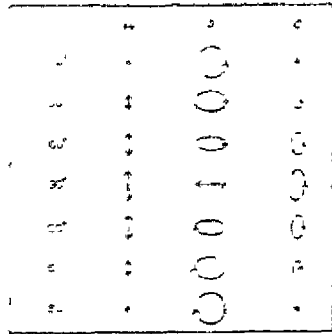


FIG 18.—SPHERICAL WAVES. The observer, on a sphere in co-latitude on the left, looks toward the centre. The amplitude and polarization of light received are shown (a) Line-wave, (b) circle-wave, (c) screw-wave.

receives circularly polarized light and it is important to notice that they will be of opposite types—one right-handed and the other left-handed. For other directions the light is elliptically polarized and becomes plane polarized at the equator. The intensity is twice as great at the poles as at the equator.

We must also consider a third type of wave which is not so simple. In the electromagnetic equations there is a mathematical symmetry between the electric and magnetic forces, so that we can obtain a solution by interchanging their roles. If we construct a wave by adding to the ordinary line-wave a small "magnetic" line-wave with the same pole and same frequency, we obtain a wave in which the light is everywhere of the same intensity as for a line-wave but is elliptically polarized with axes in constant ratio and lying in the directions of the circles of latitude and longitude. Such a wave is illustrated in fig 19 (c). It is important to notice that in this case unlike the circle-wave, the light-vector turns in the same direction in both hemispheres. Thus the whole wave has the same screw character and we shall call it a *screw-wave*. The screw-wave cannot be emitted by any motion of an electron. It would be emitted if there were a single magnetic pole moving with the electron, but such a thing does not exist and in fact the wave can only arise from a system itself emitting the screw character, such as a molecule with a chemically asymmetric atom in it.

The Scattering of Light.—When light falls on an atom it sets the electrons in motion and they therefore re-emit light, and the character of this scattered light will depend on the nature of the atom as well as the incident light. But the effect of a single atom is too small to be observable so that we always have to use a large number and the compounding of their effects produces complications. In fact the scattering of light by matter is a more primitive quality than is refraction, and it is therefore best to reduce everything into terms of scattering before we approach the theory of the behaviour of the single atom. There are several different ways in which an atom may emit light under the stimulus of light, but we can exclude some of them from consideration. Thus certain substances respond by *fluorescing*, that is to say emitting light of a different wave-length, and again there is the important phenomenon of *resonance radiation* (qv) where the wave-length of the light is unaltered but where it appears that there is no phase relation between the incident and the scattered light. (See PHOSPHORESCENCE AND FLUORESCENCE.) Both these phenomena are extremely interesting but from the present point of view they may be regarded as an absorption and simultaneous re-emission of the light and so they belong to the theory of the emission of light and are outside our scope.

The most universal way in which atoms react to light is by the

scattering of light. The most primitive exhibition of scattering is not found in refraction, but in such phenomena as the light of the sky (qv), and it is therefore appropriate to discuss this first. Supposing that the observer looks at a point not very near the sun the light that he sees will have been scattered through a broad angle, and the phase of the light-path, sun—atom—observer, will be different for each atom. Consequently the waves from the separate atoms do not reinforce one another. If the atoms were arranged with perfect regularity their waves would arrive at the eye with regular differences of phase and would destroy one another so that the sky would look black, however the uniform density of gases is not due to systematic regularity, but to the unsystematic regularity produced by the enormous number of atoms. The atoms of a gas have no ordered positions as they have in a crystal, hence the brightness of sky light will depend on compounding a large number of similar waves of quite arbitrary phases and taking the average value of the result. Consider a set of n atoms each of which is giving a wave of the same magnitude, but with phases $\epsilon_1, \epsilon_2, \dots, \epsilon_n$. The resultant amplitude will be proportional to $\cos \epsilon_1 + \cos \epsilon_2 + \dots + \cos \epsilon_n$ and the intensity is the square of this. Now the square will consist of terms like $\cos^2 \epsilon_1$ and others like $2 \cos \epsilon_1 \cos \epsilon_2$. The latter of these are as likely to be negative as positive, so that they will average out, but the former has average value $\frac{1}{2}$ for each separate term. Thus the average intensity scattered by the n atoms is just n times that scattered by one. If then we want to know the brightness of the sky we only require to calculate the intensity scattered by a single atom and multiply by the number of atoms in the field of view.

We will suppose that N is the total number of atoms in a small solid angle, the illumination from which is to be found. Then, from the formula for line-waves, we shall have an intensity proportional to $NE_0^2 \rho / \lambda^4$, and here E_0^2 is the intensity of the direct sunlight. Now in fact ρ , the scattering constant of the atom does not depend very much on the wave-length, as long as we only consider visible light and we can therefore say that the light scattered is inversely proportional to the fourth power of

h wave length. The expansion why the kv is blue even though the wavelength is shorter than the blue part of the spectrum. In red for the a lens h o ed lgh s about 3 mes na or blue and so factor λ is about 10 times as large for blue light as for red.

Another property of the sky-light is its polarization. Consider a point of the sky at right-angles to the sun. The unpolarized light from the sun may be broken into two polarized components one of which has electric force pointing at the observer. The line-waves induced by this component will have the observer at their poles and so will give no light towards him. He will therefore only receive the light of the other component, and this will be polarized in the direction perpendicular to the line joining the sun to the point observed. At other angles both polarized components are present, one in constant intensity and the other proportional to the squared cosine of the distance from the sun. If the sky is actually observed at right-angles to the sun with a nicol, it will be found that the polarization is not complete. This is partly to be attributed to rays that have been scattered several times on their way to the eye, and also to the fact that, though we have spoken only of atoms, the air is mostly composed of diatomic molecules, and for these the line-wave need not have its pole exactly coincident with the direction of the incident force. There is also usually a complication due to dust which acts by direct reflection and makes the sky much brighter near the sun than at broad angles.

A most interesting application of the theory of sky-light was made by Lord Rayleigh (3rd baron). The barometer shows the mass of the atmosphere, and so, by a direct comparison between the brightness of the sky and that of the sun, it is possible to deduce how much light is scattered by one cubic centimetre of air at ground level. In fact, if N is the number of atoms in 1 cu cm, we can evaluate $N\rho^2$. Now, as we shall see, we can also find $N\rho$ by a study of refraction, and hence we can estimate N . The process led to one of the earliest good determinations of the fundamental constant of Avogadro, the number of molecules in a gram molecule. Similar processes have since been applied in the laboratory, with the advantage that the incident light can be itself polarized, and similar results are obtained.

Scattering As the Cause of Refraction.—When we deduce refraction from scattering we are dealing with an incomparably greater effect than in sky-light, because here there will be phase relations between the original and the scattered waves, so that we compound the effects of the separate atoms by amplitudes instead of by intensities. We suppose that light-waves as they traverse matter have the same velocity as light in free space, but that they set up secondary waves from the atoms which, also proceeding with the velocity of light, interfere with one another and with the original wave. When the compound effect has been calculated, it is found that it can be expressed by altering the wave-velocity of the original wave and disregarding altogether the scattered waves and in this way refraction is explained.

Take a thin sheet of atoms spread over a plane on which monochromatic light falls perpendicularly. The diagram of fig 7 will describe the process, provided that we now regard the plane as composed of matter. Each atom will emit a line-wave, and the effect at P will consist of the superposition of these waves on the original beam which is supposed to arrive at P undisturbed. The process is very like Fresnel's discussion of diffraction, though there we imagined that the original wave was suppressed at the plane AB . Suppose that there are N atoms per unit volume, in a thin sheet of thickness l spread over the z plane, and let the incident wave be

$$E_x = F \cos \frac{2\pi}{\lambda} (ct - z)$$

The effects that all the atoms produce at P can be summed just as in Fresnel's construction, and the result is an amplitude

$$-2\pi FNl\rho \frac{2\pi}{\lambda} \sin \frac{2\pi}{\lambda} (ct - z)$$

The important point to notice is that the phase differs by a

quarter wavelength from that of the original wave. This is due to the fact that the scattered waves are in phase with the incident and so in contrast with Fresnel's construction in which in order to get the right result the phase had to be advanced by a quarter wave-length. We now add the two waves together, and taking advantage of the smallness of the scattered wave, we find

$$F \cos \frac{2\pi}{\lambda} [ct - z + 2\pi Nl\rho]$$

If we adopt the ordinary process of refraction and attribute the change of phase to the changed wave-velocity during the passage through the thickness l of the sheet of matter, we should say the emergent wave was

$$F \cos \frac{2\pi}{\lambda} [ct - z + (n-1)l],$$

and so we may identify $n-1$ with $2\pi Nl\rho$. This is the physical origin of refraction. We see also how the reflected wave arises for the line-wave from each atom will be exactly the same at the point which is image of P in the plane AB as it is at P and so the total amplitudes of the scattered waves will be the same at the two points, but for the reflected wave there is no interference with the incident light. It is easy to verify that the actual reflected intensity is that which should arise from a thin sheet of refractive index n and thickness l .

We have only treated of the small effect of a thin film and this contains the essence of the process, but it is of course necessary to discuss matter in bulk. Here the scattered wave from every atom acts on every other atom and so complicates the wave scattered by it. Nevertheless the problem proves soluble and leads to a result not very different from the simpler case. The

main difference is that we now have $\frac{n^2-1}{n^2+2} = \frac{4}{3}\pi N\rho$, in the special

case when $N\rho$ is small, n is near unity, and this reduces to $n-1 = 2\pi Nl\rho$ as before. The general solution for oblique incidence verifies all the formulae that are given by the ordinary bulk theory but the idea of scattering is helpful in seeing directly how reflection and refraction come about. When light falls on a thick slab, the atoms are set in motion and their scattered waves are all in definite phase relations to one another. If we consider a point outside the face of the slab it will receive all these waves, but those from the interior will have phases spread uniformly round the 360° and so will cancel out. Thus the reflected wave will arise from the atoms in the face where this uniformity ceases to hold. The existence of the polarizing angle becomes immediately obvious, as it is nothing but the rule that in a line-wave there is no emission towards its pole, which is perpendicular to the direction of the refracted wave.

The formula $\frac{n^2-1}{n^2+2} = \frac{4}{3}\pi N\rho$ was discovered by Lorentz (by a

rather different method) and becomes the foundation of the theory of dispersion. He deduced an important consequence from it. When a substance can exist in two states, ρ will be nearly the same for both and N will be proportional to the density, so that,

if d is the density of either state, $\frac{n^2-1}{n^2+2} \frac{1}{d}$ should be the same for

the two. This is verified by comparing the refractive index of a liquid and its vapour. Since their densities often differ by a factor of some hundreds it is a very stringent test and is often fulfilled to within one or two per cent. We should hardly expect perfect agreement, because the liquid molecules are being perpetually disturbed by one another, so that there may be a small change in the value of ρ attached to each molecule.

The explanation of double refraction follows a very similar course. The sheet of matter must now be supposed to react differently under the stimulus of light according as it is polarized along x or along y . In each case there is a line wave emitted with pole along the direction of the incident force, but the amplitudes are different and so the phase changes in the two components of the transmitted wave will be different. The detailed consider

The scattering from a crystal is a more complete one, there are difficulties in writing an atomic scattering factor, because the adjacent atoms in a crystal are not arranged isotropically and will disturb one another in a complicated manner. As a consequence the expression for the scattering factor ceases to apply, but the full discussion can only be made by a further study of the theory of the solid state. With the help of this theory and a knowledge of the arrangement of the atoms in a crystal it has been found possible to explain its high double refraction with fair numerical accuracy.

The Scattering from Absorbing Substances.—A similar process of scattering can be used to explain the action of absorbing substances, but here it is necessary to take the scattered wave in a different phase from the incident. Supposing this phase change to be η the scattered wave from the thin sheet of atoms will now be

$$-2\pi N \rho \cos \frac{2\pi}{\lambda} (ct - z - \eta).$$

If this is added on to the original wave we get

$$F \cos \frac{2\pi}{\lambda} (ct - z - \pi N \rho \cos \eta).$$

The first factor means a reduction in amplitude, i.e. absorption, and there is also refraction just as before. Thus by a suitable choice of ρ and η we can describe the observed behaviour of any absorbing substance. This full theory is best expressed in terms of complex quantities and leads to the equation

$$\frac{n^2 - k^2 - 1}{n^2 + k^2 - 2} = \frac{4\pi}{3} N \rho e^{-i\eta} \quad (\text{where } i = \sqrt{-1}),$$

so that we can deduce ρ and η from a knowledge of n and k .

It has been mentioned that transparent substances are usually opaque for light in some parts of the spectrum and the theory of this is fairly well understood. In these regions the phase η can take any value between 0° and 180° . This theory however does not apply to metals, and it is a very interesting fact that, if we use the observed values of n and k to calculate ρ and η for metals, the phase change η is in all cases quite small. For the very highly reflecting sodium it is only 7° , and for silver little more than 1° while, even for such a poor reflector as steel (58% at perpendicular incidence), the phase change is not 10° . These facts are quite unexplained, they suggest however that the phase change is not the typical characteristic of metals, but that their high reflection is rather to be attributed to a large scattering power. For, if we consider a transparent substance in which $\frac{4\pi}{3} N \rho$

is greater than unity, we find that n^2 must be negative and therefore n is imaginary and this means that the waves in the medium are strongly damped. From this point of view metallic reflection is more like total internal reflection than like the reflection from an absorbing substance.

Natural Gyration.—We have seen how gyration arises from the difference between the wave-velocities of right- and left-handed circularly polarized light. It is a screw property and can only be exhibited by molecules containing a chemically asymmetric atom. The condition is exactly that which permits of the emission of what we have called a screw-wave, and to explain gyration it is only necessary to suppose that, under the influence of plane polarized incident light the molecule scatters a screw-wave. We take as before a thin sheet in the xy plane illuminated by plane polarized light,

$$E_x = F \cos \frac{2\pi}{\lambda} (ct - z)$$

Each molecule emits a screw-wave which has axis along x . In any direction a screw-wave can be resolved into a main component which is like that of a line-wave and a weaker component at right-angles and a quarter period behind. Take ρ for the scattering constant of the line-wave and σ for the other com-

ponent. The wave we need now is scattered by the molecules the line-waves will compound as before into

$$-2\pi N \rho \cos \frac{2\pi}{\lambda} (ct - z)$$

along x , but there will now be a component along y of magnitude

$$-2\pi N \sigma \sin \frac{2\pi}{\lambda} (ct - z)$$

If we add these small quantities on to the original wave we find approximately

$$E_x = F \cos \frac{2\pi}{\lambda} (ct - z + 2\pi N \rho l),$$

$$E_y = -2\pi N \sigma l \sin \frac{2\pi}{\lambda} (ct - z + 2\pi N \rho l);$$

and this means that the light is now plane polarized at angle $-2\pi N \sigma l \cdot 2\pi/\lambda$ to the x direction. The rotation is proportional to l , the thickness of the sheet, and the other factors express the gyration constant. The theory for matter in bulk gives a similar result, but presents it by showing that there are different refractive indices for right- and left-handed circularly polarized light.

Magnetic Gyration.—In our discussion of the refraction of isotropic bodies, we saw that plane polarized light might be supposed to stimulate the emission by the atom of a line-wave. Now circularly polarized light can be constructed out of two plane polarized components at right angles and differing by a quarter wave-length in phase, and what we have called a circle-wave can be constructed out of two line-waves with perpendicular poles and phases differing by a quarter period. Consequently we could have worked out the theory of refraction just as well using circularly polarized light and circle-waves, and in discussing magnetic gyration it makes a convenient starting point to do so. When an atom is in the presence of a magnetic field it behaves in a sense as though it were in rotation, about an axis along the field's direction with velocity proportional to the field strength. We shall see how this comes about when we discuss dispersion, but can explain the gyration without reference to the detailed theory. If then the atom is illuminated by circularly polarized light, it will react differently according as its magnetic rotation is with or against the rotation of the light-vector. We may describe what happens by saying that the atom's scattering constant will no longer be ρ , but $\rho + \tau$ and $\rho - \tau$ for the two types of circularly polarized light. Here τ will be proportional to the strength of the field and it is usually to be regarded as much smaller than ρ .

Suppose that the incident light is

$$E_x = F \cos \frac{2\pi}{\lambda} (ct - z), \quad E_y = F \sin \frac{2\pi}{\lambda} (ct - z)$$

When the scattered wave from a thin sheet is superposed on this we have, by the same construction as before,

$$E_x = F \cos \frac{2\pi}{\lambda} [ct - z + 2\pi N(\rho + \tau)l],$$

$$E_y = F \sin \frac{2\pi}{\lambda} [ct - z + 2\pi N(\rho + \tau)l].$$

But if the incident light is of the opposite type it will be

$$E_x = F \cos \frac{2\pi}{\lambda} (ct - z), \quad E_y = -F \sin \frac{2\pi}{\lambda} (ct - z),$$

and the resultant wave will be

$$E_x = F \cos \frac{2\pi}{\lambda} [ct - z + 2\pi N(\rho - \tau)l],$$

$$E_y = -F \sin \frac{2\pi}{\lambda} [ct - z + 2\pi N(\rho - \tau)l].$$

If we add these two solutions together the incident light is

$$E_x = 2F \cos \frac{2\pi}{\lambda} (ct - z), \quad E_y = 0,$$

LIGHT

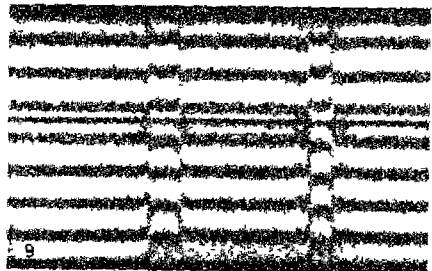
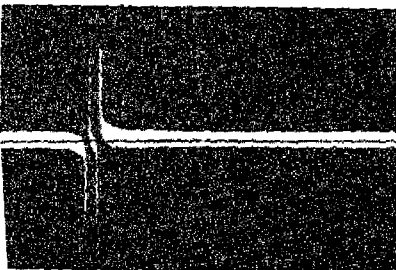
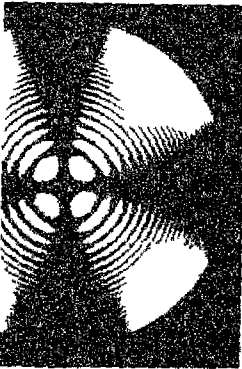
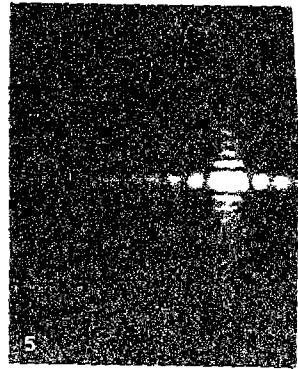
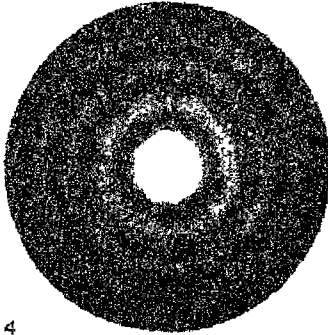
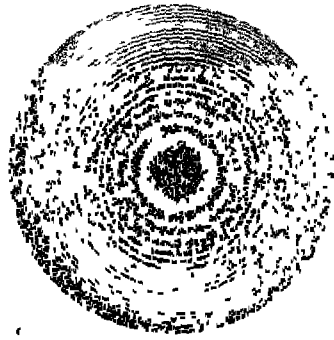
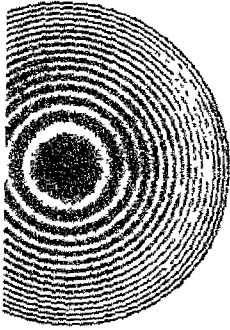


FIG. 1) ADAM HILGER LTD. PHOTOGRAPHS, (4, 5 & 9) MICHELSON STUDIES IN OPTICS, UNIVERSITY OF CHICAGO

DISPERSION OF LIGHT

The two sets of rings fall together here

in light of mercury. The two sets of rings are very close together in the spectrum

in light of mercury. The two sets of rings are very close together in the spectrum in light of mercury. Inset is shape of hole in plate. Figure is narrow

6. Uniaxial crystal illuminated between crossed nicols
7. Biaxial crystal illuminated between crossed nicols
8. Anomalous dispersion of sodium vapour. The vapour is between crossed nicols. The two breaks in the horizontal line are the D-lines, where light is absorbed. For each the line on the left is strongly refracted downwards, and on the right is refracted upwards. At greater distance refraction is too small to be perceptible.
9. Magnetic gyration of sodium vapour. The line on the left has two components, whereas that on the right has two pairs.



and the transmitted light is

$$E_x = 2F \cos \frac{2\pi}{\lambda} (ct - z + 2\pi N_p d) \cos \frac{2\pi}{\lambda} (2\pi N \tau l),$$

$$E_y = 2F \cos \frac{2\pi}{\lambda} (ct - z + 2\pi N_p d) \sin \frac{2\pi}{\lambda} (2\pi N \tau l);$$

so that the plane of polarization has turned through an angle $\frac{2\pi}{\lambda} (2\pi N \tau l)$. This is proportional to the thickness of the sheet and, through τ , to the strength of the magnetic field. The remaining factors are individual to the substance of which the sheet is made. The constant is often called the Verdet constant after one of the earlier investigators who measured it for a number of substances.

The magnetic gyration is usually very small for practicable magnetic fields. It occurs in all transparent isotropic substances and for light going along the axis of uniaxial doubly refracting crystals, for other directions it is masked by the double refraction. There is a very remarkable similar effect when polarized light is reflected from the polished pole of a magnet. For perpendicular incidence the plane of polarization rotates, and for other directions there are similar more complicated changes in the rule of reflection. The Kerr effect, as it is called from its discoverer is evidently like the magnetic gyration in transparent substances, but its theory is very incomplete.

The two types of gyration, natural and magnetic, are radically different in character, as is shown by the fact that one depends on a screw-wave the other on a circle-wave. The consequence is that in natural gyration, if the light is reflected back so as to traverse the sheet again, its direction of polarization turns in each passage like a screw of the same type and so it comes back to its original polarization. On the other hand magnetic gyration is due to a rotation not a screw so that if the light is reflected back again it rotates in the same direction as before and the angle of turning is doubled.

DISPERSION

We have traced the optical effects of matter in bulk to their source in the atoms, and in doing so have only found it necessary to use the ordinary conceptions of the classical theory of dynamics, but as soon as we begin to consider the atoms themselves we get into difficulties, because in fact the atom obeys quite different dynamical rules. These rules, which are the principal subject of the quantum theory (*q.v.*), are fairly well understood, but since our whole practical experience is based on classical dynamics, they are very hard to apprehend in anything but mathematical form; regarded physically they appear to contain an unsatisfying element of irrationality, which is really to be attributed to limitations in our habits of thought. For the purposes of the present subject it is fortunately possible to some extent to avoid these difficulties. The quantum theory gives certain rules, very unlike those of ordinary dynamics, for the intensities and frequencies of the spectral lines emitted by an atom or molecule, and it also predicts how such an atom will behave under the influence of light. Though both these aspects of the theory are quite different from ordinary dynamics, they have this in common with the classical theory, that if we make up a purely classical model to imitate the emission (though in many other properties it will be quite wrong), it will react correctly for the scattering of light. For convenience of calculation we thus imagine that associated with each atom is a phantom *virtual atom*, which will suffice to work out the optical effects. An actual atom contains only a few electrons, but the virtual atom contains a *virtual electron* for each line of its spectrum, and the charges on the virtual electrons are usually much smaller than the known charge of an electron. Since the spectrum is composed of nearly monochromatic lines, we suppose that each virtual electron is free to execute approximately harmonic vibrations. The relation between the emission and the scattering of light by the atom is then akin to the relation of free to forced vibrations in a harmonic vibrator.

Free Vibrations of the Atom.—Let us suppose that we have

a virtual electron of mass m vibrating along the axis of x , under a force Kx towards the origin. It will obey the equation

$$m \frac{d^2x}{dt^2} + Kx = 0, \text{ or } \frac{d^2x}{dt^2} + (2\pi\nu)^2 x = 0 \text{ if } K = m(2\pi\nu)^2.$$

If left entirely to itself such an electron would vibrate with constant amplitude and frequency ν_1 for ever; but it cannot be regarded as left alone because the moving electricity will be perpetually changing the electric forces everywhere in the manner that we have described as a line-wave. This wave will carry away energy, which is supplied at the expense of the electron so that its amplitude must decrease. The electron is always linked with the aether and it may be shown that the reaction of the aether on it can be represented by introducing a damping term so that the vibration is expressed by

$$m \frac{d^2x}{dt^2} + m(2\pi\nu_1)^2 x = \frac{e^2}{3c^3} \frac{d^3x}{dt^3},$$

where e is the charge and c as usual the velocity of light. The new term is very small (except for penetrating X-ray frequencies), and the equation may be solved by approximation, and gives

$$x = Ae^{-i(2\pi\nu_1 - \sigma)t} \cos 2\pi\nu_1 t$$

This represents a vibration which decreases during each vibration by a fraction $\frac{1}{3} \frac{e^2}{m c^3} 4\pi^2 \nu$, or l/λ where l is $\frac{4\pi^2}{3} \frac{e^2}{m c^3}$; for an ordinary electron it is 3.7×10^{-12} cm and, as the charge of a virtual electron is usually smaller, the approximation is evidently justifiable for ordinary light of wave-lengths about 10^{-5} cm. The line-wave emitted by this electron will also be damped with the consequence that, in Michelson's interferometer, when the two light-paths differ by a considerable amount the interference will become imperfect. This is in fact observed, but usually for path differences somewhat shorter than might be expected. If we imagine the light to be passed through a grating we observe the same phenomenon in a slightly different way, the damping factor gives the line a finite breadth and in fact spectral lines are nearly always somewhat broader than is indicated by the theory of pure electromagnetic damping. A variety of causes contribute to this broadening, such as the frequent collisions between the radiating atoms and air molecules for these collisions will change the phases of the emitted waves, and the Doppler effect of the motion of the atoms, which slightly alters the frequency. These effects can both be observed directly by alterations of pressure and temperature, but it is uncertain whether they are sufficient causes of the broadening. The whole question is getting very near to the point where the classical conception of a virtual atom fails, and also to the limits of experimental technique, and all that can be said is that under the most favourable conditions it seems that the damping is not far from the value predicted by electromagnetic theory. We can avoid raising the question by introducing a fictitious damping factor which replaces the electromagnetic and may write as our equation.—

$$\frac{d^2x}{dt^2} + \sigma \frac{dx}{dt} + (2\pi\nu_1)^2 x = 0,$$

so that the electron's motion is resisted by a small force $m\sigma \frac{dx}{dt}$, and as long as σ is small we do not need to enquire into its origin.

It is necessary next to suppose that the atom contains a number of virtual electrons with different frequencies, and so to adjust their properties that the spectrum lines will occur in the correct relative strengths. Suppose that the first electron, with charge e_1 , frequency ν_1 , etc., is vibrating with amplitude a_1 . Then it emits a line-wave, and, at distance r in the equator, we have seen that the intensity will be proportional to $\nu_1^2 e_1^2 a_1^2 / r^2$. In order to compare this intensity with that given by the second electron e_2 , we have to consider what their respective amplitudes will be. This requires an assumption, and the appropriate assumption to make (subject to some conditions which we shall not discuss) is the equipartition of energy, that on the average each virtual electron has the same energy. Now the energy of

We conclude by stating that the intensity of the scattered light is proportional to ν^4 . It happens that the quantity ρ in the expression for the intensity is not the intensity itself but is proportional to the fourth power of it. The quantity ρ has no name, but is always referred to as the scattering constant. We shall therefore denote this constant by B . We shall also denote by ν_0 the frequency of the incident light, and the intensity is proportional to ν_0^4 .

Forced Vibrations of the Atom.—When the virtual atom is exposed to an external force in addition to the force acting on it, the equation of motion of the first electron will now be

$$m \frac{d^2x}{dt^2} + \gamma \frac{dx}{dt} + m\nu^2 x = eE \cos 2\pi\nu t$$

where F is the amplitude of the incident electric force E and ν is its frequency; the direction of the wave-front does not matter. This is the equation which gives the ordinary phenomenon of resonance, and we must consider the form that its solution takes for different frequencies of the incident light. In the first place σ plays practically no part in the solution when it is small unless ν is very near ν_0 . Excluding that case we have

$$x = \frac{eE}{m} \frac{\cos 2\pi\nu t}{\nu_0^2 - \nu^2}$$

If $\nu < \nu_0$, x is in phase with the electric force E and its amplitude increases strongly as ν approaches ν_0 . If $\nu > \nu_0$ the phases are opposite, the amplitude is small for large values of ν but as ν is approached from above it becomes large (see fig. 20). There is thus a transitional stage when ν passes through ν_0 , and in this stage the amplitude of x has to pass from a large positive to a large negative value. In order to see how it does so we must include the damping term in our equation. There is now a phase difference between ν_0 and E , and the solution is

$$x = \frac{eE}{m} \frac{\cos(2\pi\nu t - \gamma)}{\nu_0^2 - \nu^2 + \sigma^2 \nu^2}$$

where $\tan \gamma = \frac{\sigma\nu}{\nu_0^2 - \nu^2}$. If ν is much less than ν_0 the phase angle

γ is practically zero, and continues so up to values differing from ν_0 by a not very large multiple of σ . From this point on the phase grows rapidly and becomes 90° at $\nu = \nu_0$ and then increases further, so that at an equal distance on the other side of ν_0 it is practically 180° . The amplitude follows the course of fig. 20 nearly up to ν_0 , but instead of becoming infinite it attains

a very large maximum at $\nu = \nu_0$ of amount $\frac{eE}{m} \frac{1}{2\pi\sigma\nu}$, and then

decreases. When well beyond ν_0 it has the same course as in fig. 20, but with changed sign now because the negative value is allowed for by the phase. Fig. 21 shows the general features, but it has been necessary to take a comparatively large value of σ in order to show the form clearly. In the figure σ is $2\pi\nu_0/5$, whereas for actual spectra it is of the order of $\nu_0 \times 10^{-7}$, so that many diagrams which showed the maximum the rest of the figure would be quite invisible. It thus appears that, except for frequencies very near ν_0 , the damping can be disregarded and we shall for the most part take advantage of this simplification and so make use of the curve of fig. 20 instead of fig. 21.

The Dispersion Formula.—The motion of the electron, forced in this way, will cause a line-wave to be emitted of which the

amplitude will depend on the amplitude of the electron's motion by its charge. Omitting the damping factor, we thus say that the electron has a scattering constant

$$B = \frac{2}{3} \frac{e^2}{m^3 c^3 (\nu_0^2 - \nu^2)^2}$$

which is proportional to $E \nu_0^4 / (\nu_0^2 - \nu^2)^2$. The other virtual electrons will give similar effects and they are all to be superposed. Thus the virtual atom will have scattering constant proportional to

$$\rho = \frac{B_1 \nu_1^2}{\nu_1^2 - \nu^2} + \frac{B_2 \nu_2^2}{\nu_2^2 - \nu^2} + \dots$$

This is the best form for theoretical purposes, but experimental work more frequently makes use of wave-lengths. Re-writing the equation we have

$$\rho = \frac{B_1 \lambda^2}{\lambda^2 - \lambda_1^2} + \frac{B_2 \lambda^2}{\lambda^2 - \lambda_2^2} + \dots$$

as the dispersion formula which should apply for any wave-length not too close to λ_1, λ_2 , etc. The relative magnitudes of the terms are derivable from the intensities of the associated lines in emission spectra. Their absolute values can also be given

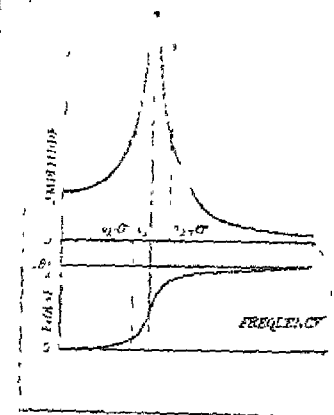


FIG. 21.—THE RESPONSE OF A DAMPED RESONATOR. THE ORDINATE OF THE UPPER CURVE SHOWING THE AMPLITUDE, THE LOWER THE PHASE, OF THE RESONATOR.

by carrying the theory somewhat deeper, and we shall touch on this below.

We may now consider the march of events when a substance is illuminated by light of increasingly shorter wave-length. We will suppose $\lambda_1 > \lambda_2 > \lambda_3$. We saw that the refractive index depends on the product of ρ and the number of atoms in a cubic centimetre, but as we have omitted a factor of proportionality already, we may also omit the factor for the number of atoms, and may equate ρ above to $(n^2 - 1)/(n^2 + 2)$. For very long waves we shall have practically $(n^2 - 1)/(n^2 + 2) = B_1 + B_2 + \dots$. If n^2 is deduced from this it should agree with the dielectric constant determined by purely electrical means. Though there is little doubt that this would be verified, optical observations are usually lacking for sufficiently long waves. As λ decreases the first term grows in comparison to the others, because $\lambda^2 - \lambda_1^2$ gets more rapidly smaller, and just before λ_1 this term entirely dominates the refraction. At λ_1 there will be a region of absorption and on the other side the first term will be negative, the rest still positive. As λ decreases further the first term, still negative, shrinks in importance and the second grows until near λ_2 when it becomes dominant. Passing beyond λ_2 it changes sign and later shrinks in importance, its place being taken by λ_3 and so on. Finally when all the lines have been passed, $(n^2 - 1)/(n^2 + 2)$ will be negative and proportional to the square of the wave-length. For a strict test of the theoretical dispersion against experiment we should have to work out the value of n from that of $(n^2 - 1)/(n^2 + 2)$;

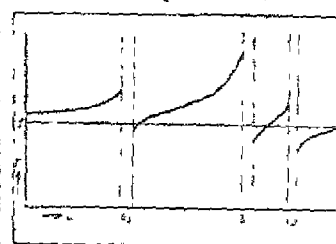


FIG. 22.—A DISPERSION CURVE SHOWING THE WAY REFRACTIVE INDEX DEPENDS ON LIGHT FREQUENCY. AT ν_1, ν_2, ν_3 THERE WILL BE ABSORPTION.

but for a rough comparison this is not necessary. Where $(n^2 - 1)/(n^2 + 2)$ is large so is n , when the former is negative n is less than unity, and, if n is plotted against frequency the curve will have the same general characteristics as has $(n^2 - 1)/(n^2 + 2)$. An example of the general course of the dependence of n on frequency is given without any numerical accuracy in fig. 22. There are supposed to be three lines of which the middle one is the strongest. In the neighbourhood of each line the refraction cannot be observed on account of absorption. As each line is passed there is a strong decrease in the refractive

index associated with the change of phase of the corresponding virtual electron by 180° . Whether the refractive index actually becomes less than unity will depend on the breadth of the unobservable region and on the strength of this line compared to the others. At frequencies higher than the highest frequency of the atom the refractive index will always be less than unity, and such values have been found for X-rays, though, strictly speaking, even here the atom has higher frequencies still.

Much the most striking example of dispersion is the phenomenon called anomalous dispersion though in fact it is not at all anomalous. There are dyes which strongly absorb certain colours in the spectrum while being transparent to the others; thus if the green is absorbed, the dye will look purple by transmitted light. In consequence of the very strong green absorption there is a reversal in the usual order of refraction. The blue light, which lies on the short wave-length side of the green, is much less refracted than the yellow which lies on the side of long wave-lengths. Fig. 23 shows with some exaggeration the way in which a prism made of such a colour would fold the spectrum back on itself. A similar effect is shown in Plate, fig. 8 for sodium vapour. Sodium has two very strong lines close together in the yellow, and both of them show anomalous dispersion. A flame containing the vapour is given the form of a prism, and white light is sent through it. This light is then sent through a spectroscope so as to spread out the colours in a direction at right angles to the dispersion of the prism. The colours on opposite sides of either of the sodium lines will be deflected in opposite directions by the prism, so that their images on the photographic plate are shifted up and down in Plate fig. 8. The form of the dispersion curve is thus made directly evident.

On account of the brilliance and fineness of the sodium lines sodium vapour has been used with more success than any other medium in the study of dispersion, and several important results have emerged. It has been found possible to make direct measures of the absorption of light in the immediate neighbourhood of the two lines and so to evaluate the damping factor σ ; this was found to be in quite good agreement with the electromagnetic damping factor. Another important experiment consists in finding the absolute value of the scattering constants for these two lines of the sodium atom. The theory of this depends on quantum principles, and cannot be given in detail; but, loosely speaking, the two virtual electrons together correspond to a single actual electron, so that if we can make experiments in which the two lines are indistinguishable, the scattering constant should be given by the use of the ordinary values of σ and m . The straightforward way of doing this would be to observe the refraction with light of a very different colour because then the difference between the influences of two such close lines would be insensible, but this is useless because the refraction itself becomes too small. Indirect means depending on magnetic gyration have been used, and have entirely supported the theoretical prediction that both lines are due to a single electron.

The most accurate measures of refractive index have been made with transparent substances, substances in which the absorption only occurs far in the infra-red or ultra-violet. To analyze the dispersion the usual procedure is based on the fact that for the infra-red terms, $\lambda^2/(\lambda^2 - \lambda_0^2)$, can be expanded in powers of λ^2 , while for the ultra-violet terms it can be expanded in inverse powers of λ^2 . A formula is therefore constructed of the type $A + C\lambda^2 + \dots + E\lambda^{-2} + F\lambda^{-4} + \dots$, and A, C, E, \dots are fitted to the observed values of $(n^2 - 1)/(n^2 + 2)$. The term in C corresponds to the infra-red lines, and A, E, F to the ultra-violet. The actual positions of the lines are then found by trial. The infra-red lines, or, more usually, bands, can often be fixed with fair accuracy, both by experiments with rest-rays and by observing the refraction near them, but the ultra-violet are more

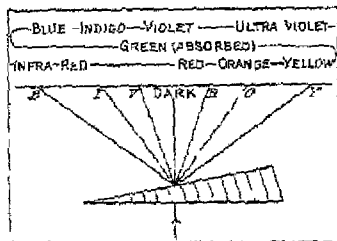


FIG. 23.—ANOMALOUS DISPERSION. The absorption in the green makes the yellow more refracted than the blue.

troublesome because it is often not possible to get observations very close to the lines. Indeed it is usually found that wave-lengths and B 's can be chosen with considerable latitude and can yet give all the observed results with a high degree of accuracy. The whole process is very laborious and has only been carried out for a few substances, such as rock-salt and potassium chloride. It is found possible to represent the refraction by one term for the infra-red and perhaps two in the ultra-violet, together with a third constant term which must correspond to wave-lengths so short that $B_0\lambda^2/(\lambda^2 - \lambda_0^2)$ does not change perceptibly in value in the whole region accessible to observation. The ultra-violet lines are attributed to electron vibrations of some kind, but those in the infra-red arise through the motions of whole atoms, and have been fitted satisfactorily into the general dynamical theory of the crystalline state.

The theory of the refractive indices of gases is distinctly more advanced, because their emission spectra can be studied without the radical change of state that would be necessary for solids. In the case of metallic vapours, such as sodium, the theory may be considered complete, though its practical verification is somewhat difficult. The spectrum of helium is known, and the measurement of its refraction has led to an interesting result. The lines of all atomic spectra fall into series which converge towards a finite limit λ_0 , but beyond this limit there is a region in which there is emission over a continuous range of wave-lengths. Corresponding to this it is found that the refraction of helium requires an expression

$$\frac{n^2 - 1}{n^2 + 2} = \frac{B_0\lambda^2}{\lambda^2 - \lambda_0^2} + \int_0^{\lambda_0} \frac{B_0\lambda^2}{\lambda^2 - \lambda^2} d\lambda$$

In the case of the ordinary permanent diatomic gases the spectrum is not so well-known, for an electric discharge is required in order that the gas should be luminous and this breaks the molecules into atoms. Even without this knowledge, however, one feature can be predicted for a molecule composed of two identical atoms, the atomic vibrations which are of infra-red frequency will have no optical effects at all. This is confirmed by the dispersion formulae which for the permanent gases have only ultra-violet terms.

The Dispersion of Magnetic Gyration.—The dispersion of doubly refracting and naturally gyrating substances has been studied, and fits into the same general type of formula but the theory is very complicated. On the other hand magnetic gyration is fairly completely understood, and, as it has thrown much light on the behaviour of atoms, we may consider it in more detail. We first take the simplest case, which is not in fact exhibited by many types of atom. In a magnetic field an electron experiences a force proportional to the field and to its own velocity, in a direction perpendicular to both, and we cannot therefore now limit the electron's motion to a single line. Taking the field along z (and omitting the damping factor by the exclusion of cases where it would be important), the motion will be

$$m_1 \frac{d^2x}{dt^2} + m_1(2\pi\nu_1)^2x - \frac{e}{c}H \frac{dx}{dt} = e_1E_x,$$

$$m_1 \frac{d^2y}{dt^2} + m_1(2\pi\nu_1)^2y + \frac{e}{c}H \frac{dy}{dt} = e_1E_y.$$

Take the incident light to be circularly polarized, so that

$$E_x = F \cos 2\pi\nu t, \quad E_y = F \sin 2\pi\nu t$$

Then the solution is

$$x = \frac{e_1}{m_1} \frac{F \cos 2\pi\nu t}{4\pi^2(\nu_1^2 - \nu^2) - \frac{e_1H}{m_1c} 2\pi\nu},$$

$$y = \frac{e_1}{m_1} \frac{F \sin 2\pi\nu t}{4\pi^2(\nu_1^2 - \nu^2) - \frac{e_1H}{m_1c} 2\pi\nu}.$$

But if the incident light is polarized the other way so that

$$E_x = F \cos(\omega t - \nu z) \quad E_y = -F \sin(\omega t - \nu z)$$

$$\nu = \frac{F \cos(\omega t - \nu z)}{\dots}$$

$$\nu = \frac{F \sin(\omega t - \nu z)}{\dots}$$

The change in the denominator of these shows that there is a different magnitude of response to the two types of circular polarization and this may well explain the gyration.

It is of some interest to see how the gyration behaves in the immediate neighbourhood of ν_1 . To simplify we will write $\nu_1 - \omega = \nu$ and it will be justifiable to write the denominator of the first solution as $\nu^2 - (\nu_1 - \omega)^2$, since for practicable fields ω is always negligible. In the second type of motion the denominator will be $\nu^2 - (\nu_1 + \omega)^2$. Considering the first solution we see that for values of ν on opposite sides of $\nu_1 - \omega$ there will be a phase difference of 180° . On the other hand the second solution will not show this change at the same point, but at $\nu_1 + \omega$ instead. This suffices to outline the behaviour of the gyration in fig. 24. As ν increases towards the value $\nu_1 - \omega$ the gyration rapidly increases. At $\nu_1 - \omega$ the light is absorbed, but on the other side where it is again observable it gyrates strongly the opposite way. As ν increases farther the gyration becomes less, though always negative, and then again increases as ν approaches $\nu_1 + \omega$. After passing this it is positive and large and rapidly decreases as ν recedes from $\nu_1 + \omega$. By seeing which way the plane of polarization rotates, it is possible to find the sign of the electric charge e , this is negative as is that of the actual electron. It will be seen that our calculation indicates the presence of two regions of absorption, which implies that the original line ν_1 has been split into two by the magnetic field. The phenomenon can also be observed in emission, and is then called the Zeeman effect (*q. v.*). This effect is much more complicated than our explanation would suggest but, with the help of the quantum theory, it has been more or less completely elucidated. Most spectral lines do not split into only two members but into a pattern composed partly of line-waves and partly of circle-waves, and the circle-waves control the gyration. In the case of the two sodium lines, there are two pairs for one and one pair for the second.

The theory of the gyration of solids and liquids is less complete than that of metallic vapours in just the same way as is that of refraction, but it is known to bear a very similar relationship.

We can imagine that each virtual electron has an appropriate eH/mc which determines its response to the two types of circularly polarized light. If the incident light has frequency far from any of the natural frequencies of the substance, it is found that the gyration depends on terms of the form $\nu^2/(\nu_1^2 - \nu^2)^2$, this means that for ordinary substances it increases much more rapidly than does the refractive index, as the colour changes from red to blue. By a comparison of the gyration of any substance with its refraction, the values of e/m for its virtual electrons can be estimated, and they are usually a fraction (mostly between $\frac{1}{2}$ and 1) of the accepted value for an actual electron. The discrepancy has not been explained, but it is to be attributed to a complication rather like that of the Zeeman effect which occurs in vapours.

In this account the principles of optics have been presented

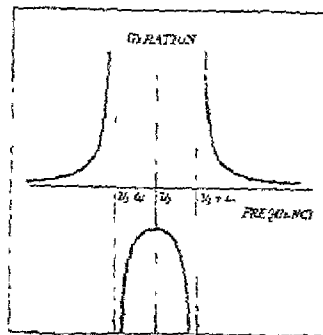


FIG. 24.—THE DISPERSION OF MAGNETIC GYRATION

ν_1 is the spectral line of frequency split by the magnetic field into $\nu_1 - \omega$

as a completed body of knowledge. Only where we leave the consideration of matter in bulk and come to atoms do we encounter more dubious questions. Since the beginning of the 20th century atomic theories have been in a state of flux and it is necessary that we should radically revise our conception of particles, and probably of time and space as well, but, however great the changes, and however new the language we may be sure that the older work will stand, and that the new theory will accommodate within itself the wave-theory of light.

BIBLIOGRAPHY—There are several excellent books on the theory of light, for example *The Theory of Optics* by P. Drude, or *The Theory of Optics* by A. Schuster (the last edition by Schuster and Nicholson includes an account of modern spectrum theory). *Physical Optics* by R. W. Wood covers the same ground from a rather more experimental point of view. An admirable account of the history of the subject is given in *History of the Theories of Matter and Electricity* by E. T. Whittaker. *The Theory of Electrons* by H. A. Lorentz is concerned with many optical subjects especially refraction, including the refraction of moving media. In Rayleigh's *Collected Works* there are many important papers on the light of the sky, resolving power and other optical problems. (C. G. D.)

LIGHT AND RADIATION IN RELATION TO HEALTH. The phenomena of life result from the reactions of living substance to radiant energy and depend primarily on the sun.

All radiations are conceived of as electro-magnetic waves conducted in a hypothetical medium aether, and travelling with the velocity of light, 186,000 miles a second. According to theory each of the atoms (*see* ATOM) of which a chemical element is composed consists of a central nucleus positively charged (protons and electrons densely packed, and electrons negatively charged, revolving round the nucleus in a variety of orbits with enormous speed, comparable to the planets revolving round the sun). The more complex the atom the greater the number of its electrons. When an electron is displaced from an inner to an outer orbit, radiant energy is given off. When an electron jumps from an outer to an inner orbit energy is absorbed. Only a certain variety of orbits are possible for an electron to revolve in, a certain quantum of energy is required to effect each jump.

To have any effect on matter radiant energy must be absorbed. There then takes place a change of energy, e.g., into electrical effect, heat, fluorescence, chemical action. All radiations when absorbed by a perfect black body are transformed into heat. A thermocouple coated with lamp black is used for measuring in calories per sq. cm. per second, or in ergs per sq. cm. per second, intensity of radiant energy emitted by a source or received by a surface. This is the final standard of measurement. The body is composed of an infinite number of living cells. The living cell is the seat of an infinitely intricate play of energy, containing millions upon millions of molecules. We have to conceive of electrons being displaced by radiations in the atoms of these molecules, of molecular change enhanced thereby, provoking reactions which manifest themselves as signs of life, of the spirit of man evolving out of such transformations of energy.

Radiations are classified by frequency of vibration and by wave length, they include first, the Hertzian waves used in radio with wave lengths extending to a thousand metres or more; to these waves the body is transparent: to be heard they must be transmitted, received and transformed by suitable electrical apparatus. Then come the infra-red rays with wave lengths from 600,000 to 7,000 A.U. (Angstrom Unit = one ten-millionth of a millimetre). Absorbed largely by water and converted into heat, these rays are caught as they pass to or come off, the earth by the vapour-charged atmosphere. Thus is the earth kept warm to a temperate degree and life made possible. (*See* RADIATION.)

Absorbed by the wet substance of the skin these rays heat particularly the outer layers whence heat is conducted to deeper parts and distributed by the blood circulating through the skin. Acting on the cool dry skin, these rays when intense provoke a dry prickling and not very agreeable sensation of heat. Next to the infra-red come the visible rays, a very narrow part of the vast radiation spectrum with wave lengths from 8,000 to 4,000 A.U. The media of the eyes have been evolved transparent to these rays. The skin is much less transparent, while a part is reflected,

a part of these rays penetrates to the cutaneous blood vessels and there is changed into heat. The cooled skin then these rays provoke transudation of water and give thus a more agreeable sensation of heat.

The transformation of energy of visible rays taking place in the blood may have important effects as yet unknown. It is in this respect that sources of visible radiation have a superiority over infra-red rays as means of providing artificial heat, infra-red rays from hot water pipes heat rather the surface of the skin while visible rays from sun, fire or lamp penetrate and heat the blood and tissues below the surface. Red rays are not wholly absorbed by the blood in the skin and so penetrate deeper still. By means of powerful incandescent lamps and red glass screens an agreeable and easily controlled method of applying heat to the body and provoking hyperaemia is obtained.

In the case of the eye, the parts of the visible spectrum evoke different sensations of colour, viz., red, orange, yellow, blue, violet, as the wave lengths shorten from 8000 to 4,000 A.U. The living substance of the retina has evolved so as to react differently to the different groups of wave lengths. The living cells of the skin and the blood in the skin also react differently to infra-red, visible and ultra-violet rays, but little is yet known about this subject.

The U.V. rays are shorter than violet ones, and they therefore lie beyond the violet of the spectrum and are invisible, but may be made visible by fluorescent screens.

The horny layer of the skin fluoresces faintly, it can be made to fluoresce strongly by a coat of vaseline or solution of quinine. Fluorescence is produced by electrons displaced from atoms by the rays jumping back into inner orbits. A part of the energy of the rays is thus spent, fluorescence of the surface of the skin is then a means of protection against U.V. rays.

For study of the U.V. rays a quartz spectroscope is required, as glass absorbs most of these rays. They are classified by wave length as "near," 4,000 to 3,000 A.U., and "far," 3,000-2,000 A.U. The region about 3,100-2,900 A.U. is sometimes called the middle U.V., or "Dorno region," and has the most powerful sunburn action on the skin. These middle U.V. rays are so completely absorbed by living substance that they have very little power of penetration; thus, only some $\frac{1}{100}$ of rays, about 3,000 A.U., penetrates as far as the capillaries beneath the epidermis.

The main action of these rays is then, on the living cells of the epidermis. The U.V. rays shorter than 2,500 A.U. are so completely absorbed by the outer horny layer of the epidermis that they have very little action on the living cells beneath; the very far U.V. rays less than 1,800 A.U. do not penetrate air. A powerful source of U.V. has a bluish white light and produces a pricking sensation in the conjunctiva of the eyes. To prevent conjunctivitis the eyes must be protected by glasses from such sources.

The skin is insensitive to these rays on exposure, but after sufficient exposure and a latent period of a few hours there follow inflammatory reactions of the skin; these are pricking, flushing and slight swelling followed later by peeling and brownning. The reaction is caused primarily by the rays displacing electrons in the atoms of certain substances in the living cells, and so inducing molecular changes which after a latent period result in coagulation and death of the living substance. The dead cells desquamate and are replaced by new ones. Products of the damaged cells, by exciting the nerve endings in the epidermis cause flushing of the blood vessels of the skin and transudation of lymph and leucocytes. These local reactions in the irradiated skin provoke secondary reactions in the blood and body generally.

The effect of U.V. rays on living cells can be studied under the microscope, e.g., on infusoria enclosed in a suitable quartz chamber. With the help of a quartz microscope and photography the effect of U.V. rays on microbes has been studied. Such a method shows up structures in living micro-organisms previously unknown. The remarkable discovery has been made that a substance, ergosterol, which is present in foods and in the skin, is activated by middle U.V. rays and becomes vitamin D required for bone formation. The want of this vitamin causes rickets and softening of the bones. Rickets can be prevented by adequate exposure of the skin to the U.V. rays of the sun or arc lamps, or by taking enough

vitamin D in the food.

This one fact by itself shows the immense importance of getting rid of smoke pollution of the air and having sun baths. Walls, glass, smoke, fogs and clothes cut off people from these beneficent rays. Irradiation of rickety children with U.V. rays increases the percentage of inorganic phosphorus and calcium in the blood, which is in them abnormally low. While provoking the formation of the brown pigment (melanin) in the skin, the U.V. rays lessen at the same time the percentage of the amino-acid tyrosin in the blood, the probable precursor of melanin. The inflammatory reaction set up by the U.V. rays provokes an increase of the power of the blood to destroy microbes as tested *in vitro*, a sign that these rays may possibly increase resistance to infection. It must be borne in mind that an over-dose has the opposite effect.

Right dosage with U.V. rays increases the sense of well-being and alertness of mind, and acts as a tonic in the winter months. Much of the stimulating effect of a visit to the Alps can be imitated by arc-light baths, combined with car rides and exercise in the open air. The fact must not be lost sight of that exposure to cool open air is as important as exposure to light. Such exposure stimulates the heat production of the body and appetite and tones up the muscles; breathing cool open air provokes blood flow through, and secretion from the respiratory membranes; these are excellent effects. Open air is clean compared with house air which is contaminated with dust, mould and microbes.

Protection of the skin from U.V. rays is brought about mainly by sweating and thickening of the horny layer of the epidermis. The pigment which results from sunburn chiefly protects the blood from over-heating by visible rays. By absorbing of visible rays, nerve endings in the epidermis are excited, and this provokes sweating which cools the skin by evaporation. The naked pigmented races have a thin skin, and sweating readily in the sun, lose heat easily in the shade. The pigmented skin of such races can be inflamed by U.V. rays. So long as the skin is kept cool by a flow of water, visible rays, even when concentrated by a lens (burning glass), have no sunburn effect on the skin.

The U.V. rays, on the other hand, sunburn the cold skin. Glacial burns are often very severe. It is possible to sensitize the skin to visible rays by injection of various dyes, eosin, erythrosin, and by a derivative of haemoglobin, viz., haematoporphyrin. The white skin thus sensitized, reacts to visible rays as it does to U.V. rays. Black skins are immune. Certain foods may have this sensitizing effect. Thus, only black pigs can be kept in tropical America, where the red mangold grows. There are rare cases of unfortunate people sensitive to visible rays. Exposed to light, their skin becomes inflamed and necrosed. They have to live like night animals. In some of these, haematoporphyrin is found in the urine.

Ultra-violet rays have great power to kill microbes, but as their penetrating power is very small, they only sterilize surfaces. In a skin disease such as lupus, these rays effect cure, not by directly killing the infecting tubercle bacilli, but by provoking an inflammatory reaction of the tissues which results in killing of the microbes and repair of the damage. Ultra-violet rays benefit the health of chicks and provoke egg-laying and fertility of fowls kept indoors under glass. They also, in suitable dosage, benefit growth of vegetables and fruits under ordinary glass. A particular kind of glass, called vitaglass, is transparent to the U.V. rays of the sun, and this is used for skylights with advantage. At the new monkey house at the London Zoo the animals are given warm shelves, incandescent lamps, vitaglass skylights, louvres always open in the roof, and free access to open air playgrounds through openings closed by hinged flaps. Bathing pools are set in the playgrounds. Food rich in vitamins, with plenty of fruit and raw vegetable, is provided. These are conditions which, if provided in crèches in cities, would raise an Aryan population.

Light-baths are very useful for treatment of rickets and tuberculosis, particularly tuberculosis of the skin (lupus), glands and joints; also many skin and eye diseases, and some forms of baldness. They may benefit chronic infections, e.g., chronic bronchitis and asthma. Combined with visible and infra-red rays, or red rays, they may benefit forms of chronic rheumatism. Used in winter months, light-baths act as a tonic, and prevent rickets and

rays of shorter wave length.

The sources of U.V. rays are the sun and arc lamps. The U.V. rays from the sun are longer than about 300 m μ owing to absorption of shorter rays by a layer of ozone placed miles high in the sky.

The artificial sources of U.V. rays are—(1) The mercury vapour lamp, (2) the short flame arc, (3) the long flame arc. The short flame arc is a quartz arc or metal-cored carbon poles. If metal poles such as iron or iron may be used with a short flame arc. The mercury vapour lamp is a powerful but not so dry source of U.V. rays. A high intensity short lamp added to the source of long flame arc introduced rays for heating. The short flame arc lamp with carbon poles gives much visible and infra-red and some U.V. rays as the sun does. The long flame arc with metal-cored carbon poles gives plenty of visible and infra-red and is at the same time a powerful source of U.V. rays. Given equal energy the U.V. from the long flame arc may at right angles to the flame be 14 times that of the short flame arc. Much of the U.V. rays come from the flame and to effect the best output, the positive pole must be placed below and the metal-cored (iron) negative pole, placed above, can be plain carbon.

Half a dozen people can sit round a long flame arc taking 200 Watts at two feet distance, a dose of five minutes suffices. One half of the body can be bathed at a time and two baths a week given. For intense local treatment e.g. required for lupus, the Kromayer or water-cooled mercury vapour lamp is most valuable. The dose given being five minutes, with the quartz glass of the lamp pressed on the skin—a dose sufficient to produce strong reaction and desquamation. The dose is repeated when the desquamation has passed away and the skin is again susceptible. The mercury vapour lamp or the short flamed arc with metal poles can be run on the ordinary house circuit and afford efficient sources. By means of a frosted Vitreosil screen the powerful mercury vapour lamp can be reduced to an intensity safe for domestic use.

With a screen of Chance's dark glass which transmits almost only long U.V. rays the fluorescence of substances can be studied in a dark room. This is a most useful method of identification. Thus, hair infected with ring-worm can be identified.

The far U.V. rays merge into the soft X-rays. The penetration of the skin increases again with the shortening of wave length. The X-rays produce inflammatory reaction after a long latent period, e.g. two to three weeks. They are used to check the growth of cancer cells and to produce sterility. Acting on embryos deformities in growth and monsters may be produced by their means. Owing to the great penetration of the soft tissues by X-rays in comparison with bones, photographs of fractures and disease of bones can be obtained. The shorter the X-ray the greater is the penetration. General mild doses of X-rays have been used in treatment of asthma and to prevent recurrence of cancer after removal of the primary growth.

X-rays are used for cure of skin diseases such as ring-worm. Great care must be used, for X-ray burns have a tendency to turn into cancer. The gamma rays of radium resemble very short (hard) X-rays, and have the same effect as these. Tubes containing radium emanation are buried in cancers which cannot be removed with the knife with the view of stopping growth. In certain accessible sites this treatment may be successful.

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(L. E. H.)

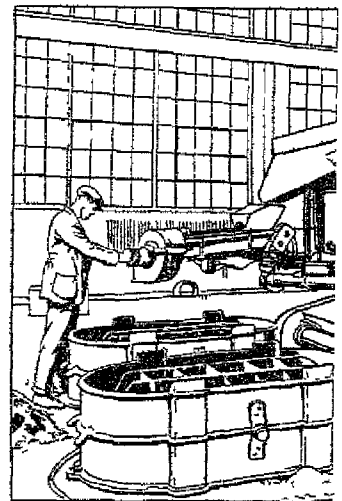
LIGHT BRIGADE. The brig command of Lord Cardigan won at Balaklava on October 25, 1855. The charge has been immortalized. The Charge of the Light Brigade which comprised the light brigade Hussars and 17th Lancers.

LIGHT (THIN) CASTING specialized development of the iron casts are designed almost exclusively building trades, domestic purpose structural requirements. Its development pace with development in standard in both public and private is cast in thin section and to high phosphorus content, giving actual process is quite similar in other branch of founding, but it has a trade that the average iron foundry produce castings of such fine section.

Classification.—For purposes classified under the following main

- 1 *Unfitted Goods*, including soil pipes, hot water pipes, gutters and water pipes and the various therewith electric and gas pillar, stable fittings, manhole covers, etc.
- 2 *Fitted Goods*, including such and steam cooking ranges, grate.
- 3 *Baths and Sanitary Ware*, or
- 4 *Hollow-ware* including kettle, ace pans, etc.
- 5 *Light Structural and Ornamental*, stairs, fire escape stairs, verandah shop fronts, etc.

The development of the industry branch of iron founding may be said of the 19th century, and it was wit



BY COURTESY OF FOUNDRY PLANT AND MACHINERY TRACTOR SAND SLINGER MACHINE RANGES

This machine rams any size of box, at 50 feet per minute. Other models can be used up to the floor of the moulding shop.

of Health under the Act of 1848 duties devolved on local authorities for light casting sanitary products but the awakening of public interest measure against disease, individual hygienic appliances also grew, and for what were first deemed luxuries to become necessities, with The Light castings industry set itself and a real appreciation of what

direction can best be gained from a consideration of what light castings articles are included in the structure of a modern dwelling house, and of the various functions which they perform

Gutters, etc.—The outside requirements are gutters or rhones rain water pipes and soil pipes cast in 6ft. lengths and varying from 1½ to 6in diameter. The gutters, which are made to many patterns, intercept rain water from the roof and conduct it to an outlet hole to which is attached the rain water pipe which leads the water down the outside of the house to an earth drain at the foot and thence to the public sewage system. The ordinary rain water pipe and gutter are round and half round respectively but for buildings more pretentious in design, rectangular rain water pipes and ornamental gutters are frequently required and supplied. All waste matter from the house is taken away by an outside pipe of heavier make than the rain water pipe, known as a soil pipe, which connects the lavatory, bath and sinks with the earth drain and main sewer. It projects up to the roof of the house the upper part acting as a ventilating pipe.

As regards the inside structure of the house, light castings requirements comprise the bath range, interior grates for living rooms, mantel registers for bedrooms, lavatory cistern, and portable wash boiler.

Baths.—At first baths were merely painted inside. Demand for higher quality and better finish led to the introduction of what is known as the metallic enamelled bath, which was grained on the inside to give a marble effect; but this type has been almost entirely superseded by what is known as the porcelain enamelled bath, which may be either in green or white. Baths are made either parallel or taper, generally with a square end and a scoop end, although in some patterns both ends are square. The popular sizes are 5 and 5½ft long, of varying widths and depths. Better quality baths are made with wide rolls or rims and in some cases are cast or fitted with outside panels reaching to the floor. The normal bath type, however, stands on feet which are cast separately and bolted to snugs on the bath casting. A modern development to suit the small modern house where bathroom space is limited is the combined bath and basin, the basin being either cast in one piece with the bath or cast separately and fitted on at the square end. The whole is fitted with swivel taps for hot and cold water serving bath and basin. Better class baths are also, if required, fitted with canopies for douches, sprays, etc. These canopies are generally of plate glass.

Ranges.—Ranges are made in various types and fitted with one or more ovens which may be placed level with or to one side above the fireplace. As a general rule ranges are fitted with a hot water boiler at the back of the fire. This boiler is supplied from the cold water cistern and feeds an intermediate tank which is connected directly to the bath, basin, and sink taps. A modern labour-saving device is to substitute for the range a combination article consisting of an ordinary sitting-room fireplace with an oven attached. The oven may be either at the side or on top, and in such cases the hot water boiler is placed at the back of and heated from the interior.

Interior Grates and Mantel Registers.—An interior grate is simply a framework with a bottom grate fitted into tiles which are cemented to bricks built in between the fireplace and the wall of the house. It may be entirely open or fitted with a fixed or movable canopy of plain or ornamental design. The cheaper types are finished in ordinary black, but interior grates are supplied in oxidized copper or silver, in armour bright which gives the interior a steel appearance, and in steel itself.

The mantel register is a combined casting designed to supply both fireplace and mantelpiece. This may be supplied plain or with ornamental tiles set into the sides.

In addition to the foregoing, which may be classified as structural requirements, light castings foundries produce what may be termed furnishings in the shape of kerbs or fenders for fireplaces, kettles, pots and pans for cooking purposes, and smoothing or sad irons (ordinary, gas, and electric). The kerbs or fenders may, as in other cases, be finished in plain black or in some better quality finish.

There is also that branch of the industry which supplies the

service requirements of municipalities and local authorities in connection with their gas, water, and sewage systems. The requirements in such cases are pipes which are made in 6 and 9ft lengths with bores of varying diameters. In the trade the water pipe is known as the underground pipe. The drain pipe is of high inside finish and tested under high pressure. Hot water pipes, which are usually made in 9ft lengths and varying diameters, are mainly used for the heating of greenhouses, outbuildings, and public buildings such as churches, halls, etc.

Making the Patterns.—The first step in the process, which is common to all classes of castings, takes place in the drawing office where a drawing of the pattern is made. This is passed to the pattern shop where the pattern is made in wood, stucco, or an amalgam of tin and lead. It is then passed to the moulding shop, where an iron or aluminium working pattern is cast.

Unfitted Goods.—This category consists mainly of pipes and gutters and their connections. They are made in boxes of two parts, top and bottom or in trade language top part or "cope" and drag. The pattern is placed on a board on the floor and the bottom or drag part of the box is placed over it. The drag is rammed with damp sand, technically called 'greensand' until it is absolutely firm. It is then turned over and the top part of the box is placed on it. The top part is rammed firm, and holes or gates leading down to the pattern are made in the sand. These holes or gates are for the running of the molten metal. The top part is then lifted off, the pattern drawn out, and the mould dusted and sleeked to make it absolutely smooth. A core which consists of a cylinder of the requisite length of hard sand made in a core box round a metal bar which projects at both ends is inserted in the hollow left by the pattern. The ends of the core when in place rest on two prints or bearings in the mould left by the pattern. The top part is put on and the box closed by hooking the two parts together. The mould is then ready to receive the metal. In the case of the lighter pipes, e.g., rain water and soil, the gates are made on the top and the casting is run horizontally, while in the case of the heavier pipes, e.g., drain and underground, the pipes are made and cast on a slope technically known as 'the bank'. The gates are placed at the top end of the mould and the casting is run on the slant. Still larger and heavier pipes are cast in a vertical position.

The metal is brought from the cupola in large bogies and is poured into the mould by means of hand ladles through the gates. Before the box is opened and before even the metal has cooled the gates are knocked off. When the iron has cooled the top part is lifted off and the pipe lifted out. The pipes are then collected and taken to the dressing shop, where any fins or raw edges are taken off them and they are brushed with steel brushes. All pipes then go before a man known as the passer for acceptance or rejection, and if passed, are taken to be painted or coated with a tar preparation before despatch.

Fitted Goods.—The moulding process for fitted goods is in principle exactly similar to that for unfitted goods except that in the case of a perfectly flat casing a core is not required.

From the moulding shop these castings are sent, like the others to the dressing shop, where the rough edges are taken off. Thence after inspection they pass to the grinding mill where they are ground and buffed to give the necessary polished surfaces. They are then taken first to the fitting shop, where they are given a preliminary fitting and slight inequalities are remedied, and secondly to the finishing shop, where the individual parts are blacked, oxidized, or nickel plated, according to requirements. Thereafter they are returned to the fitting shop for final assembly. The article is then ready for the showroom or for despatch.

Baths and Sanitary Ware.—After a moulding process similar to that previously described, the bath is annealed or burned, i.e., heated in a furnace known as a muffle. The purpose of annealing is to soften the metal and in particular to remove or drive out all of the various gases which may remain imprisoned in it. The bath is then dressed, sand blasted, and coated to give a suitable ground to which the enamel can adhere. It next passes to the shop where it is again put into the muffle

... the sand is then ready for the warehouse or for despatch.

Cast-iron sanding; molten brass dried and painted white ...

With reference to rail-work and structural and ornamental castings the process apart from moulding follows the lines described on p. 85, namely drawing, lining or enamelling, in the case of pots and pipes and in the case of spiral stairs, verandahs, shop fronts etc. drawing and lining.

Plate Moulding.—A development in the moulding process is the use of plate patterns. Instead of working with a loose pattern one or two or more articles whose size and nature of the casting find themselves to it are put on what is known as a plate. At first these plates were made of cast-iron but they have since been made where possible of aluminium so as to lighten the handling of the job. There is however no difference in the actual moulding process and successive processes known as before described according to the nature of the article.

Machine Moulding.—For a considerable time machines have been employed to assist in the ramming of the moulds but formerly these were chiefly used for smaller classes of work e.g., connections and certain types of lat castings. They are variously operated—by electricity by compressed air by hydraulic power, or by hand. In all cases the moulding box has to be filled by hand, the machine doing only the ramming. Since the World War however, there has been put on the market a machine called the Sand Slinger which is being operated in foundries throughout the world. This machine not only fills the boxes with sand but in the act of doing so rams it hard. It is made to different designs for different purposes and can ram practically any size of box at speeds varying from five to ten cubic feet of sand per minute. The type most commonly in use in light castings shops is known as the Tractor machine. This takes the sand from the floor, riddles it and passes it on by means of a moving belt to the ramming head, whence it is discharged into the moulding box. The ramming head is attached to the end of a swivelling arm which has a radius of from 9 to 21 ft. on either side of the machine. The machine is also made to work in a stationary position, in which case it is bolted to the floor of the moulding shop. It is also supplied in portable form so that it can be moved to any job in any part of the moulding shop. In the case of the stationary and portable types the sand has to be fed to the machine. Another type is the Motive type to which is attached a large tank with a sand carrying capacity of from eight to ten tons. This can conveniently be filled by means of an overhead conveyor.

As the ramming of the boxes in the moulding shop is one of the heaviest and most tiring jobs in the foundry it would appear to be only a question of time before practically all classes of work are automatically rammed by the Sand Slinger or some similar type of machine. (J. K.)

LIGHTER, a barge employed in ports in loading or unloading the cargoes of ships, the name being derived from the verb "to light; i.e., to relieve of a burden. The men employed on them are termed lightermen. (See BARGES AND CANAL CRAFT.) Also a small mechanism, used instead of matches, in which a small wheel is twirled against a piece of ferro-cerium throwing off sparks which ignite petrol fed through a cotton wick.

LIGHTFOOT, JOHN (1602-1675), English divine and Hebrew scholar was born at Stoke-upon-Trent on March 29, 1602, and studied at Christ's college, Cambridge. He was a supporter of the parliament, and an original member of the Westminster Assembly (see his *Journal of the Proceedings*, vol. xiii. of his works). In 1643 he was made master of Catherine hall, Cambridge, and rector of Much Munden, Herts, preferments in

... the Restoration. In 1654 he became vice-chancellor of the university. He wrote various learned exegetical works. His later years were devoted to helping Brian Walton with the *Polyglot Bible* (1657) and to the preparation of his own best known work, *Horae Hebraicae et Talmudicae* (5 vols., 1658-74). He died at Ely on Dec. 6, 1675.

See his *Whole Works*, in 15 vols. edited, with a life, by R. Pitman (1722-3) and D. M. Welton, *John Lightfoot, the Hebraist* (Leipzig, 1875).

LIGHTFOOT, JOSEPH BARBER (1828-1889), English theologian and bishop of Durham, was born at Liverpool on April 12, 1828. He was educated at King Edward's school, Birmingham and Trinity college Cambridge. He graduated senior classic and 30th wrangler, and was elected a fellow of his college. From 1854 to 1859 he edited the *Journal of Classical and Sacred Philology*. He became tutor of his college (1857), Hulsean professor (1861), chaplain to the prince consort and honorary chaplain to the queen. Whitehall preacher (1866) and canon of St. Paul's (1871). In 1875 he became Lady Margaret professor of divinity in succession to William Selwyn. He had previously written his commentaries on the epistles to the Galatians (1865), Philippians (1865), and Colossians (1875), which mark a new departure in New Testament exegesis in England. Lightfoot was a great grammarian and textual critic; he endeavoured to make his author interpret himself, and by considering the general drift of his argument to discover his meaning where it appeared doubtful. Thus he was able often to recover the meaning of a passage which had long been buried under a heap of contradictory glosses, and he founded a school in which sobriety and common sense were added to the industry and ingenuity of former commentators. In 1879 Lightfoot was consecrated bishop of Durham. He continued to work on his editions of the Apostolic Fathers, and in 1885 published an edition of the Epistles of Ignatius and Polycarp, collecting also much valuable material for a second edition of Clement of Rome which was published after his death (1st ed., 1869). His defence of the authenticity of the Epistles of Ignatius is an important contribution to that very difficult controversy. He died at Bournemouth on Dec. 21, 1889, and was succeeded in the episcopate by Westcott his schoolfellow and lifelong friend who published a sketch of his *Life* (1894).

LIGHTHOUSES. Under the general heading of Lighthouses this article includes, in addition to a description of marine lighthouse structures and apparatus some reference to Unattended lights, Light-vessels, Lighted buoys, Aerial lighthouses and Acoustic and wireless fog signals. (See the following section, *Lighthouses of the United States*, for similar information concerning America.)

A lighthouse is a structure erected to carry a light for the purpose of warning or guidance in connection with marine and aerial navigation.

Early History.—The earliest lighthouses, of which records exist, were the towers built by the Libyans and Cushites in Lower Egypt, beacon fires being maintained in some of them by the priests. Lesches a Greek poet (c. 660 B.C.) mentions a lighthouse at Sigeum (now Cape Incisari) in the Troad, which appears to have been the first light regularly maintained for the guidance of mariners. The famous Pharos of Alexandria, built by Sostratus of Cnidus in the reign of Ptolemy II (283-247 B.C.) was regarded as one of the wonders of the world. A full account of it is given in Hermann Thiersch's *Pharos Antike, Islam und Occident* (1909). The tower, which took its name from that of the small island on which it was built, is stated to have been 600 ft. in height, but the evidence in support of this is doubtful. It was destroyed by an earthquake in the 15th century, but remains are said to have been visible as late as 1350. The name Pharos became the general term for all lighthouses, and the term "pharology" has been used for the science of lighthouse construction. The tower at Ostia was built by the emperor Claudius (A.D. 50). Other famous Roman lighthouses were those at Ravenna, Pozzuoli and Messina. The ancient Pharos at Dover and that at Boulogne, later known as *la Tour d'Ordre*, were built by the Romans and were probably the earliest lighthouses erected in western Europe. Both are

LIGHTHOUSES

on a rock in the sea at the mouth of the example now existing of a wave-swept on the same rock are supposed to have us le Debonnaire (c AD 805) and the ck Prince. The existing structure was eign of Henry II. of France and comer part of the beautiful Renaissance ards the end of the 18th century, and replaced by a softer cylindrical structure rising to a height of 207 ft above the rock (fig 1). Until the 18th century the light was exhibited by means of an oak-log fire, and subsequently a coal fire was in use for many years. The ancient tower at Corunna known as the Pillar of Hercules, is supposed to have been a Roman Pharos. The Torre del Capo at Genoa originally stood on the promontory of San Berrique. It was built in 1139 and first used as a lighthouse in 1320. It was rebuilt on its present site in 1643 and rises 230 ft above the cliff. The Pharos of Meloria was constructed by the Pisans in 1154 and was several times rebuilt until it was finally destroyed in 1290. On the abandonment of Meloria by the Pisans they erected the still existing tower at Leghorn in 1304, which has well borne the brunt of time.

In the 17th and 18th centuries numerous towers on which ates containing wood or coal fires, were tions on the coasts of Europe. Among i Kingdom were Tynemouth (c 1608), St. Agnes (1680), St. Bees (1718) and ldest lighthouse in the United States is light situated on Little Brewster Island an entrance to Boston Harbour, Mass the present structure dating from 1859 i the New England coast were those at ance to Newport Harbour (1740), and o Nantucket Harbour (1754). A watch- o have been erected on Beacon or Light- Point Allerton Hill near Boston prior ures would seem to have been in the ; in time of war rather than light-houses ers.

HOUSE STRUCTURES

houses may be divided into two classes. s or in other situations exposed to the b) the more numerous class of land

-In determining the design of a light- in a wave-swept position consideration ytical features of the site and its sur- is description are classified as follows. te structures, (2) Openwork steel and pile or other foundations; (3) Cast- ructures erected on caisson foundations. re generally preferred for erection on ig good foundation and have also been ions where adequate foundations have ussons into a soft sea bed. Smeaton's ock is the model upon which most later rs have been based although many im-

provements in detail have since been made exposure the following principles in design (a) The centre of gravity of the tower struc as possible. (b) The mass of the structure horizontal section must be sufficient to pre

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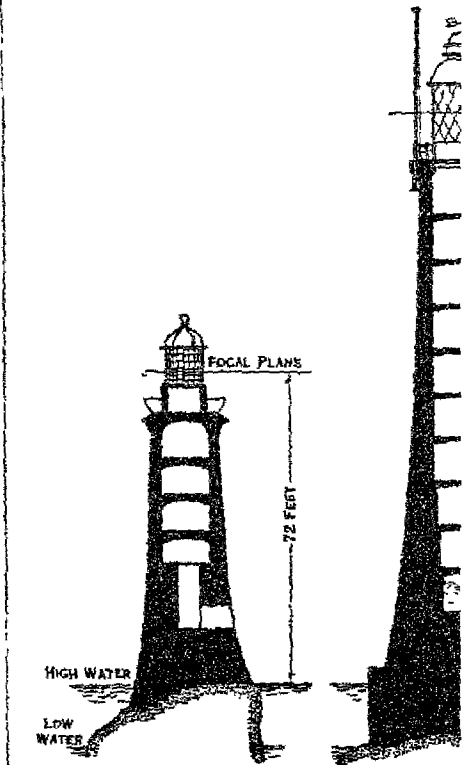
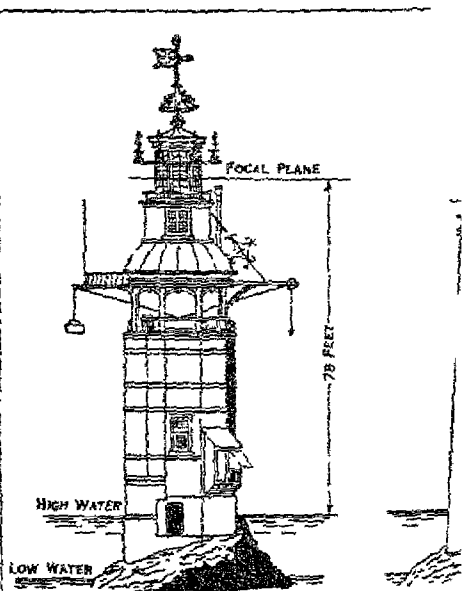


FIG 2—THE FOUR LIGHTHOUSES ON THE The towers are drawn to the same scale. The first great storm of 1703, and the present tower was con by the combined forces of wind and waves the adhesion at horizontal joint-faces or stones introduced as an additional safegu. should be circular in plan throughout. ti least resistance to wave stroke and wind tion. (d) The lower portion of the tower horizontal stroke of the waves should. f structured with a vertical face. The upper p

slight wind, uniform better or continuously curved in the vertical plane. Excessive projections from the face of the tower except in the case of a gallery under the lantern should be avoided. The opening through the lantern should be large. The height from sea-level to the top of the tower should be sufficient to avoid the obscuration of the light by fog, rain water or salt spray driving over the lantern. The foundation of the tower should be carried well into the rock and should be of high density and of resistant character. The stones used in the construction of the tower at any part, if they on the outer face should be dove-tailed or joggled one to the other in order to prevent their being dislodged by the sea during the process of construction and to afford additional support. Portland cement concrete has been used to a considerable extent for maritime structures, including lighthouses, but more or less with masonry. Reinforced concrete has not been employed.

Many examples of openwork steel and iron lighthouses exist. Some typical examples are described hereafter. This form of design is suitable for situations where the tower has to be carried on a foundation of iron or steel piles driven or screwed into an insecure or sandy bottom, etc., on shoals, coral reefs and sand banks or in places where other materials of construction are exceptionally costly and where facility of erection is a considerable advantage.

Cast-iron pitted towers have been erected in many situations where the cost of stone or scarcity of labour would have made the building of a masonry tower excessively expensive.

Cylinder or caisson foundations have been used for lighthouse towers in numerous cases where such structures have been erected on sand banks or shoals. A remarkable instance is the Robbersand tower. Two attempts have been made to sink a caisson in the outer Diamond Shoal off Cape Hatteras on the Atlantic coast of the United States, but these endeavours have proved to be futile.

Famous Wave-swept Towers.—The following are brief descriptions of some of the more important wave-swept towers in various parts of the world.

Eddystone (Winstanley's Tower)—The Eddystone rocks, which lie about 14 m off Plymouth are fully exposed to south-western seas. Four towers have been constructed on the reef which is submerged at high-water spring tides. The first lighthouse (fig 2a) was polygonal in plan and highly ornamented with galleries and projections which offered considerable obstruction to the sea stroke. The work was begun by Henry Winstanley, a gentleman of Essex, in 1695 and finished in 1698. In the following year in consequence of damage by storms, the tower was increased in diameter from 16 ft to 24 ft by the addition of an outer ring of masonry and made solid to a height of 20 ft above the rock, the tower being raised from 30 ft. to nearly 120 ft. This work was completed in 1700. The lower part of the structure appears to have been of stone, the upper part and lantern of timber. During the great storm of Nov. 20, 1703, the tower was swept away, those in it at the time including the builder, being drowned.

Eddystone (Rudyard's Tower)—This lighthouse was begun in 1705 and completed in 1709 (see fig 2b). The structure consisted principally of oak timbers securely bolted and clamped together, the lower part being filled in solid with stone to add weight to the building. The simplicity of the design and the absence of projections from the outer face rendered the tower very suitable to withstand the onslaught of the waves, but the lighthouse was destroyed by fire in 1755.

Eddystone (Smeaton's Tower)—This famous work, which consisted entirely of stone, was begun in 1756, the light being first exhibited in 1759 (see fig 2c). John Smeaton was the first engineer to use dove-tailed joints for the stones in a lighthouse structure. The stones, which averaged 1 ton in weight, were fastened to each other by means of dove-tailed vertical joint faces, oak key wedges and by oak tree-nails wedged top and bottom, extending vertically from every course into the stones beneath it. During the 19th century the tower was

occasionally until in 1877, owing partly to the u rock on which the tower was built and the in the structure the Corporation of Trinity House erection of a new lighthouse in place of it.

Eddystone (J. N. De la Glass' Tower)—The new Eddystone tower (fig 2d) is 120 ft SSI lighthouse where a suitable foundation was considerable section of the lower courses had to level of low water. The base is vertical 14 ft all the stones are dove-tailed both horizontally and joint faces those of the foundation course the rock by Munz metal bolts. The lantern helically-framed structure with domed roof of and cast-iron pedestal. The optical apparatus consists of two superimposed tiers of refra. The burners originally fitted in Eddystone to pattern but these were replaced in 1904 by vapour burners. At the time of the completion two bells, weighing 2 tons each and struck by were installed for fog-signalling purposes, the replaced by an explosive gun-cotton fog signal paring the foundation was begun on July 17, 1 was first exhibited on May 18 1882. The Smeaton's tower was removed on completion house and re-erected on Plymouth Hoe, where Trinity House sea mark. One of the principal design of the new Eddystone lighthouse tower base. Heavy seas are immediately broken up spray alone rising to the height of the lantern e to which the gallery cornice of the old tower w great that stones were sometimes lifted from t cessor presents another point of dissimilarity structure, in that the stones forming the floor corbels built into the wall instead of stone ar which, in the earlier tower, was taken by the by building in chains in the form of hoops. T structing corbelled stone floors was first adopte in the Bell Rock lighthouse.

Bell Rock—The Bell Rock tower (fig 3a) off the coast of Forfarshire stands on an ex

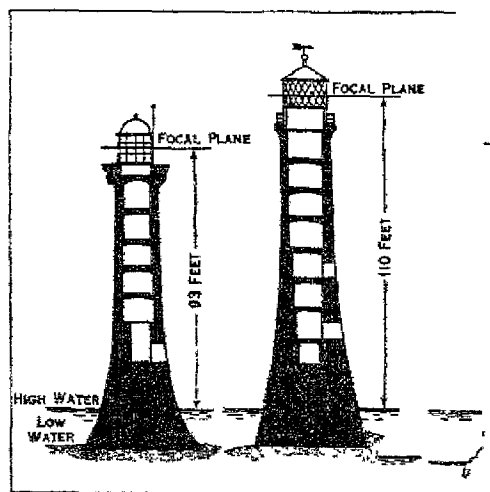


FIG 3.—SECTIONS OF ROCK LIGHTHOUSES DRAWN a, Bell Rock off the east coast of Scotland; b, Wot Cornwall; c, Armen, off the coast of Finistère.

low water and submerged to a depth of about 1 of spring tides. The rock is of hard sandstone was constructed by R. Stevenson in 1807-11.

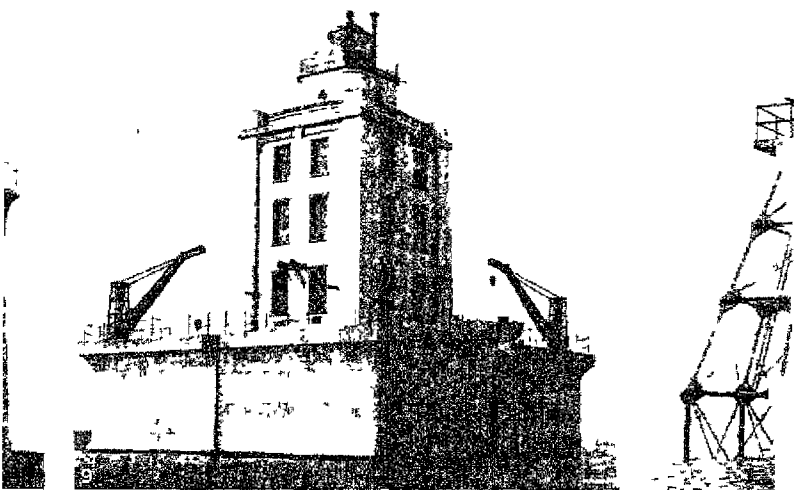
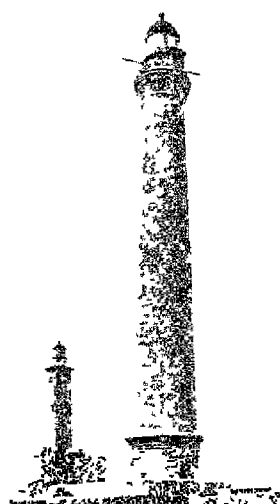
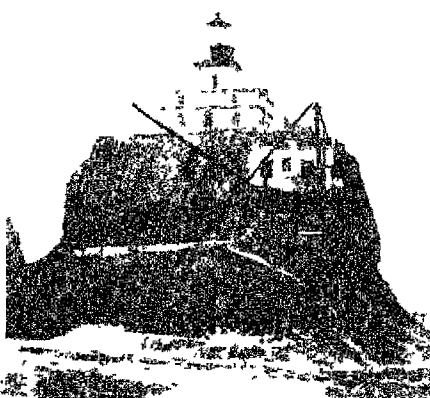
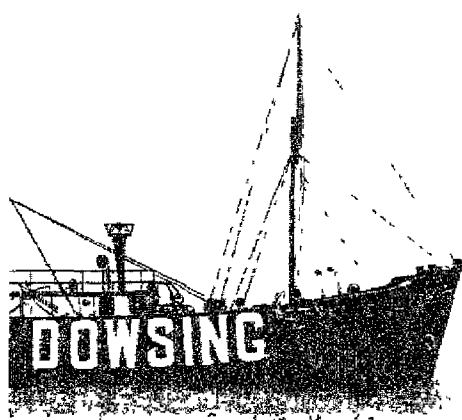
Skerryvore—The Skerryvore Rocks, 12 m Tyree in Argyllshire, are wholly open to the A 150 ft in height and designed by Alan Stever 1838 and finished in 1844.

Bishop Rock—The lighthouse on the F westernmost landfall rock of the Scilly Islands

¹Proc Inst. C.E. vol. LXXV (-833)

Proc Inst. C.E. vol. CVIII (1892)

LIGHTHOUSES



5 DEPARTMENT OF COMMERCE, (7) THE A G A COMPANY, LTD

10 LIGHTHOUSES OFF THE COASTS OF ENGLAND, FRANCE AND AM

ing shoal in the North Sea, about 50

This light vessel is equipped with constant-level table. The illuminant is The vessel has a diaphone fog signal Northeast End Lightship, stationed a modern vessel with Diesel engine electric, on foremast, with reserve lighthouse. Hurst, one of two leading Solent, opposite the Isle of Wight automatic acetylene plant (building station, off the Oregon coast), a stone 133 feet above the sea. 5. The V. ergs be completed. Tows 247 feet. The old light house about 14

south-east of Boston, a granite tower, built in an ex Atlantic 7 Aerial Lighthouse, Cranbrook, Kent of England. Glazing of lantern is extended over the optical apparatus to direct beams of light from zenith. 8. Kilauea Point Lighthouse, Hawaii, a rein 52 feet high, standing on a cliff. The lens, enclosed in double panels, and shows a double flashing light of every 10 seconds. 9. Martin Reef Light Station on part of Lake Huron. It stands in 6 feet of water to heavy ice action. The light is electric, 70 feet Pacific Reef Light standing in 7 feet of water. 10. Coral reef off the Florida coast. It is supported by feet of the coral reef. It is an unusual design of acetylene light.



a more exposed situation than any other in the world. The first lighthouse erected there was begun in 1847 under the direction of V. Douglass. The tower consisted of a cast and wrought-iron openwork structure having the columns deeply sunk into the rock. On Feb. 5, 1850, when the tower was ready to receive the lantern, a heavy storm swept away the whole structure. In 1851 the erection of a granite tower was begun and the light was first exhibited in 1858. This structure also proved insufficient to withstand the very heavy seas to which it was exposed. Soon after its completion the 5-cwt fog bell, fixed to the lantern gallery 100 ft above high-water mark, was washed away and the tower vibrated considerably during storms. In 1874 it was strengthened by bolting continuous iron ties to the internal surfaces of the walls. In 1881 further signs of damage appeared and the structure was encased from its base upwards with granite blocks dove-tailed to each other and to the existing work. At the same time the elevation of the light was increased. The work was begun in 1883 and completed in 1887. Profiting by the experience gained after the construction of the new Eddystone tower, Sir J. V. Douglass decided to build the lower portion of the improved Bishop Rock tower in the form of a cylinder, but with considerably increased elevation (fig 4).

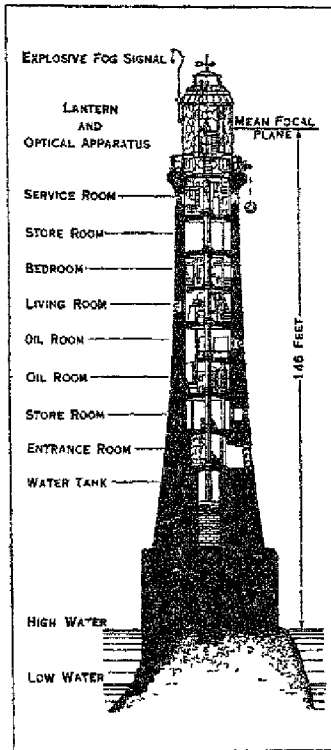


FIG 4—BISHOP ROCK LIGHTHOUSE, SCILLY ISLANDS. This is the second granite tower. The first granite tower was encased and raised in height in 1883-87.

Imot's Ledge (Plate I). The tower, 89 ft in height is built of granite upon a reef off Boston Harbour, Mass., and occupied five years in construction, being completed in 1860. The rock just bares at low water. The stones are dovetailed vertically, but not on their horizontal beds, bonding bolts being substituted for the horizontal dovetailed joints in the lower 40 ft., or solid portion of the tower.

Wolf Rock—This much-exposed rock lies midway between the Scilly isles and the Lizard point, and is submerged to the depth of about 6 ft at high water. The tower was erected in 1862-9 (fig 3b). The lower part of the base has projecting steps or scarcements in order to break up the sea.

Dhu Heartach Rock—The Dhu Heartach Rock, 35 ft above high water, is 14 m south-west of the island of Mull. The tower occupied six years in erection, and was completed in 1872. The total plane is at a level of 145 ft. above high-water.

Ar'men—The masonry tower, erected by the French Lighthouse Service, on the Ar'men rock off the western extremity of the Île de Sein, Finistère, occupied fifteen years in construction (1867-81). The rock is barely uncovered at low water and of small area, which made it impossible to construct a tower having a base diameter greater than 30 ft (fig 3c).

St George's Reef, California—This structure, completed in 1891, consists of a square pyramidal stone tower rising from the easterly end of an oval masonry pier, built on a rock to a height of 60 ft. above the water. The focal plane is at an elevation of 146 ft above high water. The site is one of great exposure.

Fastnet—The first lighthouse on the Fastnet rock, off the south-west coast of Ireland, was a circular cast-iron tower 86 ft in height completed in 1854. It was erected on the summit of the rock which in 1895 was found to be considerably undermined. In 1899 a granite structure of increased height and founded upon a sound ledge of rock on one side of the higher but undermined

portion of the reef with its foundation laid near high water, was commenced and completed in 1904 (Plate II). The focal plane is at a level of 158 ft above high-water mark.

Maplin—The screw-pile lighthouse erected on the Maplin Sand in the estuary of the Thames in 1838 is the earliest of its kind and served as a model for numerous similar structures in various parts of the world. The piles, nine in number, are of solid wrought-iron with screws 4 ft in diameter.

American Shoal, Florida—This tower is typical of the openwork pile structures on the Florida reefs, and was completed in 1880. The focal plane is 109 ft above high water.

Wolf Trap—This lighthouse was erected during the years 1893-94 on Wolf Trap Spit in Chesapeake bay, near the site of an old openwork structure which was swept away by ice early in 1893. The tower is built upon a cast-iron caisson 30 ft in diameter sunk 18 ft into the sandy bottom. The depth of water on the shoal is 16 ft at low water. The caisson was filled with concrete, and is surmounted by a brick superstructure 52 ft in height from low water to the focal plane of the light. A somewhat similar structure was erected in 1885-87 on the Fourteen-Foot Bank in Delaware Bay. The foundation in this case was however, shifting sand, and the caisson was carried to a greater depth.

Rothersand—This lighthouse, off the entrance to the river Weser, in Germany is a structure of great interest on account of the difficulties met with in its construction. The tower had to be founded on a bottom of shifting sand 20 ft below low water and in an exposed situation. Work was begun in May 1881, when attempts were made to sink an iron caisson under pneumatic pressure. Owing to the fact that scour removed the sand from one side of the caisson it tilted to an alarming angle, but eventually it was sunk to a depth of 70 ft. below low-water. In October of the same year the whole structure collapsed. Another attempt made in May 1883, to sink a caisson of bi-convex shape, in plan 47 ft long, 37 ft wide and 62 ft. in height, met with success, and

after many difficulties the structure was sunk to a depth of 73 ft below low-water, the sides being raised by the addition of iron plating as the caisson sank. The sand was removed from the interior by suction. Around the caisson foundation were placed 74,000 cu yd of mattress-work and stones, the interior being filled with concrete. The lighthouse (fig 5) was completed in 1885.

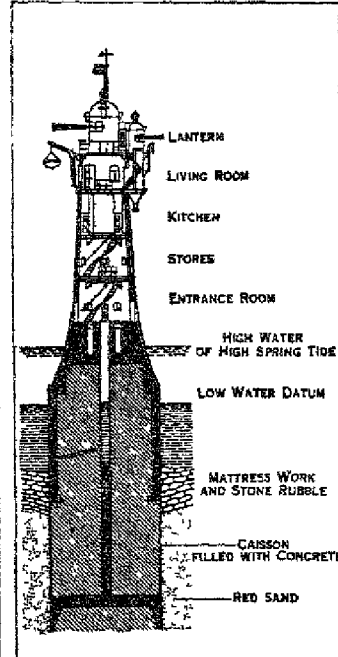


FIG 5—ROTHERSAND LIGHTHOUSE, NEAR THE MOUTH OF THE WESER ESTUARY, GERMANY.

Other well-known wave-swept towers are those at Haulbowline Rock (Carlingford Lough, Ireland, 1823), Heaux de Brehat (Brittany, 1839); Horsburgh (Singapore, 1851); Bayes d'Olonne (Bay of Biscay, 1861), Smalls (Pembrokeshire, 1861), Hanois (Alderney, 1862), Dædalus reef, iron tower (Red sea, 1863), Alguada reef (Bay of Bengal, 1865), Longships (Land's End, 1872), Great Basses (Ceylon, 1873), the Prongs (Bombay, 1874), Spectacle reef (Lake Huron, 1874), Chicken

rock (Isle of Man, 1874); Fowey Rocks (Florida, 1878), Rattray Head (Aberdeenshire, 1895); Beachy Head (Eastbourne, 1902); the Graves (Boston, U.S.A., 1905); and Jument d'Ouessant (Brittany, 1911).

Jointing of Stones in Rock Towers.—Various methods of jointing the stones in rock towers are employed in building. The great distinction between the towers built by successive engineers to the Trinity House, and other rock lighthouses is that, in the former the stones of each course are dove-tailed together both laterally and vertically and are not ed by metal or

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 of various ... The ... in the joint

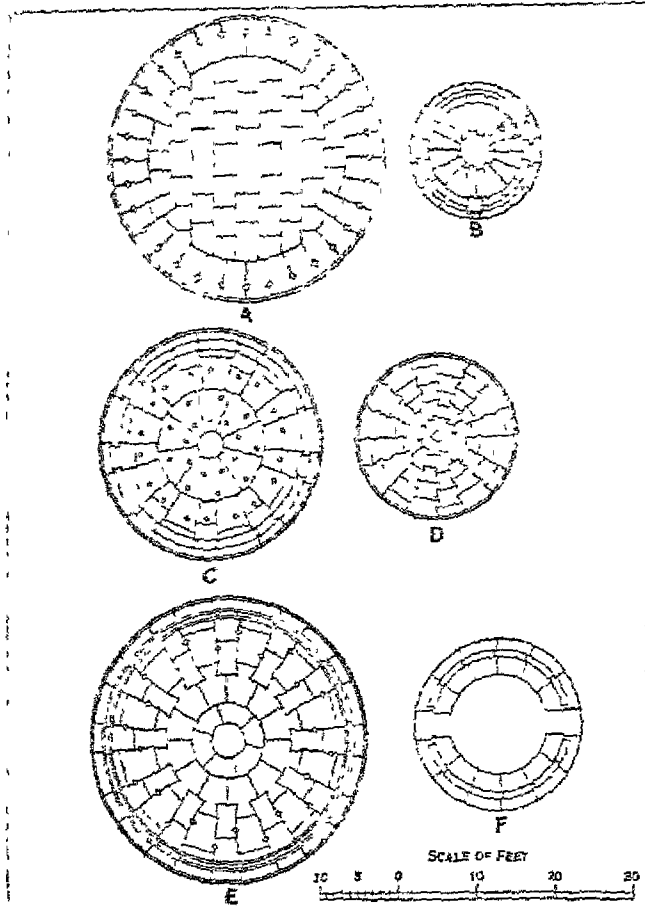


FIG 6 - COURSES OF STONES OF VARIOUS TOWERS

A. Dhu Heartach, 1st Course B Bell Rock Floor C. Wolf 12th Course.
 D Eddystone, 12th Course, Smeaton's Tower E Chickens 6th Course. F.
 Eddystone, 48th Course, Douglas Tower

formed between the faces so locks the dove-tails that the stones cannot be separated without being broken

TABLE I Comparative Cost of Exposed Rock Towers

Name of structure	Total cost	Cu ft.	Cost per cu ft of masonry
Eddystone (Smeaton) (1757)	40,000	15,343	2 10 11
Bell rock, Firth of Forth (1811)	55,000	28,530	1 10 0
Starryvore, Scotland (1844)	70,200	58,380	1 4 8
Bishop rock, first granite tower (1848)	34,500	35,200	1 0 7
Small, Bristol Channel (1861)	50,124	46,386	1 1 7
Harrow Alderney (1862)	25,200	24,542	1 0 7
Wolf rock, Land's End (1860)	62,726	50,070	1 3 3
Dhu Heartach, Scotland (1872)	77,684	42,050	1 14 6
Longships, Land's End (1872)	43,500	47,010	28 5
Eddystone (Douglas) (1882)	50,255	65,108	18 2
Bishop rock, reconstruction (1887)	64,830	45,080	1 8 9
Great Basses, Cevion (1873)	63,560	47,819	1 6 7
Mizut's Ledge Boston, Mass (1860)	67,500	36,342	1 17 2
Spectacle reef, Lake Huron (1872)	78,125	42,742	1 16 2
Armen, France (1881)	57,002	32,400	1 3 3
Pastnet, Ireland (1874)	70,000	62,500	1 5 5

Effect of Waves.—The wave stroke to which rock lighthouse towers are exposed is often considerable. During the erection of the tower at Dhu Heartach, 24 joggled stones, each of 2-tons weight, were washed away after having been set in cement at a height of 57 ft above high water, and similar damage was done during the construction of the Bell rock tower. The effect of waves on the Bishop rock and Eddystone towers has been noted above.

Land Structures for Lighthouses.—The erection of light-

... er ... buildings on ...
 difficulties of construction; such building ...
 architectural character. Besides being b ...
 reinforced concrete, land towers are fre ...
 cast-iron plates or open steel-work with a ...
 examples of the former are to be found i ...
 and elsewhere, that on Dassen Island (...
 being typical. A cast-iron tower erected at ...
 in Howland, in 1875 is 197 ft in height to ...
 open-work structures up to 200 ft in ...
 Examples are the towers erected at Cap ...
 in 1852 148 ft. to the focal plane. Mo ...
 180 ft., and Sanganeb Reef (Red sea) 19

OPTICAL APPARATUS

Optical apparatus in marine lighthouse concentrating the rays of light derived from the vertical plane only to show a fixed light or horizon which can be made either flash or eclipsing the light or by interposing (1) and (2) in both the vertical and horizontal plane to produce a high-powered beam or cone of light revolved, to show a flashing light or fixed light or narrow channel where a light is interposed in the vertical plane and after passing through a plane for diverting or condensing a part of the light to strengthen a sector.

Three types of apparatus are used to effect (a) *Catoptric* in which the rays undergo reflection at the surface of a mirror; (b) *Dioptric* in which the rays pass through a glass medium and are bent or refracted as they emerge from it (fig 7); and (c) *Catadioptric* after entering the glass medium suffer total

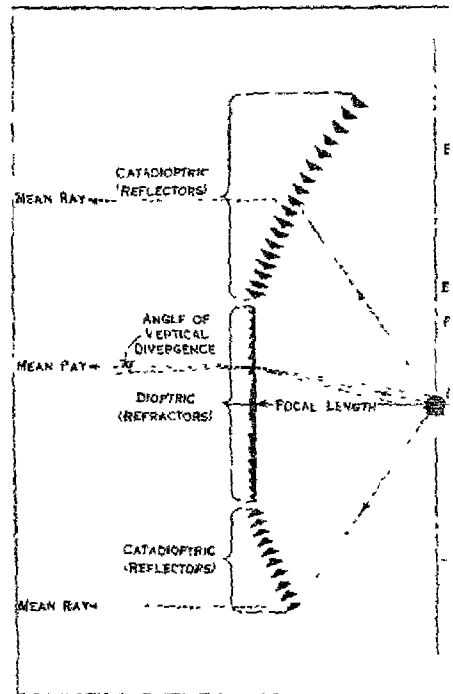


FIG 7 - DIAGRAM SHOWING THE GLASS ELEMENTS OF LIGHTHOUSE OPTICAL APPARATUS

... fore emerging from it (fig 7). The object of optical apparatus is not only to produce distinctions in lights to enable them to be seen by mariners, but to utilize the light rays to their condensation. This is accomplished by the use of revolving annular lenses than by which intensities are thereby attained. Fig 7 shows the various sections and disposition of the optical apparatus commonly used in lighthouse optical apparatus.

Catoptric System.—Paraboloidal mirrors with small faces of silvered glass set in pla

In some of the Mersey lights by William Denckwiler a L. Ersson's periscopic lens was introduced in France in 1811, followed by silvered copper in 1790 in England and in 1803. The earlier lights were of reflectors being arranged on a frame so that the emergent rays overlapped and filled the horizon continuously. In 1783 the first was erected at Marstrand in Sweden. Similar to that at Cordouan (1790), Flamborough Head rock (1811). To produce a revolving or revolving apparatus were fixed on a rotating carriage having a paraboloidal reflector is still used for

reflecting mirrors were used in the Heligoland with electric-arc lamps. The French built (1919) a quadruple-flashing light at Cap de la Hague has large gilded and burnished paraboloidal oil burners. It is however, unlikely to take the place of dioptric lenses. Paraboloidal also been used in some aerial lighthouses. Valérien, near Paris.

The first adaptation of dioptric lenses was due to T. Rogers, who used lenses at lighthouses between 1786 and 1790. Count Rumford proposed to grind out of a solid piece of glass concentric zones, in order to reduce the thickness. Condorcet in 1773 and Sir David Brewster built-up lenses consisting of stepped zones of these designs, however, was intended for illumination. In 1822 Augustin Fresnel invented an annular lens in which the centres of curvatures receded from the axis according to the radius, so as practically to eliminate the only spherical surface being the small "eye" (fig 8). These lenses were intended to be used by Fresnel next produced his cylindrical lens consisting of a zone of glass generated by the vertical axis of a meridional section of the lens. The lens belt condenses and parallelizes the rays in the vertical plane only, while the annular lens does so in the horizontal plane. The first revolving light constructed was erected at the Cordouan lighthouse in 1823. It consisted of 8 panels of annular lenses of 45° vertical angle and a focal distance of 920 mm. To utilize the light otherwise escape above the lenses, Fresnel

used metallic reflection in his design, which was greater than that of silvered copper. Shortly before his death in 1827 Fresnel devised his totally reflecting or catadioptric prisms (fig 7) to take the place of the silvered reflectors previously used above and below the lens elements. In these the principle of internal reflection from the face of a glass prism is made use of as well as the principle of refraction. Thus a ray of light falling on the prismoidal ring is refracted as shown in the enlarged detail of the reflecting prism and then is totally reflected emerging after a second refraction in a horizontal direction. Fresnel devised these prisms for use in fixed-light apparatus but the principle was applied to flashing lights by T. Stevenson in 1850. Both the dioptric lens and catadioptric prism invented by Fresnel are still in general use. The mathematical calculations of the great French designer still forming the basis upon which lighthouse opticians work.

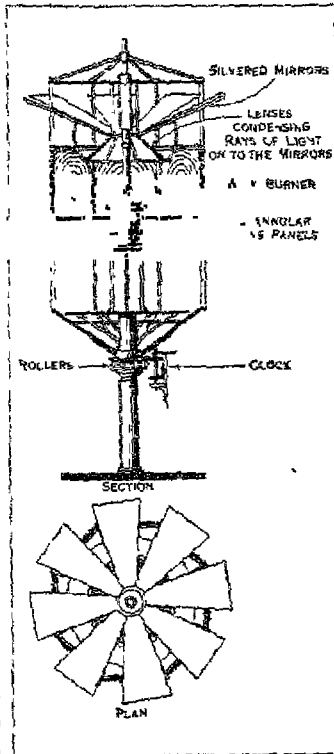


FIG 9.—FRESNEL'S FIRST REVOLVING LIGHT, ERECTED IN 1823

This apparatus of 920 mm. focal distance, formerly at Cordouan lighthouse (river Gironde), was the first dioptric revolving light to be established.

also designed a form of fixed and flashing light in which a fixed light, varied by flashes was produced by placing panels of straight refracting prisms in a vertical position on a revolving carriage outside the fixed light apparatus. The revolution of the upright prisms periodically increased the power of the beam by condensation of the rays emergent from the fixed apparatus, in the horizontal plane.

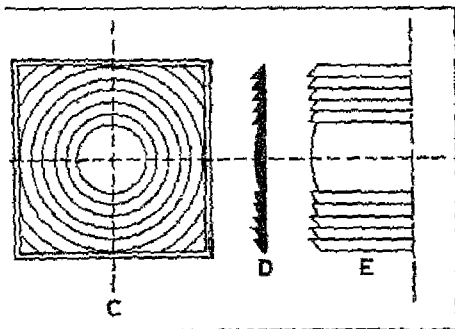
The lens segments in Fresnel's early apparatus were of polygonal form instead of cylindrical but subsequently manufacturers succeeded in grinding glass in cylindrical rings of the form

now used. The first apparatus of this description was made by the Cooksons of Newcastle in 1836 at the suggestion of Adam Stevenson, and erected at Inchkeith, Fifeshire. The first dioptric apparatus erected by the Trinity House to show a fixed light was the one formerly at Start Point in Devonshire. It was constructed in 1836.

Azimuthal Condensing Prism—To condense the rays from a fixed-light apparatus in certain azimuths, T. Stevenson devised in 1850 his azimuthal condensing prisms which have been variously applied in the construction of optical apparatus as, for instance, for the strengthening of coloured sectors. Applications of this system will be referred to subsequently (see fig 10).

Dioptric Mirror—An important improvement in lighthouse optical work was the invention of the dioptric mirror by (Sir) J. T. Chance in 1862. This mirror is a modification of a spherical mirror devised by T. Stevenson in 1850, in which double reflection from the internal surfaces of a catadioptric prism was employed. Chance generated the zones of prisms round the vertical axis, separated the elements and set them at increasing radii, thus producing an instrument of practical utility. By the use of the dioptric mirror rays of light which would otherwise be lost are reflected back through the focus of the source of light and are refracted or reflected with the main rays. This form of mirror is still in general use and is constructed for vertical angles up to 100°.

Spherical Lens—Mr C. A. Stevenson devised in 1883 annular lens panels consisting of lens elements spherical in the horizontal and vertical planes, and these, with equiangular prisms, have been used in a number of apparatus for Scottish lighthouses.



DEVELOPMENT OF FRESNEL'S LENSES

Fig. 8. a, d, elevation and section of Fresnel's lens; c, e, section and half elevation of Fresnel's lens belt.

light plain silvered mirrors on which by a system of lenses. At a subsequent date so placed in the lower part of the optic mounted on rollers and revolved by clockwork. The first combination of dioptric and catadioptric design (fig. 9). Fresnel also designed for use a dioptric lens with catoptric mirrors, which was the first of its kind installed. This combination is geometrically perfect, on account of the great loss of light

Optical Glass for Lighthouses

The manufacture of optical glass was made in France at St Gobain and Fraconnoire works which have long been celebrated for the high quality of optical glass they produce. The early dioptric lights erected in the United Kingdom some 13 in all were made by the Cooksons who were instructed by L'Esprit Frenel, the brother of Augustin. At first they tried to mould the lens and then to grind it out of one thick sheet of glass. The manufacture of lenses was abandoned by Cooksons' successors in 1825 and in 1829 Chance Bros and Co. of Birmingham began to make optical glass assisted by M. Fabouret, a French expert who had been a colleague of Augustin Frenel himself. The first light made by the firm was shown at the Great Exhibition of 1851 since when numerous dioptric apparatus have been constructed by Messrs Chance who are at this time the only manufacturers of lighthouse glass in the United Kingdom. Most of the glass used for apparatus constructed in France is manufactured at St Gobain. Some glass used by German constructors is made at Rathenau in Prussia and Goslar in the Harz. The glass generally employed for lighthouse optics has a mean refractive index of $\mu = 1.51$ the corresponding critical angle being $41^{\circ} 30'$. Messrs Chance have used dense flint glass for the upper and lower refracting rings of high-angle lenses (up to 97° vertical angle) and for dioptric mirrors in certain cases. This glass has a value of $\mu = 1.62$ with critical angle $36^{\circ} 5'$. The use of refracting elements for an angle greater than 60° aperture is attended by any advantage over reflecting prisms.

TYPES OF LIGHTS

Occulting Lights—During the last quarter of the 19th century the disadvantages of fixed lights became more and more

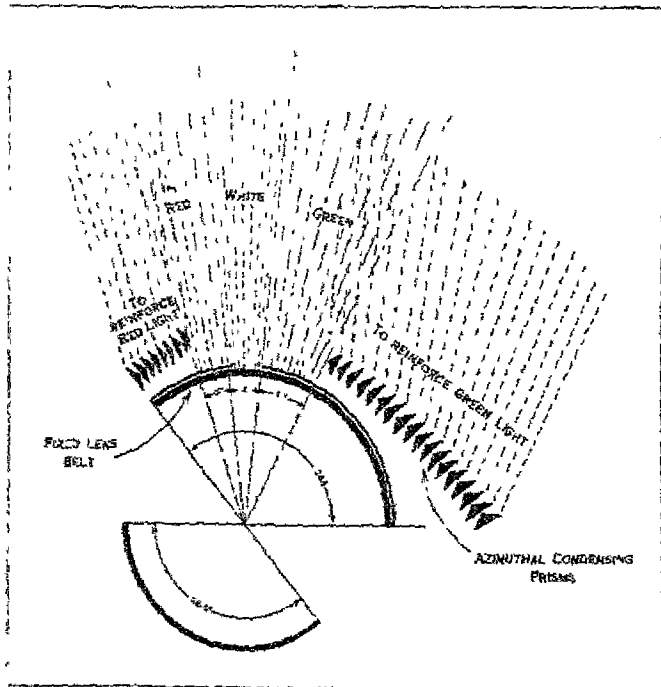


FIG. 13.—WOODMAN POINT DIRECTION-LIGHT FREMANTLE, WEST AUSTRALIA
The diagram is a plan of the optical apparatus at the level of the focal plane. The light is condensed and directed over the channel, the dangers at the sides of which are covered by the red and green lights.

apparent and they have fallen into disuse except in the case of the less important harbour and river lights. The necessity of providing a distinctive characteristic has led to the conversion of many of the fixed-light apparatus of earlier years into occulting lights, or to their supersession by more modern and powerful flashing-apparatus. The occultation of a light is produced either by a cylindrical screen lowered and raised around the burner; or by a revolving screen; or, when some form of gas burner is used, by intermittently extinguishing the light itself. Varying charac-

See W. M. Hampson, *Trans. Optical Soc.*, vol. XXIX (1928)

ter, comprising one or more by means of such contrivances employed in cases where it is desirable to occultations in two or more different sectors marking shoals, metal blacked and arranged vertically the laths of a venetian blind, and

Leading Lights.—In the case

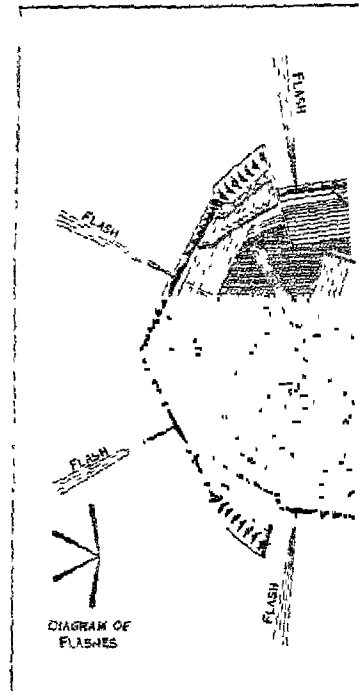


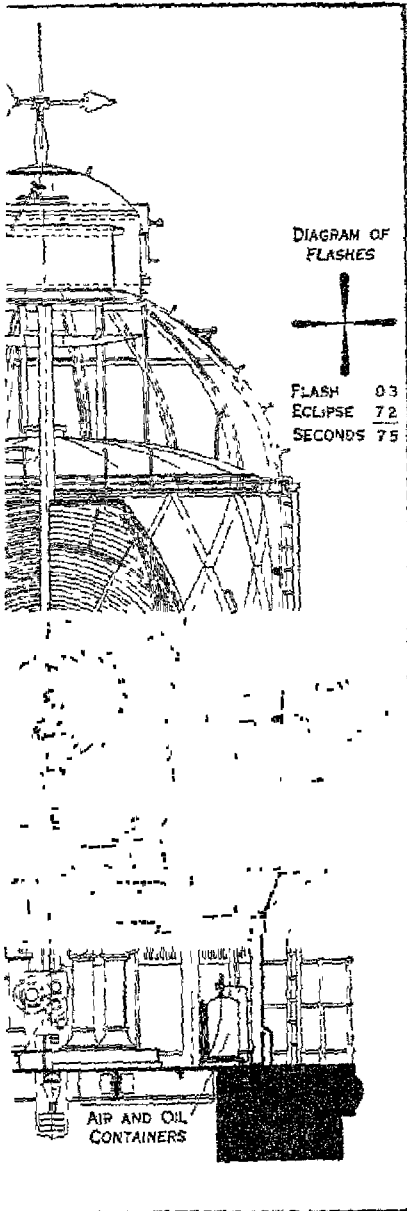
FIG. 11.—FLAMBOROUGH
Sectional plan of the first-order optical apparatus shows 4 flashes every 15 seconds

lead through a narrow channel desirable to employ a revolving apparatus used in such cases, generally fitted with a typical apparatus of this description. A typical apparatus of this description at Point, Fremantle West Australia light covers the fairway, and is marked with red and green-light marking devices. A good example of this is that at Suzac lighthouse (France), which consists of an annular lens 500 mm focal length and 157° vertical, with a lens which throws a red beam of about 50,000 candle-power, over a narrow channel. Incandescent petroleum-vapour lenses of this type can only be used in a parabolic section and are also used in a direction light. For leading lights are employed to indicate a channel or between dangers the front of a good lead, the front of a lower elevation than the rear.

Coloured Lights.—Colour is used to distinguish, entailing as it does a loss of power of the light. It is however used for differentiating sectors over different purposes. Alternating colours of light commenced on account of the use of bright rays by the atmosphere has been employed, as in the White beams have been approximated by constructing the lens and prism at a larger angle than those for the white by the red colouring of the glass.

ty of the corresponding white light. of green light is 25%. When red or n conjunction with a white light from uld if it is practicable be reinforced lensing prisms or other means, to approximately the same intensity as introduction of group-flashing charac- sng colour as a means of distinction ad. In situations such as a river fair- of buoy or beacon lights have to be y characteristics, coloured lights are, ed

--One of the most useful distinctions wo or more flashes separated by short group being succeeded by a longer



(KARACHI) APPARATUS AND LANTERN
focal distance, it is rotated on a mercury oil burner at its focus. The right hand half of hand as a vertical section

more flashes of, say, half-second dura- ter at intervals of about 2 seconds and of, say, 10 seconds. In 1874 Dr John improvement of arranging the lenses t together with their panels of reflect- setting them at an angle to produce the ic. The first apparatus of this type ow in use at Tampico, Mexico (triple- Basset light-house Ceylon (double-

flashing. A modification of the system consists in grouping two or more lenses together and filling the remaining angle in azimuth by a reinforcing mirror. A sectional plan of the quadruple-flashing first-order apparatus at Flamborough, Yorkshire is shown in fig 11 on page 92

Hyper-radial Apparatus.—In 1855 Messrs Barbier of Paris constructed the first hyper-radial apparatus (1,530 mm focal distance) to the design of D and C Stevenson. Apparatus of similar focal distance were subsequently established at a number of other lighthouses. That at Manora Point, Karachi, India (1908) is illustrated in fig 12. The introduction of incandescent oil burners and electric lamps of focal compactness and high intrinsic brightness has rendered unnecessary the provision of optics of such large dimensions.

Fixed and Flashing Lights.—The use of these lights which show a fixed beam varied at intervals by more powerful flashes is undesirable, though a large number were constructed in the earlier years of dioptric illumination and some are still in existence. In certain conditions of the atmosphere it is possible for the fixed-light of low power to be entirely obscured while the flashes are visible, thus the true characteristic of the light is vitiated

Screens and Cuts.—Screens of coloured glass, intended to distinguish the light in particular azimuths and of sheet iron, when it is desired to "cut off" the light sharply on any angle, should be fixed as far from the centre of the light as possible in order to reduce commingling in the first case, and the escape in the second case of the light rays due to divergence. These screens are usually attached to the lantern framing

Divergence.—A dioptric apparatus designed to bend all incident rays of light from the light source in a horizontal direction would, if the flame could be a point, have the effect of projecting a band or zone of light (in the case of a fixed apparatus) and a cylinder of light rays (in the case of a flashing light) towards the horizon. Under such conditions the mariner in the near distance would receive no light as the rays would pass above the level of his eye and be visible only on the horizon. In practice this does not occur, sufficient natural divergence being produced ordinarily owing to the magnitude of the flame. When the electric arc or an incandescent electric-lamp of small focal diameter is employed it is sometimes necessary to design the prisms so as to produce artificial divergence. The measure of the natural horizontal divergence for any point of the lens is twice the angle whose tangent is the ratio of the radius of the illuminating source to the distance of the point from the geometrical centre of the lens and for calculating the vertical divergence the vertical dimensions of the light source above and below the focal plane, must in turn be substituted for the radius, and the sum of the angles thus obtained is the total divergence. In fixed dioptric-lights there is, of course, no divergence in the horizontal plane. In revolving lights the horizontal divergence is a matter of considerable importance, determining as it does the duration of flash, *i.e.*, the length of time the flash is visible to the mariner

Feux-Éclairs or Quick-flashing Lights.—One of the most important developments in lighthouse illuminating apparatus was in the direction of reducing the length of flash, initiated by the French lighthouse authorities about 1891 and shortly afterwards followed in other parts of the world. The early *feux-éclairs*, designed by the French engineers and others, had usually a flash of $\frac{1}{10}$ to $\frac{1}{2}$ sec duration. As a result of experiments carried out in France in 1903-04, $\frac{2}{10}$ sec. is now generally adopted as the minimum duration for white flashing lights. If shorter flashes are used it is found that the reduction in duration is attended by a corresponding, but not proportionate, diminution in effective intensity. In the case of many electric flashing-lights the duration is of necessity reduced but the greater initial intensity of the flash permits this loss without serious detriment to efficiency. Red or green requires a considerably greater duration than do white flashes. The intervals between the flashes in single-flashing lights of this character are also small, usually $2\frac{1}{2}$ to 5 seconds. In group-flashing lights the intervals between the flashes are about 2 sec or even less, with periods of 7 to 15 sec between the

The usual type of apparatus enables a higher intensity of beam to be obtained by reason of the greater rate of condensation of light, the employment of beams of greater angular breadth than those formerly used being possible with a slower rotatory velocity. It has been found that short flashes are inefficient for taking bearings, but the flash of a light in this respect does not seem to depend so much upon the actual length of the flash as upon its frequent recurrence at short intervals.

It was formerly impracticable to revolve an optical apparatus which is mounting, sometimes weighing as much as 7 tons, at the higher rate of speed required for *four-clocks* by means of the old system of roller carriages though for a certain number of small quick-revolving lights ball bearings have been successfully adopted. It has therefore become almost the universal practice to carry the rotating portions of the apparatus upon a mercury float. This application of mercury rotation was the invention of G. Bourneles. The arrangement consists of an annular cast-iron trough containing mercury with a similar but slightly smaller annular float immersed in it and displacing a volume of the liquid metal whose weight is equal to that of the apparatus supported. In all cases provision is made for lowering the mercury bath or raising the float and apparatus for examination. An example of a mercury float is shown in Plate II, fig. 4.

Multiform and Twin Apparatus.—In order to double the power to be obtained from a single apparatus at stations where lights of exceptionally high intensity are desired, the expedient of superimposing one complete lens apparatus on another has sometimes been adopted, as at the Bishop rock (fig. 4), Hartland point (Plate II) and at the Fastnet lighthouse in Ireland (Plate II.) Ternum and quadrum apparatus have also been erected in Ireland. The adoption of the multiform system involves the use of lanterns of increased height. Another method of doubling the power of a light is by mounting two complete and distinct optics side by side on the same revolving table. This expedient has been frequently adopted by French designers.

"Orders" of Apparatus.—Augustin Fresnel divided his dioptric lenses into "orders" or sizes depending on their focal distance. This division is still used, although two additional "orders" known as 'small third order' and "hyper-radial" respectively are in ordinary use. The following table gives the focal distance of the several sizes—

TABLE II.

Order	Focal distance, mm.
Hyper-radial	1330
1st order	630
2nd "	700
3rd "	500
Small 3rd order	375
4th order	320
5th "	187.5
6th "	150

Lenses of smaller focal distance are also made for buoy and beacon lights.

Light Intensities.—The powers of lighthouse lights given in the Admiralty *Lists of Lights* are expressed in terms of "lighthouse units" (one lighthouse unit = 1,000 pentane candles). In France the "*brûle décimale*" and in America the "American candle" are identical with the standard pentane candle. The Helmer unit used in Germany, Holland, etc., is 0.9 of the pentane candle. The intensity of a beam of light emitted from a dioptric apparatus depends upon the brilliancy or intrinsic brightness of the source of light and the projected area of the optical panel, in the case of a revolving light or of the pillar of light in the case of an optic of fixed section. The theoretical value of the intensity can be computed from the formula $I = \frac{1}{2}A$. Where I is the total intensity of the emergent beam; $\frac{1}{2}$ is the mean intrinsic brightness obtained by dividing the total light intensity of the source by the area of its projected image in various planes and A the projected area

of the source (or of the emitting apparatus) or the height or area of the glass multiplied by the breadth of the illuminating source (for optics of fixed section).

In practice owing to the inequalities of the illuminating source and the losses due to refraction, reflection and absorption experienced by the rays in their passage through the optical elements and the lantern glazing, the actual value is found to be about 50% of the theoretical value. By the addition of a mirror the intensity of that part of the panel reinforced by it is increased by about 30%. Deductions must be made in the case of coloured lights (see paragraph on 'coloured lights' p. 92).

The mathematical theory of optical apparatus for lighthouses and formulae for the calculations of profiles will be found in the works of the Stevensons, Chance, Allard, Reynaud, Hopkinson, Ribiere and others.

ILLUMINANTS

The earliest form of illuminant used for lighthouses was a fire of coal or wood set in a brazier or grate erected on top of the lighthouse tower. Until the end of the 18th and even into the 19th century this primitive illuminant continued to be almost the only one in use. The coal fire at the Isle of May light continued until 1810 and that at St. Bees lighthouse in Cumberland until 1823. Fires are stated to have been used on the two towers of Nidingen, in the Kattegat until 1846. Smeaton was the first to use any form of illuminant other than coal fires. He placed within the lantern of his Eddystone lighthouse a chandelier holding 24 tallow candles each of which weighed $\frac{3}{4}$ lb. and emitted a light of 23 candle power. The aggregate illuminating power was 672 candles and the consumption at the rate of 3.4 lb. per hour.

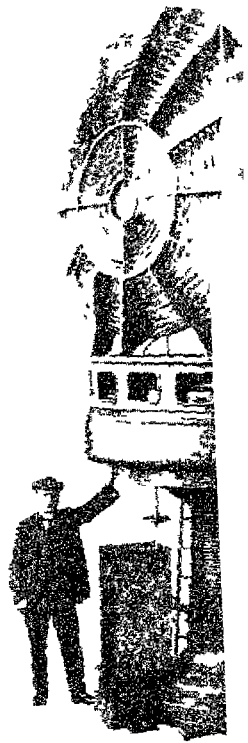
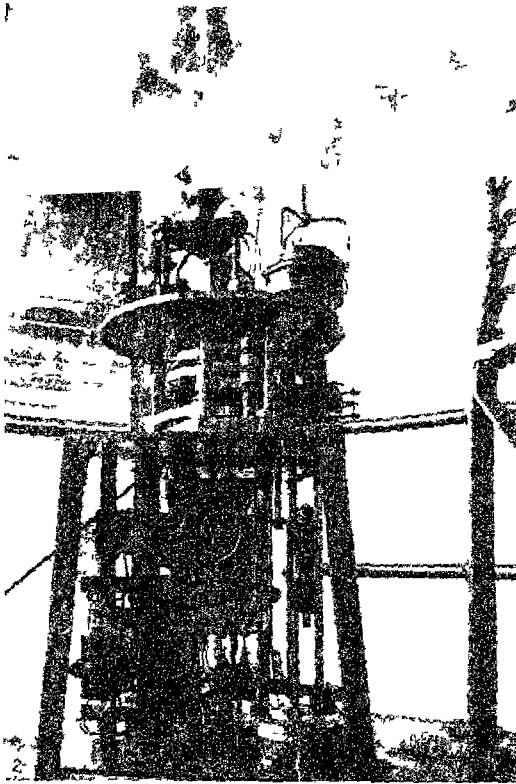
Oil.—Oil lamps with flat wicks were used in the Liverpool lighthouses as early as 1763. Argand between 1780 and 1783 perfected his cylindrical-wick lamp which provides a central current of air through the burner, thus allowing the more perfect combustion of the gas issuing from the wick. The principle of the multiple-wick burner was devised by Count Rumford. Fresnel produced burners having two, three and four concentric wicks. Sperm oil was used in English lighthouses until 1816 but about that year the much cheaper colza oil was employed generally. Olive, lard, and cocoanut oils have also been used for lighthouse purposes in various parts of the world.

The introduction of mineral oil, costing a mere fraction of the expensive animal and vegetable oils, revolutionised the illumination of lighthouses. It was not until 1868 that a burner was devised which successfully consumed hydro-carbon oils. This was a multiple wick burner, invented by Captain Doty, which was quickly taken into use by lighthouse authorities. The "Doty" burner and other patterns involving the same principle, remained practically the only oil burners in lighthouse use until the last few years of the 19th century.

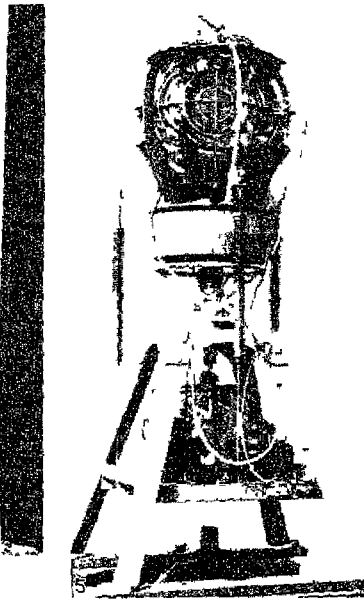
Coal Gas.—Coal gas was introduced in 1837 at the inner pier light of Troon (Ayrshire) and in 1847 it was in use at the Heugh lighthouse (West Hartlepool). In 1878 cannel-coal gas was adopted for the Galley Head lighthouse, with 108-jet Wigham burners. Sir James Douglass introduced gas burners consisting of concentric rings, two to ten in number, perforated on the upper edges.

The invention of the Weistach mantle placed at the disposal of the lighthouse authorities the means of producing a light of high intensity combined with focal compactness. For lighthouse purposes gaseous illuminants other than coal-gas are as a rule more convenient and economical, and give better results with incandescent mantles. Mantles have, however, been used with ordinary coal-gas in instances where a local supply of suitable types is available.

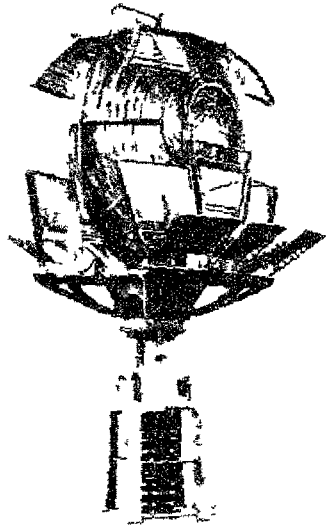
Incandescent Mineral-oil Burners.—Incandescent lighting with high-flash mineral oil was first introduced by the French lighthouse service in 1898 at L'Île Penfret lighthouse. The incandescent burners now in use in lighthouse services all the world over are all made on the same principle, but differ in details. The principle consists in injecting the liquid petroleum under pressure into a vaporizer where it is heated by subsidiary jets and on-



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RS AND COMPANY, LTD (5, 6) THE A. B. A. COMPANY (7) LORANCE BROTHERS AND COMPANY AND TRINITY HOUSE

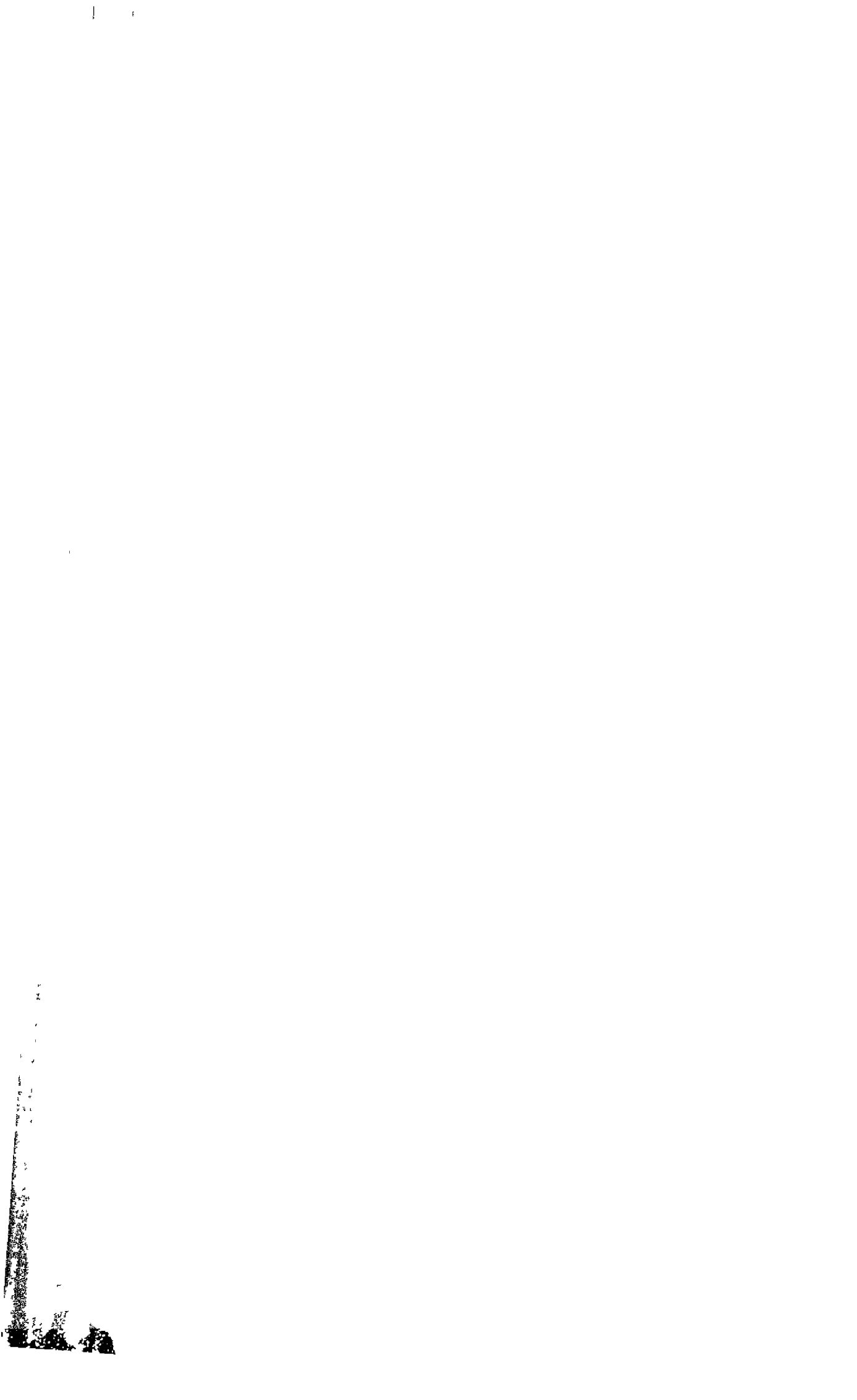
OPTICAL APPARATUS FOR LIGHTHOUSE ILLUMINATION

Fastnet Lighthouse, Ireland (1904),
 ry 5 secs. An incandescent oil mantle-
 of the two superimposed optics

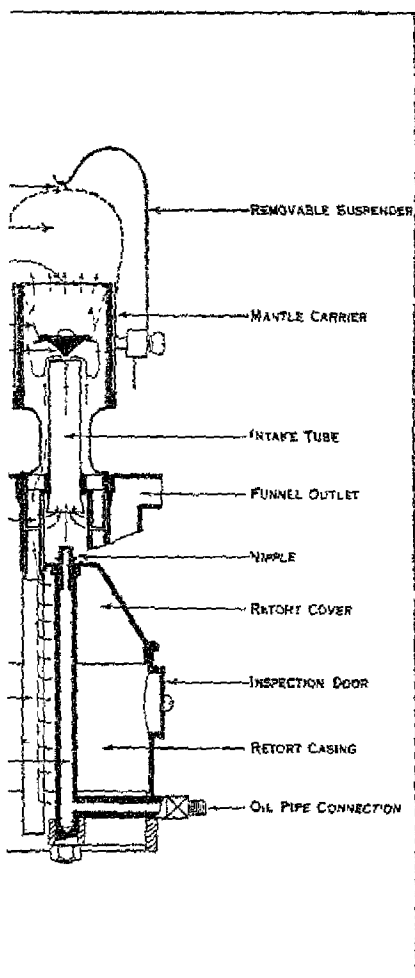
set (1928). An incandescent gas-filled
 us of one of the fixed optical apparatus,
 and stand-by acetylene burner (right).
 de a flashing device. At left are fixed
 ght, portion of dioptric mirror. Since
 tallied in 1928 the two lighthouses are

(a first order apparatus of four panels,
 trough containing mercury, in which the

- float carrying the rotating apparatus is immer
 examination by rotating it on the central screw
- 4 Great Basses Rock Lighthouse, Ceylon. This first-
 on a roller carriage, made in 1872, is an
 revolving lights employed before the introdu
 and wide lens-panels. Rotating mechanism see
 5. Optical apparatus in Spurn Lightvesse), with cor
 - 6 Apparatus for aerial lighthouse at Cranbrook, Ke
 7. Third-order biform apparatus of 6 panels and
 Lighthouse, North Devon (1927), which sh
 secs. At focus of each optic is gas-filled inc
 of 3 K.W.



apour issues from a nozzle and driven by a member in the head of the burner here the sole gas for the incandescence of the small proportion of the gas is diverted to a small reservoir of compressed air—hand-pump—is used for providing the



" PETROLEUM-VAPOUR BURNER

action. On first ignition the vapourizer is heated to the required temperature. The apparatus in which ordinary multiple-burners are employed is increased more than tenfold in size. The mantles are of the soft autoform type which has taken the place of the hard mantles of the older forms of burner. Particular use are as follows —

Height of burner	Intrinsic brightness per sq cm of projected area in standard candles	Consumption of oil—pints per hour
3	53	0.75
2	53	1.25
1	50	2.25
0	48	3.25

gas system introduced in the '70s of the century. The use of ordinary oil-gas

burners is a disadvantage which has led to its gradual supersession by acetylene or other forms of oil-gas (see below).

An oil-gas, known by the name of its inventor, Blau, of Augsburg has been employed to some extent, particularly in Germany and Holland, since about 1906 as a substitute for ordinary oil-gas. It is produced in retorts in much the same manner as the older variety but at a lower temperature (550°–600° C) and can be compressed to 100 atmospheres at which pressure the hydrocarbons are liquefied. This liquid gas is stored and transported in cylinders weighing about 130 lb and is expanded from them at about 9 atmospheres pressure into the body of the buoy or the receivers at the beacon or lighthouse. When it is used with an incandescent mantle of large size an intrinsic brightness of about 25 candle-power per sq cm, or about 40% more than ordinary oil-gas, is obtainable.

Another variety of compressed oil-gas known as B B T, introduced in France about 1924, has also been used for buoy and beacon lighting. It does not liquefy at 140 atmospheres, at which pressure it is transported in containers each weighing about 2 cwt. It is burnt only in conjunction with an incandescent mantle and the intrinsic brightness obtained is slightly higher than that realized with Blau gas.

Acetylene.—Acetylene (C₂H₂) was first experimented with for buoy and beacon lighting about 1806, open-flame burners being used. An incandescent-mantle burner consuming acetylene was used at the Chassiron lighthouse (France) in 1902. Oil-gas, enriched by the addition of 20% of acetylene, was for a time used in Germany and Holland for buoy and beacon lighting. It was not, however, until about 1906, when the difficulties associated with its employment had been overcome by the introduction of dissolved acetylene, that the gas came into general use for coast lighting. Acetylene in this form is stored at a pressure of 10 to 15 atmospheres in cylinders, usually weighing about 2 cwt., filled with a porous material and charged with acetone in the presence of which the gas is dissolved. Owing to the higher intrinsic brightness of the flame and the convenient transport of the gas it is now in common use throughout the world not only for buoy and beacon lighting but also for many coast lights of secondary importance and unattended revolving lights, mantle burners being sometimes employed.

Acetylene generated on the spot on the carbide-to-water principle is nevertheless still used by some lighthouse authorities, for unattended lights. Comparatively frequent attention in renewing the charge is, however, required in these cases. The intrinsic brightness obtained in some incandescent-acetylene burners is about equal to that of autoform-mantle petroleum-vapour burners.

Electricity.—Electricity for lighthouse illumination was first experimented with in England in 1838 at South Foreland by Trinity House. This was followed by its adoption at Dungeness in 1862, and at Souther point on the coast of Durham in 1871. Both these installations were later abandoned, the former in 1874 and the latter in 1923 when a first-order biform flashing-light with incandescent oil-burner replaced it. Electricity was installed at St. Catherine's in the Isle of Wight in 1888 and was also in use at the Isle of May lighthouse at the mouth of the Firth of Forth from 1886 to 1924. Arc lamps formerly provided the illuminant in all large apparatus, but the development of high power, gas-filled, electric-flament lamps has caused their supersession for lighthouse use. A special type of lamp with highly concentrated filament was evolved by the Dutch lighthouse service in 1918 and has been made in sizes up to 4 kw. (Some experimental 4 kw. lamps under trial in Holland [1928] have an intrinsic brightness of about 1800 candles/cm². Lamps of 20 kw have been used experimentally for aerodrome lighting.)

Economies have been effected by the introduction of these lamps combined with automatic electric equipment, and where in addition a local supply of current is available the reduction of maintenance charges at electric stations is considerable. For instance at the South Foreland, which has been a permanent electric station since 1872, an engineer and four keepers were formerly required

the lantern room of the establishment was reduced to one keeper. Lighters in charge were brought from Dover to the lighthouse. The oil or machine revolving the lens is wound electrically and a lamp-changer automatically replaces a lamp when the filament of the one in service burns out or brings a standard acetylene burner into focus if the electric supply fails. A watchman in the keeper's quarters warns him if any derangement takes place. The filament lamp is 5000 c.p. 50 v. and so arranged has a mean intrinsic brightness of 1000 candle-power. A somewhat similar installation has been substituted for the arc lamp at the Lizard (1926) but in this case the current is generated at the lighthouse, the personnel being reduced from five to three. At other important coast lighthouses including Portland Bessines and Harland point (Plate II), in order to ensure a watch being kept during fog both in the engine room and the lantern, electric light has been introduced in place of the petroleum-vapour lamps and the apparatus in the lantern made automatic. The electric current is generated by semi-diesel engines direct-coupled to the dynamos. Similar installations have been put into four new Trinity House light-vessels (1926-27).

Electricity was used at the old south lighthouse at La Hève (France) in 1863, and in 1910 there were 13 important electric lights on the French coast. Arc lamps were employed and generating plant usually steam driven, was provided at each station. The high cost of maintaining such stations prevented any extension of their use on a large scale in France as in other countries; but since 1920 the conversion of some of the then existing electric stations to incandescent-filament lighting has been effected. At other stations too where current from public supplies is available, electricity has been introduced. Blau gas is commonly employed for the stand-by burners in French electric lighthouses. In Holland several electric-arc and petroleum-vapour lights have been superseded by electric filament lamps since 1913. At Ameland, a generating set is provided and at Kijkduin, current is taken from the public supply.

MISCELLANEOUS LIGHTHOUSE EQUIPMENT

Modern lighthouse lanterns usually consist of a cast-iron or steel pedestal, cylindrical in plan, on which is erected the lantern glazing surmounted by a domed roof and ventilator (fig. 12). Adequate ventilation is of great importance, and is provided by means of ventilators in the pedestal and a large ventilating dome or cowl in the roof. The astragals carrying the glazing are of wrought steel or gun-metal. They are frequently arranged helically or diagonally, thus causing a minimum of obstruction to the light rays in any vertical section and affording greater rigidity to the structure. The glazing is usually $\frac{1}{2}$ in thick plate-glass curved to the radius of the lantern. In situations of great exposure the thickness is increased. Lantern roofs are of sheet steel or copper secured to steel, sunmetal or cast-iron rafter frames. At certain lighthouses it is found necessary to erect a grille or network outside the lantern to prevent the numerous sea birds, attracted by the light, from breaking the glazing by impact. Lanterns vary in diameter from 5 to 15 ft or more, according to the size of the optical apparatus. For first-order apparatus a diameter of 14 ft is usual and 12 ft for second-order.

The lantern, gallery handrails and principal metallic structures in a lighthouse should be connected to a copper lightning conductor (p. 9.) carried to a point below low water or terminating in an earth plate embedded in wet ground.

Revolving-light apparatus are rotated by clockwork mechanism actuated by weights or spring driven. The clocks are fitted with speed governors and also warning apparatus to indicate when re-winding is required. Where current is available small electric motors are often employed either for automatic re-winding of the clockwork or for driving the rotating mechanism direct. In modern gas-fit apparatus the pressure of the gas is sometimes made use of to revolve the lens table.

At rock and other isolated stations, accommodation for the keepers is usually contained in the towers. In the case of land

lighthouses developing a tower in close proximity to the shore. The watch room should be situated immediately under the lantern floor. Oil is generally stored in galvanized steel tanks.

UNWATCHED AND UNATTENDED LIGHTS

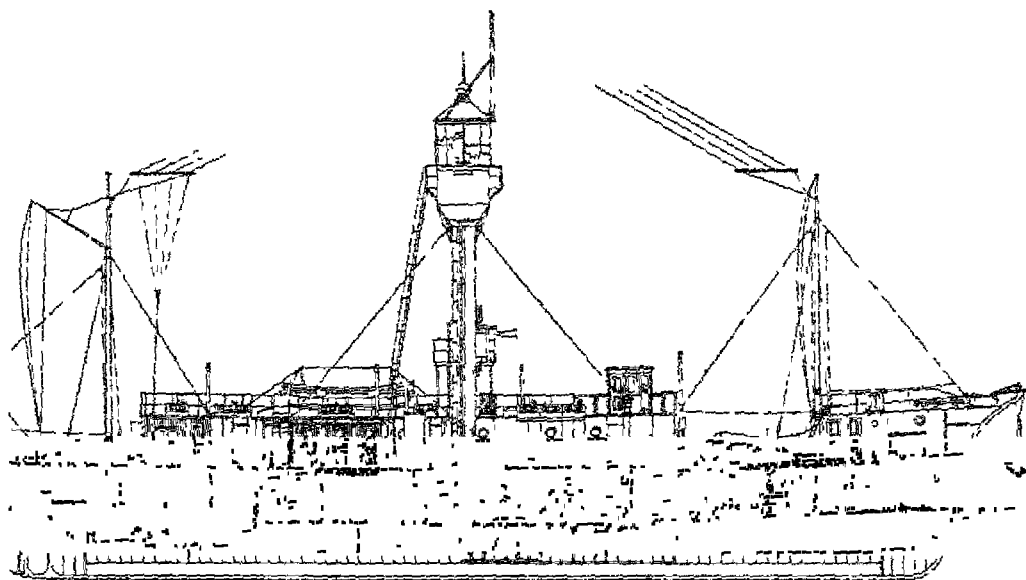
Electric.—Since 1834, when an iron beacon lighted by an incandescent-electric lamp supplied with current from a secondary battery was erected on a tidal rock near Cadiz, various forms of electric unattended lights have been experimented with. In 1928 many such lights were in permanent use where current could be obtained from a local supply circuit. Storage batteries, small automatic generating sets and stand-by gas burners are alternatively provided to guard against the failure of the main supply. Automatic devices are also fitted for changing one lamp for another if the lamp in focus should fail, and for switching in the stand-by apparatus when necessary. Both revolving and fixed optics are used. In the former case the optic is rotated by a small electric motor and in the latter some form of automatic interrupter produces the flashing characteristic. In cases where the optic is too small for a burner changer to be accommodated two lenses are employed one superimposed on the other. In one of the lenses is focussed the electric lamp in normal use and in the other the stand-by gas or electric lamp. An example of secondary lights formerly attended and now converted to electric, is at Burnham in Somerset where two leading lights over $\frac{1}{2}$ m. apart were so altered in 1928, and are now unwatched at night. In this case the optics (see Plate II) are of fixed section and the automatic features include a flashing device for giving the lights their respective characteristics.

Other Forms of Beacon Lighting.—Among other systems of unattended beacon lighting adopted in lighthouse services since about 1830 but now little used may be mentioned the Lindberg light, a Swedish invention employing a volatile spirit, the Benson-Lee lamp having a carbon-tipped wick, the French permanent-wick lamp, and the Wigham lamp in which a flat wick immersed in petroleum travelled over a horizontal roller so that the petroleum was volatilised from a constantly renewed surface. Oil-gas mostly in its modified form is still largely employed.

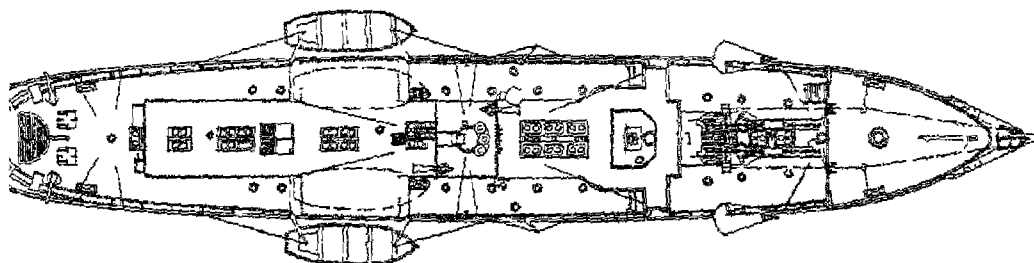
Acetylene Lights.—The gas is provided either by an automatic generator or else in the form of compressed acetylene dissolved in acetone. In order to reduce the consumption and at the same time give a distinctive characteristic to the light the gas is usually passed through an automatic flashing mechanism which works continuously until the supply is exhausted. Waste of gas during daylight is sometimes obviated by using a sun-valve, which is a device to turn off the gas at daybreak and turn it on at dusk. Sun-valves depend for their automatic action on the differential expansion of two distinct metals under the influence of light rays or on the difference in the absorption of light rays by black and bright bodies respectively. The movement of a lever arm, brought about by a small movement of the light-sensitive element actuates a valve which opens and closes the gas supply. Acetylene in unattended lights is burnt either as an open flame or in conjunction with a mantle.

The "Aga" system of acetylene lighting, developed in Sweden about 1904 has been extensively used both in that and other countries for all classes of unattended lights, including buoys. It was first adopted in England in 1913. Other systems embodying similar principles are also in use. The "Dalen" incandescent mantle burner embodies a mix-flasher which automatically controls the character of the light and regulates the mixing of air and gas for consumption in an inverted soft-mantle burner.

In some unattended lights with acetylene illumination the lenses are rotated by a gas pump as the gas passes to the mixer and burner, the lens table moving on ball bearings or a mercury float; the sun-valve automatically controls the duration of lighting; a pilot jet serves to re-ignite the main burner at sunset; and an automatic changer provides for the replacement of a broken mantle. Incandescent mantle burners and acetylene equipment have also been installed in a number of lighthouses of secondary importance, formerly attended by keepers, and now converted to unwatched or semi-watched lights. Among such an



LONGITUDINAL SECTION



DECK PLAN

NEER, NETHERLANDS LIGHT SERVICE

AS LIGHT-VESSEL (NETHERLANDS LIGHT SERVICE). A SELF-PROPELLED LIGHT-VESSEL MOORED IN THE NORTH SEA
ES FROM THE HOOK OF HOLLAND THE LIGHT IS ELECTRIC, OF ABOUT 270,000 C P. THE SHIP HAS THREE FOG-SIGNALS,
ID-AIR SIREN, A SUBMARINE OSCILLATOR AND A WIRELESS FOG-SIGNAL, THE TWO LAST BEING SYNCHRONISED

s at the Rock (Liverpool), Great Orme all (Carnarvonshire), Berry Head (S id (Scilly Isles); East Usk (Mon.); and embrookeshire) The Menai lighthouse has pen-flame acetylene equipment. In some nption of gas is large, acetylene generators er system have been installed, as at the urch lights on the coast of Northumber-t-order leading lights at Hurst (Plate I, l opposite the Isle of Wight
ssolved form is at present the best and nant for entirely unwatched lights when available Its use has enabled many un-established and maintained at a compara-sions where a light attended by keepers e as, for example, on some parts of the

LIGHT-VESSELS

essel established in English waters was re in 1732 The early lightships were of l lanterns of primitive construction sus-arms Modern light-vessels are usually of are of various dimensions The following uts in the Trinity House service.

	30 to 114 ft.
	20 " 30 "
	13 " 15 1/2 "
	200 , 500 tons

employed at outside and exposed stations, g stationed in sheltered positions and in

estuaries The moorings usually consist of 3-ton mushroom anchors and 1 1/2" or 1 3/8" open-link cables The lanterns used in some of the older vessels are 8 ft in diameter surrounding the mast upon which they are hoisted at night and lowered to the deck level during the day. Fixed lanterns mounted on hollow steel masts are now gradually displacing the older type. The first English light-vessel so equipped was constructed in 1904.

Self-propelled light-vessels, some of which are of much larger dimensions than any British light-vessel, are employed at the majority of stations in the United States, and there are a few in exposed situations in other countries including France, Sweden Holland (fig 14) and Germany.

Until about 1895 the illuminating apparatus used in light vessels was almost exclusively of catoptric form consisting for the most part of 21 in silvered paraboloidal reflectors, having mineral-oil burners in focus, hung in gimbals to preserve the horizontal direction of the beam. In a few cases incandescent mantle burners or electric-filament lamps have been substituted for the old wick-burners in catoptric apparatus. Dioptric apparatus is now usually provided in new lightships, not only in Britain but in other countries also. The French lighthouse service in 1896 devised the first dioptric revolving light for a light-vessel This ship the Talais,¹ was lit by an incandescent oil-gas burner A much larger vessel, the Sandettié, of 342 tons displacement was completed in 1902 The new type of floating light wa afterwards adopted by other lighthouse authorities, and many vessels constructed on the lines of the Sandettié were buil during the first decade of the 20th century In England the

¹The Talais and another similar vessel constructed in 1899 were late converted into unattended light

Most of these vessels were fitted with revolving dioptric lenses suspended in gimbals above the lens table and counterbalanced by a heavy pendulum weight. The apparatus was mounted on ball bearings in some cases and on a mercury float in others, the lenses being revolved by clockwork or gas. Another method of suspending the dioptric apparatus has recently been developed, the design being a Swedish invention. This device, known as the constant-level table, has been fitted in several vessels, including that at the Barrow Deep in the approaches to the Thames. In this vessel the luminant is directly employed with a mantle. The lens is mounted on a table made to revolve on ball bearings by the gas or its way to the burner. The lens table is balanced near the centre of gravity on a pivot in the lantern, and connected by three vertical pull-wires to a pivoted counter-balance weight placed in the hull or the ship at the rolling centre of the vessel which controls the movement of the upper table (Plate II, fig. 5). As the motion imparted to the lower balance weight is small, the springing of the lens table is less than with the former arrangement of pendulum and gimbal suspension. In the older vessels oil-gas illumination was employed but this has been replaced in the later ships by incandescent-acetylene or incandescent-oil burners and high-powered gas-filled electric lamps. Four light-vessels fitted with such electric lights and dioptric apparatus were in service on English stations in 1928.

An experimental electric-light installation on board a Mersey light-vessel in 1856 proved unsuccessful.

Fog signals, which are provided on modern light-vessels, are generally in the form of sirens or diaphones worked by compressed air. The compressors are driven by steam or oil engines in the older installations and by semi-diesel engines in the more modern vessels.

Unattended Light-vessels.—In 1881 an unattended light-vessel illuminated by Pintsch's oil-gas was constructed for the Clyde. The light was occulting and the vessel carried a gas-holder containing a supply of gas under a pressure of six atmospheres sufficient to maintain the light for three months. Bells are often fitted on this class of light-vessel, the clappers being swung by the roll of the ship or worked by a gas-operated machine.

The improvements made in recent years in the design and construction of unwatched lights and their proved reliability have made it possible for many attended light-ships in positions of secondary importance to be replaced by unwatched vessels. Large economies, both in the cost of construction and of maintenance, have thereby been effected. These unattended vessels range in size from small boats to large vessels and are fitted with dioptric apparatus and acetylene or Blau-gas lighting.

Communication Between Light-vessels and the Shore.—As far back as 1886 experiments were instituted at the Sunk light-vessel off the coast of Essex, with the object of providing telephonic communication with the shore by means of a submarine cable. In spite of great difficulties experienced in maintaining the cables several light-vessels were ultimately equipped with this means of communication, and cables were also laid to many pile lighthouses and isolated rock and island stations. Wireless telephonic installations have now (1929) superseded all the cable communications with light-vessels.

DISTINCTION AND DISTRIBUTION OF LIGHTS, ETC.

The following are the various light characteristics which may be exhibited to the mariner:—

Fixed—Showing a continuous or steady light. Seldom used in modern lighthouses and generally restricted to small port or harbour lights. A fixed light is liable to be confused with lights of shipping or neighbouring shore lights.

Flashing—Showing a single flash the duration of darkness

For the purposes of the mariner a light is classed as flashing or occulting solely according to the duration of light and darkness and without any reference to the apparatus employed. Thus the light shown by a fixed apparatus, in which the light source is mechanically eclipsed but yet the period of darkness is greater than that of light, is classed in the Admiralty List of Lights as a "flashing" light.

being greater than that of light. This characteristic or that immediately following is generally adopted for important lights. The French authorities have given the name *Feux-Éclair* to flashing lights of short duration.

Group-flashing—Showing groups of two or more flashes in quick succession separated by short eclipses with a larger interval of darkness between the groups.

Fixed and Flashing—Fixed light varied by a single flash, which may be preceded and followed by a short eclipse. This type of light, in consequence of the unequal intensities of the beams is unreliable.

Fixed and Group-flashing—Similar to the preceding and open to the same objections.

Occulting—A continuous light eclipsed at regular intervals the duration of light being equal to or greater than that of darkness.

Group Occulting—A continuous light with groups of two or more occultations.

Alternating—Lights having any of the foregoing characteristics and which alter in colour are indicated by the addition of the word "alternating" to the appropriate description. When used alone in describing a light the word indicates two distinct colours alternating without any intervening eclipse. Alternating lights are not to be recommended for reasons which have already been referred to.

Colour—The colours usually adopted for lights are red and green. A white light is to be preferred whenever possible owing to the great absorption of light by the use of red or green glass screens.

Sectors—Where coloured lights are employed to distinguish cuts or sectors, they should be shown from apparatus of fixed section and not from revolving apparatus. In marking the passage through a channel, or between sandbanks or other dangers, coloured-light sectors are arranged to cover the dangers, white light being shown over the fairway with sufficient margin of safety between the edges of the coloured sectors next the fairway and the dangers.

Choice of Characteristic and Description of Apparatus.—In determining the choice of characteristic for a light, due regard must be paid to existing lights in the vicinity. No light should be placed on a coast line having a characteristic the same as, or similar to another in its neighbourhood unless one or more lights of dissimilar characteristic, and at least as high power and range intervene. In the case of landfall lights the characteristic should differ from any other within a range of 100 m. In narrow seas the distance between lights of similar characteristic may be less. Landfall lights are the most important of all and the most powerful apparatus available should be installed at such stations. The distinctive characteristic of a light should be such that it may readily be recognized by a mariner without the necessity of accurately timing the period or duration of flashes. For landfall and other important coast stations flashing dioptric-apparatus of the first-order (920 mm focal distance) or its equivalent in power with powerful burners are required. In countries where the atmosphere is generally clear and fogs are less prevalent than on the coasts of Britain second- or third-order lights suffice for landfalls, having regard to the high intensities available by the use of improved illuminants. Secondary coast lights may be of second-, third- or fourth-order of flashing character, and important harbour lights of third- or fourth-order. Less important harbours and places where considerable range is not required, as in estuaries and narrow seas, may be lighted by flashing lights of fourth-order or smaller size. Where sectors are requisite, occulting apparatus should be adopted for the main light or subsidiary lights, fixed or occulting, may be exhibited from the same tower as the main light but at a lower level. In such cases the vertical distance between the high and the low light must be sufficient to avoid commingling of the two beams at any range at which both lights are visible. Such commingling or blending is due to atmospheric aberration.

Range of Lights.—The range of a light depends first on its elevation above sea level and secondly on its intensity. Most

are of sufficient power to render them visible at a range of several miles. On the other hand, in harbours and other lights which do not meet this

requirements from which lights are visible, given in lists of distances in the cases of lights of low power for the reason that the range is usually calculated in nautical miles as seen from a point above sea-level, the elevation of the lights being taken above high water. Under certain atmospheric conditions, with the more powerful lights, the glare of the lights (in the ion from the clouds) may be visible considerably beyond the usual range.

TABLE III

WHICH OBJECTS CAN BE SEEN AT SEA, ACCORDING TO THE ELEVATIONS AND THE ELEVATION OF THE EYE OF THE OBSERVER (A. STEVENSON)

Distances in nautical miles	Heights in feet	Distances in nautical miles
2.565	120	12.56
3.628	150	14.02
4.443	200	16.72
5.130	250	18.14
6.285	300	19.87
7.255	400	22.04
8.111	500	23.65
8.886	600	25.10
9.508	700	26.28
10.26	800	27.45
11.47	900	28.54
	1000	29.28

A light 200 ft. high will be visible 22.50 nautical miles to an observer whose eye is elevated 30 ft. above the water, thus, from

an elevation, distance visible 20.28 nautical miles
 " " " 10.24 " "
 " " " 22.50 " "

of Lights—The elevation of the light above sea-level in the case of landfall lights, exceed 200 ft., which give a range of over 20 nautical miles. One hundred feet is usually sufficient for coast lights. Lights placed at a lower level the atmosphere is comparatively clear (each Head light). No definite rule can, however, be taken into consideration in every case. **Location**—Landfall stations should receive first consideration; choice of location for such a light ought never be subservient to the lighting of the approaches to a light. Lights are available for the latter purpose. Lights at harbours and shoals, reefs or other dangers should when placed seaward of the danger itself as it is desired should be able to "make" the light with confirming dangers seaward of the light should not be accepted when the danger is in the near vicinity of the light. **Marking**—Lighting dangers require marking by a light placed on a floating light in its vicinity.

LIGHTED BUOYS

Acetylene gas was first used for a light carried on a buoy in 1833. The automatic occulter, worked by the gas passing from the burner, was introduced in 1833. The majority of lights by oil-gas are fitted with multiple-jet or Argand canescent mantles are also employed. Ordinary lamps are largely superseded by other forms of gas illumination. Gas buoy-lights are usually provided with sufficient capacity to run the light unattended for three months. Lanterns used for all forms of buoy lighting are of fixed-light section with cylindrical dioptric lenses of fixed-light section of 75 mm diameter. Some of the largest types of gas lanterns have an elevation from water level to the focal plane of the lens and a beam intensity of more than 1,000 candlepower placed at the entrance to the Groude in 1907 and to the focal plane of 34 feet. Spar buoys may be

scoped or used on here strong tides. currents prevail

Acetylene Gas Buoys—Although some experimental work was done as early as 1895, acetylene gas was first regularly used for buoy lighting early in the 20th century when automatic water-carbide generators were employed in Canada for producing the gas, the generators being placed in the body of the buoy. This system never gave entirely satisfactory results and its use is attended by danger of explosion. It has almost everywhere been superseded by the dissolved acetylene system first applied to buoy lighting in Sweden. The normal acetylene buoy equipment maintains the light without recharging up to 12 months (fig 15).

Electric Buoys—Buoys have been fitted with electric light both fixed and occulting. Six spar buoys were laid down in the Gedney channel, New York Lower Bay, in 1893. The wear and tear of the cables, by which current was supplied from a shore station caused considerable trouble and expense and the lights were replaced by gas-lighted apparatus in 1904. Electric buoys were also used extensively in Germany early in the present century but in 1919, very few if any, examples of this method of buoy lighting remain in service.

Bell and Whistling Buoys—Bells or whistles are frequently fitted to gas buoys as well as to unlighted marking buoys. An acetylene lighted whistle-buoy is illustrated in fig 15. Submarine bells have also been fitted to buoys but their functioning in such positions is unreliable.

AERIAL LIGHTS

Light signals are needed by air craft in night flying, just as they are required by the mariner. Air craft travel in three dimensions and also at higher velocities than a ship. Light signals for the

guidance of an airman must therefore be at short intervals and must be visible from the horizon up to the zenith. One form of optical apparatus for an aerial lighthouse comprises a lower section similar to the portion below the focal plane of a marine revolving light, above this is a section of a fixed-light optic with its axis horizontal instead of vertical as in a marine fixed-light. The lower revolving lens emits a high-power beam of light of small angle with its axis just above the horizontal while the upper segment throws a narrow band of light of lower power from the horizontal to the vertical. Although an airman would pick up the main beam emitted by such an apparatus at say 30 m. he would be above it (if flying at a height of about 6,000 ft.) when at a distance of about 20 m. and not near enough to pick up the weaker beam to compensate for this the lower lens and the illuminant are made of such dimensions and power that the main beam is stronger than is actually required in the direction of its axis and a

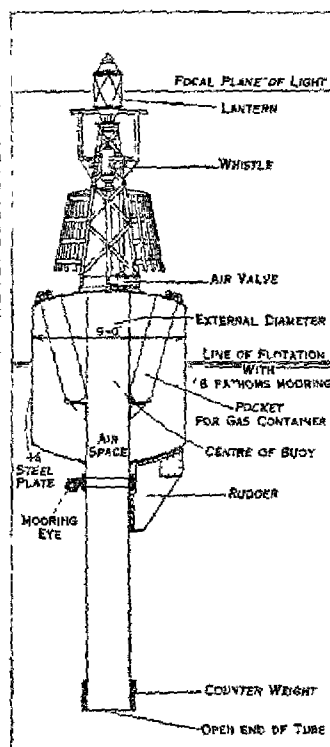


FIG. 15.—ACETYLENE-LIGHTED WHISTLING BUOY (TRINITY HOUSE). The body is welded steel; the whistle is sounded by the motion of the buoy compressing air in the central tube.

portion of the rays from this beam is bent upwards by means of refracting prisms placed in front of the panel, thus reinforcing the light in the direction where additional power is required (fig 16). The effect of this adjustment is shown by the range curve. The optical apparatus is rotated on a mercury float or on ball bearings as in a marine lighthouse.

In some aerial apparatus as at Cranbrook (Kent), reflecting mirrors are used as well as refractors in front of the lower part of the lens, and refracting prisms are employed instead of the fixed-light lens in the upper part of the apparatus.

of lamp power and in some of them powerful electric search lights have been used. The aerial light at Dover is a gas lamp and is made up of four sets of double electric lenses 8 in. in diameter, each set projecting parallel beams

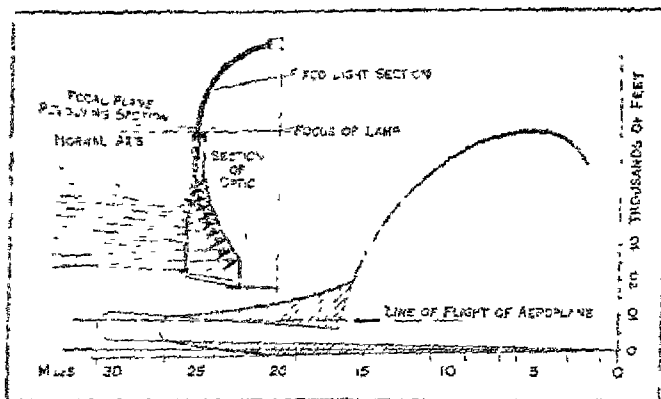


FIG. 16.—VERTICAL SECTION OF A PANEL OF AN OPTIC FOR AN AERIAL LIGHTHOUSE AND THE RELATIVE RANGE-CURVE

of light in groups or foci. The lighthouse at Mont Valerien, near Paris (1920) is provided with catoptric projectors of gilded metal, a portion of the series of mirrors being arranged to direct the light rays in directions between the margins of the main beams and the zenith. The electric arc is also employed in this case. At Le Bourget a fourth-order catoptric apparatus is installed with a gas-filled electric lamp of 8000 c.p. in focus. Lanterns containing the apparatus of aerial light have glazed roofs as well as the side glazing usual in marine lighthouses.

Neon tubes emitting a red light have been used at the Croydon aerodrome since 1921 for the guidance of airmen in fog because of the large percentage of red rays which have a higher power of penetration in fog. The Croydon beacon is of 13,500 c.p. and consists of clusters of neon tubes, 16 ft. long, without lenses or reflectors of any description. A flashing characteristic is given to the signal by interrupting the current. Many of these lamps are in use in the United States, Germany and France. It is doubtful whether the neon tube under fog conditions is superior to other methods of aerial lighting by means of which beams—both white and red—of much higher total intensity can be projected.

In Great Britain and France the guiding principle of airways lighting is (in 1929) to provide powerful lights at comparatively long distances apart which can be picked up by airmen at long range flying either low down or at comparatively high altitudes. In the United States and in Germany the practice is to lay a series of comparatively low-power lamps at short intervals along the air route the airmen being expected to follow the line marked out

FOG-SIGNALS

The introduction of coast fog-signals is of comparatively recent date. They were until the middle of the 19th century, practically unknown except so far as a few isolated bells and guns were concerned. In times of fog the mariner can expect no certain assistance from even the most efficient system of coast lighting, since beams of light of high power are frequently entirely dispersed and absorbed by the particles of moisture, forming a sea fog of even moderate density at relatively short distances from the shore. The careful experiments and scientific research which have been devoted to the subject of aerial-acoustic fog-signalling have produced much that is useful and valuable to the mariner, but unfortunately the practical results thus far obtained have not been so satisfactory as might be desired owing to (1) the very short range of the most powerful signals yet produced under certain unfavourable acoustic conditions of the atmosphere, (2) the difficulty experienced by the mariner in judging at any time how far the atmospheric conditions are against him in listening for the expected signal, and (3) the difficulty in locating the position of a sound signal by phonic observations. The future of marine fog signalling may lie in the

use of acoustic signals, but it is unlikely that acoustic signals will be dispensed with even if reduced in number.

Bells and Gongs are the oldest and generally speaking, the least efficient forms of fog signals. Under very favourable acoustic conditions the sounds are audible at considerable ranges. On the other hand gong bells have been inaudible at distances of a few hundred yards. Bells are frequently used for beacon and buoy signals. When employed in conjunction with a lighted beacon they are sometimes rung mechanically either by clockwork or by compressed CO₂ gas. Electric striking mechanism has also been employed where current is available.

Explosive Signals.—Guns were long used at many lighthouse and light-ship stations in Great Britain, and are still found at some foreign stations. In 1878 sound rockets charged with gun-cotton were first employed at Flamborough Head and were afterwards supplied to many other stations. The nitrated gun-cotton or tonite signals now in general use at rock and other lighthouses where accommodation is limited are hung at the end of an iron jib or pole attached to the lantern or other structure, and fired by means of a detonator and electric battery. An example will be noticed in the illustration of the Bishop rock lighthouse, the jib being attached to the lantern (fig. 4). Sometimes the explosive is combined with aluminum in the charge to give a brilliant flash in addition to the detonation.

The acetylene fog-gun is an automatic or semi-automatic signal in which a mixture of air and acetylene is exploded at short intervals in a gun chamber. It is economical in working cost and occupies little space, but its power cannot be compared with that of a compressed-air siren. The admission of air and acetylene is controlled by an automatic gas-valve and the charge is fired by a spark. Signals can be sounded as frequently as every ten seconds.

An acetylene gun was established at the Dhu Heartach rock lighthouse (west coast of Scotland) in 1912. The gun continues in action without attention from the time when it is started until it is stopped by the keeper. The gas is generated automatically on the carbide-to-water principle. On the Clyde there are two isolated beacon structures which are equipped with automatic guns started and stopped by wireless control from Gourock pier. Several other stations in Scotland and elsewhere are provided with these guns.

Whistles and Reed Horns.—Whistles, whether sounded by air or steam, are not used in Great Britain although they are still employed as fog signals in the United States, Canada and Sweden. It has been objected that their sound bears too great a resemblance to steamers' whistles; and they are wasteful of power.

Reed horns, in their original form, were the invention of C. L. Daboll, an experimental one, of his manufacture, being tried in 1857 by the United States Lighthouse Board. The reed horn was adopted by Trinity House in 1862 after being improved by W. Holmes and many examples from his designs are now in use at secondary stations in Britain and America. Normally they are sounded at a pressure of 15 lb. per in. with air furnished by power-driven compressors, semi-diesel engines being commonly used in modern installations. When operated by hand the working pressure is 5 lb. per square inch.

Sirens and Diaphones.—These are considered to be the most efficient aerial sound-signals which can be obtained for lighthouse purposes. (See also *Air Oscillator* under LIGHTHOUSES, UNITED STATES.) One or other of them is usually employed when first-class signals are required and space is available for the accommodation of the necessary plant. Both are compressed-air instruments, but differ somewhat in operation. The diaphone, in its modern form the more powerful instrument, was invented in Canada by J. P. Northey, about 1903, and consists of a piston reciprocating in a cylinder, around both of which are cut circumferential slots or ports. The piston is fitted with an operating head to which air is admitted, first on one side and then on the other, for giving to it the reciprocating motion. As the slots in the two units pass and repass one another air is being admitted through them to produce the impulses or sound waves, and upon the number of times these ports open and close each second de-

¹The Flamborough Head rocket was superseded by a siren fog signal in 1908.

pend the note. In the case of the siren the pressure on the diaphragm is instead of having a reciprocating motion but obeys the principle of a reed as in the same in both instruments. Each is fitted with a trumpet-horn or resonator and the working air-pressure is 30 lb. per sq. in. for the diaphone and 25 lb. per sq. in. for the siren. The diaphone note is usually about 130 vibrations per sec. or F sharp in the tenor clef; it terminates with a quick descending note termed the "grunt" at the end of each blast. This grunt is a valuable distinctive feature as it can sometimes be heard when the remainder of the signal is inaudible.

To provide the air for these instruments compressing machinery and large capacity air storage receivers are required. In recent Trinity House installations two instruments with their axes approximately 120° apart horizontally are fitted for distributing the sound over a wide arc. In the diaphone installations at Flamborough, Hartland and Skerries (1927) the mouths of the two trumpets are placed on a common vertical axis with their centres half a wave-length apart, to give effect to the theory propounded by the third Lord Rayleigh that vertical dispersion of sound was by this means avoided. A similar arrangement has also been introduced at some French stations.

The siren in a primitive form was invented by John Robison (1739-1805). Cagniard de la Tour evolved the disc form and gave it the name of siren. The first steam siren was patented by Brown of New York. The cylindrical form and the centrifugal governor now commonly used are due to G. H. Slight.

Nautophones.—A form of aerial-acoustic instrument called the Nautophone has recently been devised which consists of an electrically vibrated diaphragm sounding a high note. In its present state of development (1929) it compares, as regards intensity, with a reed horn.

Submarine Bell and Oscillator Signals.—As early as 1841 J. D. Colladon conducted experiments on the lake of Geneva to test the suitability of water as a medium for transmission of sound-signals and was able to convey distinctly audible sounds through water for a distance of over 21 m., but it was not until 1904 that any successful practical application of this means of signalling was made. Submerged bells are used principally in connection with light-vessels and are struck by clappers actuated by pneumatic or electrical mechanism. They have also been fitted to buoys and beacon structures, and placed on the sea bed. In the first case the bell is actuated by the motion of the buoy and in the others by electric current, transmitted by cable from the shore.

The oscillator or electro-magnetic submarine fog-signal is actuated electrically from the lightship to which it is attached or from the light station with which it is connected. The instrument which came into use during the World War, comprises a vibrating diaphragm of large dimensions and its principle of operation is similar to the working of a telephone. It sends out a high note to which can be given a characteristic code notation. The instrument has been fitted in several light-vessels in European and American waters. The underwater range of the oscillator has been known to exceed 50 m. as compared with 10 m. for the bell.

To take full advantage of the signals thus provided it is necessary for ships approaching them to be fitted with special receiving microphones installed below the water line and in contact with the hull plating. The signals are audible by the aid of ear-pieces similar to ordinary telephone receivers. Not only can they be heard at considerable distances and in all conditions of weather, but their direction in reference to the moving ship can be determined approximately. When they are established in conjunction with a wireless-beacon fog-signal and when the acoustic and radio-signals are made to synchronize as at the Nantucket Shoals light-vessel (U.S.A.), they provide in combination a valuable means of determining distance by observing the interval of time between the reception of the two signals (see below).

Wireless Fog Signals.—Wireless fog signals,¹ designed for

¹Other designations are—*Radio beacons, Radio fog-signals, Wireless beacons* and, in France, *Radiophares*.

connoisseurs from lighthouses provide a means by which a navigator may obtain a direct bearing on the transmitting station. They are of three types: (1) a stationary wireless-beacon transmitter from which a characteristic signal is sent out in all directions so that it can be picked up by a ship fitted with a direction-finder or wireless-compass; (2) a rotating short-wave directional wireless-beam transmitter, which sends out a different characteristic signal on all points of the compass as it revolves, these signals are received on a special aerial, and as the wireless beam is directional and as each signal represents a definite bearing, the particular signal heard gives the bearing of the ship from the station; (3) a rotating wireless-loop transmitter which is revolved at a pre-arranged constant speed and sends out on north and east zero points a characteristic signal, followed during the remainder of its revolution by a continuous dash. The bearing in this case is taken by means of a stop-watch, in conjunction with an ordinary wireless receiver, and is obtained by noting the time which elapses between the bearing of one or other of the zero-point signals and the total extinction of the continuous dash. As the loop makes so many revolutions in a definite period the determination of the bearing is merely a matter of computation between the speed of rotation and the time recorded by the stop-watch.

(1) *Wireless-beacon*.—Each system has its particular merits but the first, that is, the beacon station is probably the most effective of the three. It is comparatively cheap to install and easy to maintain, while the system is applicable either on shore or on board a light-vessel. Moreover, this form of wireless fog-signal necessitates a ship being fitted with a direction-finder which enables a bearing to be obtained not only of the beacon-station but also of other ships at sea during fog; or, as has frequently been proved with advantage, of a ship in distress. When the wireless-signal is combined with a submarine-signal and made to synchronize with it, distance from, as well as direction of, the station can be obtained.

A beacon-station of this type was established at Round Island in the Scilly Islands in 1927. In the beacon a simple valve transmitter of $\frac{1}{2}$ kw power generating interrupted continuous waves is employed working on an open twin L aerial. The wave-length is 1,000 metres. Good bearings are obtainable from it at a distance of over 100 m. The whole equipment is automatically controlled, even to the replacement of transmitting valves in case of failure, by a master-clock which sends out signals every half hour by Greenwich mean time. During foggy weather the time interval is reduced. Little attention is required and it has been found practicable to run the station without addition to the lighthouse staff. Similar signals were established in 1928 at 12 other British stations, including two light-vessels and others were in course of erection. Wireless fog-signals of the same general type have been installed by other lighthouse services notably those of the United States (where 57 stations were in operation in 1928), Holland, France, Sweden and Canada. An experimental station was established in France in 1912 but the first permanent wireless fog-signals were put into service in the United States in 1921 on light-vessels in the approaches to New York harbour.

(2) *Rotating-beam*.—A wireless fog-signal in the class of the second type has been established at Inchkeith in the Firth of Forth (1927). It works on a 6.2-metre wave-length and though the receiving apparatus is simple and inexpensive, the transmitter in its present state of development has disadvantages in that the range is small, and a large rotating structure is required for producing the beam. In addition, as the bearings must be given relative to a fixed zero, the system is inapplicable for use on a light-vessel.

(3) *Rotating-loop*.—The third system, which was developed by the Royal Air Force, possesses an advantage in that an ordinary receiving apparatus and stop-watch only are required for taking bearings, but the power employed is over ten times that of the beacon-transmitter for less range, while the cost is considerably greater. The cost of maintenance too is high, as

²Synonyms are:—*Radio-compass* and *Goniometer*.

On Jan 1 1928 the lights a
the control of the several author
follows—

TABLE IV

	Lamp- houses	Minor lights	LIGHT-SIGNALS		AERIAL-ACOUSTIC FOG	
			Number	Unat- tended	Explosive	Sirens diaphones, reed horns etc
Trinity House	27	3	43	1	13	75
Commissioners of Northern Light etc	151	7	-	4	11	40
Irish Lights Commissioners	37	4	10	-	14	23
Mersey Docks and Harbour Board	24	17	-	-	-	5
etc	-	11	-	-	-	4
Trinity Light-house Trust	7	12	-	-	2	3
Harbour Commissioners	1	4	2	1	-	3
Under local lighting authorities	192	249	-	-	4	43
Totals	540	1023	55	9	44	196

* Lighthouses and some harbour and river lights of minor character are not included in the above list.
Including some signals established during 1928.

this type of station have to be carefully selected. Like the second system it cannot be appraised on a lightship because of the necessity of having fixed zero-points. Loop stations have been established experimentally at Gosport and Farnborough and further trials of the system are being carried out at Orfordness.

Wireless fog-signalling and position-finding are (1929) still in the state of active experiment and development. They are undoubtedly destined to be one of the most important navigational aids in the future. The desideratum appears to be a system, applicable to stations both ashore and afloat, which employs a wireless signal whose bearing is quickly and directly ascertainable by the navigator himself and which, when combined with submarine acoustic-signals, can be used for ascertaining distance.

LIGHTHOUSE ADMINISTRATION

The principal countries of the world possess organized and central authorities responsible for the installation and maintenance of coast lights and fog-signals buoys and beacons.

British Isles.—In England Trinity House is the general lighthouse authority. The Corporation of Trinity House, or according to its original charter, "The Master Wardens and Assistants of the Guild Fraternity or Brotherhood of the most glorious and undivided Trinity and of St Clement, in the Parish of Deptford Strand, in the county of Kent," existed in the reign of Henry VII. as a religious house with certain duties connected with pilotage, and was incorporated during the reign of Henry VIII. In 1595 it was given certain rights to maintain beacons, etc. but not until 1680 did it own any lighthouses. Since that date it has gradually purchased most of the ancient privately-owned lighthouses and has erected many new ones. The act of 1836 gave the corporation control of English coast-lights with certain supervisory powers over the numerous local lighting authorities including the Irish and Scottish boards. The corporation now consists of a Master, Deputy-master and 22 Elder Brethren (ten of whom are honorary), together with an unlimited number of Younger Brethren who, however perform no executive duties. In Scotland and the Isle of Man the lights are under the control of the commissioners of northern lighthouses, constituted in 1786 and incorporated in 1798. The lighting of the Irish coast is in the hands of the commissioners of Irish lights formed in 1867 in succession to the old Dublin Ballast board. The principal local light authorities in the United Kingdom are the Mersey Docks and Harbour board and the Clyde Lighthouse trustees. The three general lighthouse boards of the United Kingdom, by the provisions of the Mercantile Marine Act of 1854, are subordinate to

See G. R. Putnam, *Radio Fog-Signals* (Washington, Government Press, 1924, and supplements 1927), also *Proc Inst El Engng.* (passim) and *Admiralty List of Wireless Signals* (London, annually)

In the Trinity House service at there is no fog-signal there are u stations four, one being ashore c station there is an additional kee as a rule consist of 11 men three going on shore in rotation. The nance (excluding repairs) of an two keepers, is £477. For shore and a siren fog-signal the average of a rock lighthouse with four kee is about £1,310, and an electric fog-signal costs about £1,200 annu of the average type with a po England an annual expenditure of £2,500 excluding the cost of peri

Other Countries.—The light as the Commission des Phares, d in 1811, and is under the direc works. The chief executive officer *Ponts et Chaussées* who is the other engineer of the same cor secretary. The board has contro those of Corsica, Algeria, etc Italy, Sweden, Norway and mar of marine has charge of the ligh Belgium the public works depart in Spain the lighthouse service r that of France.

In Canada the coast lighting is marine and in most of the other the public works departments hav For the lighthouse service of the

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THE UNITED STATES

The first lighthouse in America, a tall masonry tower, was built in 1716 by Massachusetts at the entrance to Boston harbour. The original colonies on the Atlantic, largely dependent on water traffic gave early attention to lighthouses. Congress, in 1789, immediately after the national government's organization, provided for lighthouses and buoys, 12 having been built by the colonial governments. Alexander Hamilton wrote the first report on lighthouses in 1790. In 1852 Congress established the Lighthouse Board, substituting for it in 1910 the Lighthouse Service.

The problems of lighthouse construction are similar everywhere in the world, but the Great Lakes and north Atlantic ice action, southern coast hurricanes, and some earthquake areas need particular attention. This country has about 30 important lighthouses on submarine or unusually exposed sites, some involving difficult engineering, only a few of these are wave-swept lighthouses of primary significance. The following are important or typical wave-swept U.S. lighthouses:

Mine Point Ledge (1860), south of Boston harbour, the most notable, built on a reef, bare only at low water, exposed to the Atlantic's sweep, its construction lasted over 5 years. Steps were cut to receive the foundation. The conical-shaped tower is of granite, the first 40 ft. solid, base 30 ft. diameter, the light elevated 85 ft. The stones are dove-tailed in each course, connected vertically by bonding bolts, and eight long iron posts pass through the lower courses into holes in the ledge.

White Shoal (1910), marking a shoal in northern Lake Michigan. A timber crib 72 ft. square towed to the site, filled with stone, was sunk in 22 feet of water; this supports concrete pier, tower and light 125 feet above water. *Martin Reef* (1927), northern Lake Huron, has a similar substructure.

On the Great Lakes important structures on submarine foundations mark shoals, usually replacing the original lightships. Timber crib foundations, economical, satisfactory in fresh water, are favoured. Other types are: Concrete caissons towed to site, sunk on bottoms previously levelled, and filled with stone, i.e., *Lansing Shoal* (1928), Lake Michigan. *Spectacle Reef* (1874), Lake Huron and *Stannard Rock* (1882), Lake Superior have coffer-dams in protecting piers, the former for a stone tower on rock, the latter for a wrought iron cylinder foundation pier fitted to rock and concrete-filled.

Sabine Bank (1906), marking a sand bank about 14 m. off the Gulf coast, is a cast iron tower and substructure, standing in 18 feet of water. The iron caisson was towed to the site and sunk 20 ft. in sand by pneumatic process, the only U.S. lighthouse foundation so placed in the open sea. There are others in protected waters.

Pacific Reef (1921), marking the outer edge of coral reefs off the Florida southern coast. It is supported by nine iron piles, each driven 9 ft. into the coral reef, the piles pass through, and are partially supported by, iron discs 4 ft. in diameter resting on the coral surface. In 7 ft. of water, it supports an iron open work structure. Although only an automatic acetylene light, 45 ft. high, it illustrates recent practice, at moderate cost. Six other lights along the Florida reefs, on similar foundations, are notable structures, the tallest being *Sombrero Key* (1858), 160 feet.

Tillamook Rock (1881), a stone structure on a small rock islet 1 m. off the Pacific coast, south of the Columbia river's mouth, the most notable lighthouse on the United States western coast due to its position on extremely exposed rock, in deep water and open to the Pacific sweep. Landing is impossible directly on the rock, and can be made only by hoisting from a boat. Seas break sometimes over the lantern 145 ft. elevation. *St. George Reef* (1891) off the California coast is in a similarly difficult

position. Many lighthouses in water were built on screw-pile foundations, but none recently one. *Sand Key Light* (1853), Florida, is 120 ft. high. Of many handsome masonry lighthouses along the coast especially the low-lying Atlantic seaboard, *Cape Hatteras* is the highest, 193 feet. Reinforced concrete has been extensively used recently to construct light towers, wharves and buildings. The most notable is *Navassa Island Light* (1917), on a desert West Indian island, tower 162 ft., cylindrical shaft 15 ft. diameter. Another primary light of reinforced concrete is *Kilauea Point* (1913), Hawaiian islands: tower 52 ft. high on a cliff.

Apparatus, Illuminants and Characteristics of American lights are similar to standard world practice, but have some diverging developments. Concentrating light by using rapidly revolving lenses with few panels, and superior illuminants, give beams of sufficient power with smaller lenses, no lenses larger than third order (500 mm., 20 in. radius) have been installed since 1913, numerous large lenses have been replaced by more efficient optical apparatus.

The primary light standard has been incandescent kerosene oil vapour lamps; but electric incandescent lamps are used if commercial current is available, or generation at the station otherwise required. Incandescent electricity is most satisfactory because of its power, convenience and adaptability. Its use increases where it is economically obtained. It is efficient to electrify certain stations for illuminant, operating sound fog signal and radio-beacon, and lighting buildings. Electricity is very convenient for signals controlled remotely as those near jetty ends. Small plants or primary cells generate electric energy for minor lights. The principal difficulty in putting incandescent electric lamps in old lenses is the too concentrated light source, and insufficient divergence of beam, this is being overcome by various methods.

Acetylene gas compressed in cylinders is increasingly used for unwatched or semi-watched lights of medium importance. There are few remaining oil gas lights, or lights using acetylene generated at the station. Acetylene under incandescent mantles or more elaborate acetylene apparatus is not used. Electric and dissolved acetylene equipment has advanced automatic apparatus installation and conversion to unattended stations. About 45% of lights, including buoys and excluding rivers, are now automatic. Automatic apparatus extends lighthouse facilities to remote regions like Alaska.

Distinguishing principal coast lights by flashing or occulting characteristics, and eliminating fixed lights, progresses steadily. Characteristics are simple, quickly and easily recognized without timing. Preferred limitations are: that a single important light flash be not less than 0.3 sec. in duration, a minor light not less than 0.1 sec., that the characteristic be repeated preferably twice a minute, and one light of a range, or two lights in line, be fixed. Colour is variable in distinguishing but illumination is reduced to about 30%—a serious drawback. Red and green are used for secondary lights.

Uniformity of Navigation Aids—The United States has long had a fairly standardized system to show the relation of navigational aids to channels, by colours, shapes and numbers, this system having in part been prescribed by law in 1850. International uniformity in buoyage and lights would add safety and convenience to navigation. Limited but important action on this at the International Marine Conference, Washington, 1889, resulted in considerable uniformity. The United States system, based largely on the 1889 conference, is, for vessels coming from sea: red buoys, conical-shaped ("nun"), even numbers, on right side of channel; cylindrical black buoys, flat tops ("can"), odd numbers on left side; horizontal red and black-banded buoys mean shoals or dangers, vertical black and white stripes show clear channels, with coloured lights, red on right and green on left of entrances or channels but white may be on either side.

Colour and shape to mark the relations of buoys to channels are in nearly world-wide use; shape alone is not enough, because not readily applicable to important classes of buoys, such as gas whistle, bell and spar. Moreover, experience shows that both

be placed on rocky coasts, to mark outstanding rocks or reefs or shoals. The first was placed in Chesapeake Bay (1802). Fixed structures of shoals, or gas buoys have replaced them, many of them placed in inland waters. Great Lakes lightships are thus being gradually retired. There are 46 lightship stations, 175 to relief ships. Of the stations 25 are outside on the Atlantic and Pacific coasts where it is impracticable to build lighthouses, but where they are vital to traffic. Nantucket lightship moored in 36 fathoms, 41 m from land guards shoals to the north and most trans-ocean vessels approaching the United States Atlantic coast steer for this vessel one of the world's most important sea-marks. A full-powered vessel, 132 ft long, crew of 16, it has an occulting incandescent electric light of 3,000 candle-power, steam fog whistle, radio-beacon and synchronized submarine oscillator. It is an oil-burning steam vessel. No 106 (1923). One lightship (No 117, North-east End 1926) has a Diesel engine and 3 ships under construction are to have Diesel-electric propulsion electricity for lights and signals. Only one outside lightship and some inside are without propelling power.

Lightships moored in the sea off the Atlantic coast, exposed to tropical hurricanes and other severe storms, receive special attention as to vessel design and moorings to ensure station permanence. For years attempts to keep lightships off New York and Cape Hatteras failed. Severe storms have sometimes torn lightships from their moorings. Cast steel chain is being tried for moorings, so as to better retain lightships on station. Mushroom anchors up to 4 tons are being used.

Buoys.—The American coast's great length and intricacies require 3,586 buoys. The increase in lighted buoys is a notable advance. In 1925 588 gas buoys were on station. Nearly all lighted buoys use acetylene gas compressed in tanks set in buoy pockets, other systems and mantles being discontinued. Steel buoys of various sizes are extensively used to mark channels and shoals. Wooden spars are being replaced advantageously by small inexpensive steel buoys. Though not very effective fog signals, there are 173 whistle buoys and 495 bell buoys, some of the latter provided with chimes having 4 different notes, to distinguish from the bells. All buoys and moorings are relieved at least once a year. Old buoys brought to depots, cleaned and repainted. Their great number makes this an important and time-consuming task. (See article on Buoys.)

Sound Fog Signals.—Radio-beacons described later, are the most effective fog signal. Various types of sound signals, using compressed air or steam are employed, but their value is limited due to short and undependable range, and the impracticability of taking accurate bearing on them. But so far as may be foreseen sound fog signals will remain indispensable. The diaphone, a Canadian invention is popular; there are now 81 diaphones and 83 sirens; both use compressed air. Steam whistles formerly used extensively, are being replaced by more efficient apparatus. Various actuated electric sirens, reed horns and bells serve for minor sound signals. The United States uses no explosive fog signals and but few signals (bells) operated by hand. Though automatic sound fog signals would be of great value, there are, besides the bell and whistle buoys, only 13 bells actuated by carbon dioxide gas; these are useful where a moderate signal suffices that can readily be reached, but are not dependable otherwise.

Most lightships on outer coasts have submarine bells operating on characteristic codes by compressed air from the vessel, water carrying sounds more effectively than air. One lightship has a submarine oscillator, a heavy steel disc suspended in the sea, emitting characteristic signals by vibratory electrical impulses. Several

o o e be g re 4 ar round signals, with favourable prospects. Nearly all fog signal machinery and apparatus is installed in duplicate for greater reliability.

Radio-beacons.—These stations emit radio signals on distinctive codes. Allied with the radiocompass on shipboard, they are considered the most important addition to navigational apparatus since the mariner's compass. They furnish the first generally available means ever provided of taking accurate bearings on invisible objects at considerable distances. The first successful radio beacons were placed at three stations near New York in 1921; the system has now grown in the United States and outlying territories to 55 stations, about half the number in the world. The transmitting apparatus is generally timed to sound one out of each three minutes during fog or low visibility, also at certain half or quarter hours in clear weather. Each station sends a characteristic code signal differing from any other within range. Signals are of interrupted continuous wave type sent with tube transmitters, tests are being made with continuous wave signals, standard wave length is 1,000 metres (300 kilocycles per second) but to lessen interference between adjacent stations in congested localities wave lengths have been staggered somewhat, between 952 and 1,052 metres (315 and 285 kilocycles). A few important stations, e.g., Nantucket lightship, are operated with 500 watts, the standard power for other coast stations and on the Great Lakes is 300 watts, for inland waterways as low as 7½ watts are being tried. This system is extending rapidly. If conditions favour, bearings correct to 1° or 2° up to 200 m away are obtained. Rotating radio-beacons have not been introduced here as they can not be placed on lightships, the most important radio-beacon stations. The above system with the radio compass on board ship is the only possible general navigational system through radio bearings. The systematic operation of radio-beacons during clear weather is being extended, correct bearings may be taken far beyond the range of any other aids.

Airways Lighting in the United States.—The laying out and marking of civil airways as placed in an airways division and made a unit of the Lighthouse Service in 1926. There are 1,275 lights for aerial navigation, 5,877 miles of airways are lighted. Under the chief engineer, this establishes air navigation facilities on civil airways, i.e., route lights and markers for night and day flying on an average 10 m apart, boundary-lighted intermediate landing fields along the routes about every 30 m, for weather and emergency, and facilities for getting and sending weather information as well as dispatch of aeroplanes. Radio direction ranges for aeroplane guidance in thick weather have been developed experimentally, a few are in use. Two radio telephone broadcasting stations for weather changes and landing conditions are in experimental use; 12 stations are under construction. Standard light equipment is a 24 m revolving beacon, parabolic mirror, 1,000 watt electric lamp developing 2,000,000 candle-power, and auxiliary course light projectors flashing code numbers identifying the beacon along the airway, and showing the course. Commercial electric power operates the apparatus, mounted on 50 ft skeleton towers. Duplicate gasoline engine generators in a small powerhouse at the tower's foot furnish electricity if commercial power is unavailable. Astronomic clocks turn lights on and off. A concrete arrow showing route and mileage points the course's direction. Boundary lights and cone markers 300 ft apart outline intermediate fields, green range lights mark best runways and red lights mark air navigation obstructions. An internally lighted fabric wind cone on beacon towers at landing fields indicates wind direction and force. (See also AERONAUTICS and AVIATION.)

Administration.—The Lighthouse Service Department of Commerce, conducts US lighthouses. Its head is commissioner of lighthouses, an engineer in the chief professional grade of the Civil Service. A central office in Washington, with engineering construction, marine engineering, airways, radio and administrative divisions, conducts the work. Coasts and interior waters are divided into 19 lighthouse districts, each with a superintendent (usually a nautically trained lighthouse engineer), each having an office with technical and clerical staff, and one or more supply depots and tenders. On Staten Island, N.Y. is a general depot

with shops and testing laboratories. In the Lighthouse Service there are 865 employees only in Washington in the various districts and 664 employees. There are 6,364 attended lighthouses, each with from 1 to 5 keepers. A large number of lights especially on navigable rivers are attended occasionally. The service has 56 tenders, small vessels to care for buoyage and transportation of supplies, about 22 of which are sea-going, able to handle 12 ton sea buoys. The largest tender is the "Cedar" (1917), in Alaska, 201 ft long, with complement of 34 persons.

The total cost of Lighthouse Service (marine) for 1928 was \$20,264,057, of which \$2,465,901 was for new works, repairs and improvements. Average costs for that year are: primary seacoast light station, \$5,592; river post light, \$122; sea-going tender (Atlantic), \$70,332; exposed lightship, \$28,300; lake lightship, \$11,817. The total appropriation for civil airways (lighting, communication and emergency fields) for the current fiscal year (1929) is \$4,659,850. Since the Lighthouse Service administers all navigation aids in U.S. Territories save the Philippines and Panama Canal it is a large organization. Total aids in 1928, 18,607 (marine) of which 6,761 are lighted. The Philippines have 405 local aids, the Panama Canal 254, making a grand total for U.S. Territories of 19,266 (marine).

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LIGHTING AND ARTIFICIAL ILLUMINATION.

From earliest times man has endeavoured to produce artificial light so as to utilize more thoroughly the hours of darkness for the purposes of work or pleasure.

HISTORICAL DEVELOPMENT

Until the first application of electricity to lighting late in the 19th century all artificial light was produced by fire. The first means of securing light at night was the wood fire. To light the way a burning stick called a fire-brand or torch was picked from the fire. Resinous gum wrapped in palm leaves has served for lighting in the Malay islands and resinous materials, such as pine wood and gum, and oily vegetables and animal carcasses have been used as solid illuminants.

Candles.—Wax candles are probably of Phœnician origin. The tallow candle is of later origin, probably the second century A.D. About the 11th century splinters of wood dipped in tallow were first used in England. The whale oil industry in the middle of the 18th century introduced spermaceti for candles. Stearin was first used about 1840. "Composites," candles made of stearic acid and stearin, were the first to require no snuffing. The composite candle of the present day is made of stearin and paraffin. (See CANDLE.)

Oil Lamps.—Oil lamps had their origin several thousand years B.C. The prehistoric lamp was probably made of stone, later clay and terra-cotta lamps were used. These lamps had one wick and a reservoir for oil or grease. The Eskimo lamp consisted of a soapstone dish in which was placed a wick made of moss rubbed into a fine powder, oil was obtained from blubber. Cave-dwellers probably used a skull burning fats taken from animals killed in the hunt. In 1784, the Geneva physicist Argand introduced a draft up through the centre of the burner. Later a "camphene" lamp with long tubes employing a chimneyless, double, flat wick, had some use. (See LAMP.)

Gas Lamps.—The Chinese probably first used "gas" for lighting, by piping natural gas in bamboo tubes from salt mines. A natural gas well underlying a ditch of water near Wigan, in Lancashire, England, was closely related with the evolution of artificial illuminating gas. About 1664 the Rev. Dr. John Clayton drained the water from the Wigan "ditch" and found that the gas came from the ground. A coal-mine was nearby and Dr. Clayton suspected a relationship. He distilled coal in a retort, and succeeded in collecting some of the coal gas in bladders. In 1784, more than a century later, Jean Pierre Minckelers, a professor

at Louvain université called man substances, including coal and iron, 185-86 lighted his lecture room with gas. In 1792 William Murdock similarly lighted his home. Philippe Lebon patented in 1799 the "thermo-lampe," a self-contained apparatus for the production of gas by distillation from wood, coal and other similar solids. In 1802 Murdock introduced "Bengal lights" (flaming open burners). The firm of Boulton and Watts spent large sums on experiments on burners made by Murdock, who used a tallow candle burning 175 grains per hour as the standard of comparison in his gas photometry. Early burners were the "cockspur" and "cockscorn" an adaptation of the Argand burner to gas lamps and the "bat-wing burner." J. B. Nielson of Glasgow in 1820 introduced the fish-tail burner in which two impinging flames spread into a flat, fan-shaped sheet. In 1805 F. A. Wintzler, a German, lighted the Lyceum theatre in London, and under his supervision, the first gas mains were laid in a public street in Pall Mall. Sheet lead was used, being bent cylindrically and soldered at the edges. Wintzler may be called "the father of the central station idea," for he headed in 1810 the first company attempting to supply lighting service to the public. The London and Westminster Chartered Gas Light and Coke Company. He was greatly assisted in this work by the engineering skill of Samuel Clegg. Goldsworthy Gurney in 1820 showed that a cylinder of lime could be made dazzlingly brilliant by the oxy-hydrogen blowpipe. About 1838, W. H. Fox Talbot discovered that even the feeble flame of a spirit lamp will heat finely divided lime to incandescence. Gillard, who introduced the intermittent process of manufacturing water-gas, made a mantle of fine platinum gauze to fit over the flame, but the rapid erosion of the platinum made it useless in a few days.

About 1855 R. W. von Bunsen invented a burner which bears his name. Thirty years later Dr. Carl Auer von Welsbach discovered the gas mantle which in 1909 was used in nearly its original form. Welsbach made gas mantles by saturating cotton fabrics in a solution of certain salts and burning out the organic matter. His first mantle was made with erbium salts and gave a marked green light. He patented the mantle and the next year patented the use of thoria which added strength to the mantle. The incandescent gas mantle composed of thoria and ceria was announced in 1890. Thereafter as soon as the colloid coating process was perfected, mantle lighting became practical. Many modifications and improvements have been made within the past 25 years. Acetylene generated from calcium carbide was first shown to be a possibility by Thomas M. Willson in 1892. The Pintsch system of gas lighting, invented by Richard Pintsch, a German, was brought to America in 1880. It uses distillation of oil.

Electric Lamp.—In 1752 Benjamin Franklin, experimenting with the Leyden jar, discovered the secret of lightning—nature's electricity. Fifty years later Sir Humphry Davy demonstrated the practicability of Volta's theory of obtaining electricity from cells consisting of unlike metals immersed in an acid solution. The earliest attempt at making an incandescent lamp was made by De la Rue in 1820. In 1840, Grove demonstrated his battery by lighting an auditorium with incandescent electric light. Foucault produced such a steady and continuous light that he was able to use it for photographic purposes. The first arc lamp patented in England was the Wright arc of 1845. These lamps were used for street lighting in Baltimore in the late '70s. The first patent on an incandescent lamp was granted by the British Government in 1841 to Frederick De Moleyns. J. W. Starr patented in 1845 the so-called Starr-King lamp, a "filament" formed of a stick of retort carbon. When new, the lamp gave a good, bright light, but blackened rather quickly. During the next few years, several inventors among whom were W. E. State, Edward C. Shepard, M. J. Roberts, De Changy and Moses G. Farmer, tried to make incandescent lamps, even though it was known that their use with current obtained from batteries would be impractical. The dynamo was not sufficiently improved for commercial purposes.

Sir Joseph W. Swan, who became one of the foremost incandescent lamp manufacturers in England, made from 1848-60 a number of experimental lamps. In 1865 Herman Sprengel in-

with the use of the Sprengel pump for obtaining the near approach to a perfect vacuum which the construction of the millimeter demanded. This led Sir Joseph Swan to resume his incandescent lamp experiments. In 1877 with the assistance of Charles H. Stein he experimented with carbon rods of various forms and sizes. These were mounted in glass bulbs which were exhausted to the highest possible degree by means of the Sprengel pump. These lamps rapidly deteriorated owing to the evaporation of zinc from the carbon. This difficulty was overcome by heating the outside of the bulb still connected to the exhaust pump while passing a strong current through the carbon. Straight carbon wires were found to buckle but arch-shaped carbon wires gave good results. In 1880 Swan invented the parchmentized thread which when carbonized produced a long thin carbon used for many years made from cotton thread treated with sulphuric acid and dried becoming agglutinated losing its fibrous condition and having the appearance and the hardness of eugene.

In 1872 Lodyguine, a Russian scientist, made a lamp having a V shaped piece of graphite for a burner operating in nitrogen. In 1875 Kostoff, another Russian made a lamp consisting of several graphite rods operating also in nitrogen. The rods were so arranged that only one operated at a time and when it burned out, another was automatically connected in circuit. Koss also a Russian invented a lamp in 1875 similar to that of Kostoff except that the graphite rods operated in vacuum. In 1876 Bouliguine another Russian, made a lamp having a long graphite rod only the upper part of which was in circuit. When this part burned out, a counterweight pushed the rod upward, placing a fresh portion of the long rod in circuit. It operated in vacuum.

With the appearance of the Gramme dynamo (1873) and the use of the Sprengel vacuum pump, rapid progress was made. In 1876 Jablockhoff put his famous "candle" on the market. This simple arc lamp consisted of two carbon rods held together side by side and insulated from each other by kaolin. The kaolin vaporized as the carbons were consumed, giving the arc a peculiar colour. A complete system was developed by Jablockhoff with an alternating-current generator used to offset the unequal consumption of the carbons on direct current. A series system of distribution was used and in order to prevent interruption, several candles were put in each fixture with an automatic device to connect a fresh candle whenever one burned out. The Jablockhoff candle had a life of from about an hour and a half to three and a half hours. Thousands of candles were sold.

In the United States there were several pioneer arc light systems. The earliest were those of William Wallace, of Ansonia, Conn. who became associated with Prof. Moses G. Farmer, Edward Weston of Newark N.J., Charles F. Brush, of Cleveland, O. and P. of El'hu Thomson, who became associated with Edwin J. Houston. Brush announced his first arc lamp in 1877 and in a few years Brush arc lights were all over the world. Early in 1879 the first Thomson-Houston arc dynamo was built in Philadelphia. In the United States also four men attacked the problem of producing incandescent lamps popularly named "sub-dividing the electric light." These were William E. Sawyer, Prof. Moses G. Farmer, Hiram S. Maxim and Thomas A. Edison. Sawyer became associated with Albon Man, his patent attorney. The Sawyer-Man Electric Company developed several lamps consisting of a piece of graphite, operating in nitrogen, covered by a glass globe cemented to a metal holder. The lamps were designed so that they could be renewed by opening the joint and putting in a fresh burner. Farmer made a lamp consisting of a graphite rod which also operated in nitrogen gas. Maxim made two lamps. One consisted of a piece of sheet platinum operating in air and the other of a graphite rod operating in a rarefied hydro-carbon vapour.

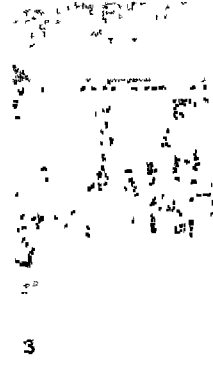
Edison gave his famous display of a complete incandescent lighting system late in Dec. 1879 at Menlo Park. As far back as 1838, Prof. Jobard, of Brussels, suggested that a small piece of carbon incandesced in a vacuum by electricity, might be em-

ployed as a lamp. Edison on a count of his work on his telephone receiver, was eminently qualified to experiment with carbon for lamps. He estimated that the carbon should be not over $\frac{1}{16}$ in diameter, or about the size of ordinary heavy sewing thread. Then he saw the possibility of carbonizing a piece of sewing thread by heating it in an air-tight crucible. There has been some misconception of exactly what Edison did invent. He was not the first man to make an incandescent lamp, as indicated in the foregoing summary. He concluded, however, that such lamps must be connected to the circuit in multiple so each one would be independent of the others. He also realized that lamps connected in multiple must be of high resistance and he named this high resistance carbon burner a "filament." Finally he realized that continuous high vacuum was essential and produced it by making the glass container closed at all points by fusion of the glass. Edison's basic lamp patent No. 223,898, which the courts upheld as covering the modern incandescent lamp, covered (1) a high resistance filament of carbon, in (2) a chamber made entirely of glass and closed at all points by fusion of the glass, which contained (3) a high vacuum and through which (4) platinum wires passed to carry current to the filament. It was a patent on a combination of old elements which produced a new thing—a lamp suitable for multiple distribution over large areas. The first commercial installation of the lamp was made on the steamship "Columbia" of the Oregon Railway and Navigation Company. The original installation of about 150 lamps ran for 15 years. During the two years 1881-82, over 150 other installations were made aggregating over 30,000 lamps. These installations included steamships, machine and car shops, mills, stores, offices, theatres, hotels, residences, etc.; all of them were entirely successful.

The enclosed arc was patented in 1894 by L. B. Marks and for about ten years was the favourite unit for high candle-power electric lighting in America. Five years later came the Bremer flame arc lamp, which was followed by other types of lamps using special electrodes, designed to increase the luminous efficiency and intensity. The best known of all the luminous arc, or the magnetite, developed in 1900, was largely due to Steinmetz. The electrodes are composed of metals and metallic oxides, without any carbon "body." The magnetite is essentially a direct-current lamp. Arons in 1892 originated the mercury-vapour arc although it was not used as an illuminant until April 1901, when Peter Cooper Hewitt displayed his mercury-vapour lamp before the American Institute of Electrical Engineers. The first practical installation was made in the composing room of the *New York Evening Post* in 1905. Dr. Nernst in 1899 produced commercially a new form of incandescent lamp which during the first decade of the present century made considerable headway in the lighting field. The filament of the Nernst lamp was a solid electrolyte composed principally of rare earth oxides.

Improvements on the manufacture and construction of the carbon lamp proceeded from the time of its first successful use. The filaments instead of being bolted or clamped were pasted to the leading-in wires. The "squirted cellulose" replaced bamboo for the carbon filament. The turn-down lamp made it possible to conserve energy when the full light value of the lamp was not needed. Evidence of a tendency toward a complete displacement of the cellulose filament by a metal filament was given in the appearance of Dr. Welsbach's osmium lamp in 1898. Then in 1905 the "Gem," a metallized carbon filament lamp, appeared in America. The first tantalum laboratory lamp was made by von Bolton and Feuerlein in 1901. It was placed on the market in 1906 but soon disappeared due to the advent of the higher efficiency tungsten filament lamps. The pressed filament tungsten lamp (1907) was the invention of Alexander Just and Franz Hanaman of Vienna. The filament was very fragile. From it in 1910 was evolved the drawn wire tungsten lamp, developed by Dr. William D. Coolidge, this filament has proved strong, durable and cheap. Improvements in this lamp have resulted in obtaining high efficiencies. The gas-filled lamp developed in 1913 by Dr. Irving Langmuir, an associate of Dr. Coolidge in the research laboratories of the General Electric Company, has an efficiency many times that of the old carbon lamp.

ING AND ARTIFICIAL ILLU MINATION



HOUSE LAMP COMPANY (4) THE NATIONAL LAMP WORKS OF THE GENERAL ELECTRIC COMPANY, (7) THE EDISON LA

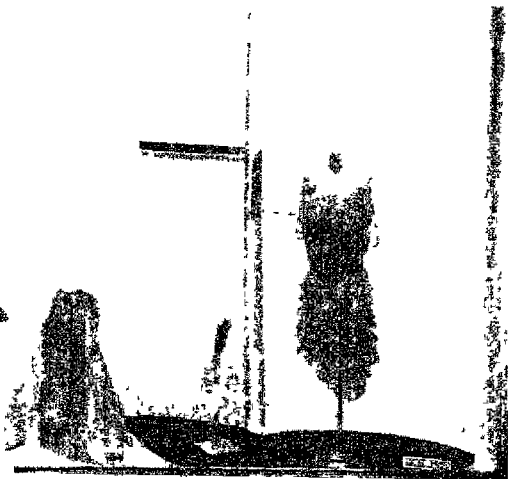
ETHODS OF OBTAINING LIGHT DISTRIBUTION FOR INDUSTRIAL PLAC

room of warehouse (1-2 foot candles) room, area illuminated to intensity of it lamps in RLM domes. Reflectors r on 10x12 ft centres between lamps walls with flat white, increasing the sity of seven foot candles. For general e the right type as shown lighting, showing advantage and dis-

advantage of raising units to give general floor arrangement (4) is dangerous where there is m and (7) are trying to the eyes, as there are concentration of light on working surfaces of m

- 6. Ideal arrangement combining focal lighting w lighting, with low candle-power in ceiling high tion of light over machines and passageway, ceiling is not bright, and there is no glare to

LIGHTING AND ARTIFICIAL ILLUMINATION



1 THE NATIONAL BROADCASTING COMPANY, 12, 3 THE EDISON LAMP WORKS (5 SAKS FIFTH AVENUE DEPARTMENT STORE)

MODERN LIGHTING ARRANGEMENTS FOR HOMES, STORES AND PUBLIC

1 The National Broadcasting Co., New York, treated with indirect lighting units consisting of hollow-coves, suspended lantern light fixtures and floor lamps.

2 Best example of the proper use of indirect lighting.

3 A room with too much lighting, the upper part of it having a

stinging effect on the eyes.

4 A properly lighted room with soft

5 A badly lighted window calling attention to merchandise.

6 A well lighted window strikingly

The efficiency of the early carbon lamp produced in 1879 was about 1.4 lumens per watt. In 1880 the carbonized bamboo filament had an efficiency of 1.6 lumens per watt, the squaried cellulose filament introduced in 1886 2.5 lumens per watt, the treated cellulose filament of 1896 about 3.3 lumens per watt and the metallized carbon filament of 1905 4 lumens per watt. The tantalum filament lamp, commercially introduced in 1906, gave 5 lumens per watt, while the first tungsten lamp sold had an efficiency of 8 lumens per watt, or double that of the best type of carbon lamp. Modern tungsten filament lamps operate at efficiencies ranging from 8 lumens per watt for the small sizes up to 30 lumens per watt for the higher wattage types.

**MODERN ILLUMINANTS
GAS FLAMES**

Illuminating gas is produced by destructive distillation of almost any organic compound, notably coal, and contains many different gaseous compounds, together with the elementary gas hydrogen and some inert nitrogen. Coal gas is manufactured from coals having a rather large percentage of volatile ingredients (17 to 35%) with a yield from 9,000 to 13,000 cu ft of gas per ton of coal. (See COAL AND COAL MINING.) Water gas is manufactured from anthracite coal, 30 lb of coal yielding about 1,000 cu ft of gas.

Carbon Content and Lamp Efficiency.—The lamp efficiency of a hydro-carbon fuel and the device in which it is burned, taken together as a source, depends on the relative number of carbon particles liberated on heating and on the temperature to which these particles are heated. To some extent the former factor is opposed to the latter. In any flame source there is always a great loss of energy through other means than temperature radiation, the principal ones being those of convection and conduction. Other things being the same, the greater the number of carbon particles, the greater will be the portion of the energy supply which will be radiated by the incandescent particles. This consideration points to a high carbon content as a desirable fuel characteristic. Other things being the same, the higher the flame temperature the greater will be that portion of the radiation which occurs within the visible limits. The temperature of a flame decreases with an increase in the number of carbon particles liberated per unit volume of the dissociated vapour. In that a greater number of carbon particles per given volume means a greater rate of loss of energy by radiation and consequently a reduced temperature this consideration points to a low carbon content as a desirable fuel characteristic. In practice, some sort of medium carbon content is, therefore, desirable.

Fuels.—In the candle the wick is the burner. In addition to bringing the fuel to the flame by capillary action, it serves to keep the flame away from the large body of fuel to such an extent that only sufficient energy is lost to liquefy it and thus prepare it for its transfer by capillary action.

Kerosene—In kerosene lamps the chimney and air vents control the air supply, protect from drafts and to some extent preheat the incoming air. The standard illuminating power for kerosene burned in a common flat flame is about 1,100 candle-hours per gallon, measured normal by the flame.

Acetylene—The use of acetylene light now seems to be limited to isolated places, to miners' lamps and navigation buoys. The burners used are usually lava tips with air vents. The tip is provided with jet openings that distribute the gas streams at such an angle as to make one stream abut upon the other and thus produce a flat flame. Due to its very high temperature, the efficiency of the acetylene flame is relatively high.

Pintsch Gas—Pintsch gas, obtained from the destructive distillation of petroleum, contains largely methane, along with some heavier hydro-carbons. Compressed in tanks from 8 to 14 atmospheres, it has been largely used for railway, lighthouse and buoy purposes. Used with a Welsbach mantle, its efficiency is greatly increased.

Carburetted Air Gas—Carburetted air gas consists usually of a mixture of air with a very volatile gasoline and is commonly employed where the use of other artificial gas, natural gas or elec-

tric lights is not possible or convenient. When burner flame burners coal and carburetted water gas or B.T.U. value give varying candle-powers ranging from per cubic foot of gas consumed. This light-giving power increased six or more times by burning the gas in a burner and introducing solid substances, other than carbon, radiation selectively in the visible spectrum.

Burners.—The open-flame burner using illuminating practically disappeared as a light source, having a much more efficient and steadier Welsbach mantle for open gas flames, whether constructed of metal or essentially limited to three types. In the bar-wire gas issues from a narrow slot and forms a thin sheet, the fish-tail burner, two circular streams of gas meet at an angle and on ignition likewise spread out into a flame. In the Argand burner, parallel cylindrical jets from a number of openings arranged in a circle and form a cylindrical flame enclosed by a glass chimney. Combustion is supplied from the bottom of the mantles of to-day give about six times the light of burning gas in the open flame, and contain about 19.99% ThO₂. They radiate energy in the portion of that includes wave lengths well suited to illuminating. The mantle would be one emitting luminous radiation spectral distribution best suited to the eye.

General.—Means for preventing back-firing are necessary for the inverted lamp than for the upright lamp. One of the necessarily high temperature of the mixture is accomplished by a burner tip considerably widened at the outlet with a gauze.

Higher gas pressures (2 lb. per square inch) give about twice that of low-pressure burners, but this is given at the expense of complicated pressure apparatus and shorter life of the mantle. However, high-pressure lamps have been extensively used in some countries for street lighting. One of the valuable contributions to the gas-lighting art has been the development of a burner whose Bunsen tube lies in a horizontal position and thus is adapted to operation in a suspension lamp. One of the hollow suspension arms serves as a gas inlet from the outlet on which the structure is suspended.

ARC LAMPS

The characteristics of arcs that are of special value are efficiency, ruggedness, adjustability, concentration of source and the control of the colour of light. The trimming of the presence of undesirable products of combustion and the complicated mechanism are objections to their use. This is largely confined to large-wattage units for outdoor or projection uses (because of its superlative cratering) and to photo-chemical uses where high efficiency, blue and violet light is necessary. Table I gives important facts in the history of arc lighting.

TABLE I

Discovery or invention	Discoverer or inventor
Carbon arc discovered	Sir Humphry Davy
The name "Arc" first applied	Sir Humphry Davy
Open carbon-arc lamp	Brush
Enclosed carbon-arc lamp	Marks
Yellow-flame carbon-arc lamp	Bremer
Mercury-vapour arc lamp	P. Cooper Hewitt
Vertical-flame arc lamp	Blondel
Magnetite (oxide) arc lamp	C. P. Steinmetz
Enclosed-flame arc lamp	A. D. Jones
White-flame photographic arc lamp	Norman Macbeth
High-intensity searchlight lamp	Beck and Sperry

Classes of Arcs.—Arcs may be divided into two main classes: (a) crater arcs and (b) luminescent arcs. The crater arc is formed at the electrode tip from which the arc starts.

In the crater arc the light is most intense. The positive crater gives about 10% of the light, the negative crater and the arc stream the balance. The energy expended in the arc stream is large, but since with the lamp-stream arcs considerable light comes from the arc stream in addition to that from the craters. To the crater arcs belong the open carbon arc, the enclosed carbon arc, the bulk arc. To the lamp-stream arcs belong the flame carbon arc, the magnetite arc, the mercury-vapour arcs and the tungsten arc.

Factors Governing Light Output.—The amount and quality of light from an arc depends on (1) the chemical composition of the electrodes, (2) the chemical composition, motion and pressure of the atmosphere around the arc, (3) the kind and amount of current and the voltage across the arc, (4) the magnetic field in and around the arc, (5) the nature of the ballast in series with the arc.

Crater Area and Light in Relation to Current.—As the chief light source of a pure carbon arc is the positive crater, this crater area is a variable of great importance. The crater area depends on the composition and size of the electrodes, the current, the arc length and the chemicals in the arc. It has been found that generally with solid carbons the crater area increases 2.4 times when the current is doubled. With flame arcs the light increases faster when the current is increased. For good stability of the arc it is important to conserve the highest temperature of the cathode; this is done by using a sharp-pointed anode. The carbon arc is the most stable of all arcs that operate on alternating current, because of the high temperature of the sublimation of carbon and the low thermal conductivity and also because the flow of arc vapours unlike that of the metallic arcs, is from the hotter positive crater to the negative crater spot, which is thereby nested. The temperature of the negative spot and hence arc stability are improved by large current and high frequency.

Chemical Composition of Electrodes.—The chemical composition of the electrodes determines the brightness of the anode crater and the spectral nature of the light of the arc stream. Only materials having the highest boiling points such as carbon, zirconium oxide, tantalum and tungsten, are suitable when the light is to be produced by the brightness of the craters on the electrodes. With flaming arcs the flame materials are carried from the anode to the cathode. The inclined-trim carbons are usually made with flame material in the positive electrode only because its high heat is sufficient to fill the arc with the light-giving vapours. The magnetite arc has a comparatively cold anode, made of copper. The cathode is composed of magnetite (electrically conducting oxide of iron), titanium oxide which is the best light giver in these arcs, chromium oxide which decreases and regulates vaporization and alkali salts for improving the arc conductivity. While in the case of the flame arc the salts are carried into the arc by vaporization from the anode, in the magnetite arc the materials are carried into the arc by vaporization from the cathode. An upper limit is reached in the use of large amounts of flame material because of (1) the increased energy required to boil the greater amount of material, (2) increased cooling effect on the arc stream, and (3) the increased obstruction of light by the condensation of the flame vapours as a dust around the arc. The chemical composition of the atmosphere around the arc affects its light materially. With tungsten arcs operating in low-pressure vapours such as titanium chloride the electrodes contribute no light-giving vapours, but the atmosphere feeds the arc with light-giving chemicals. With the carbon arc, enclosures greatly increase the light. With the flame arcs, especially those giving light by chemical reaction in the arc shell, the reverse occurs.

Consumption of the Electrodes.—The consumption of the electrodes in an arc lamp depends on oxidation and volatilization. With carbon electrodes, in general, the consumption of the positive carbon is about twice that of the negative, because of the greater heating effect of the large positive crater. The consumption of both carbons increases with the current; while the lower carbon is not particularly affected, the upper carbon burns more rapidly with increasing arc voltage. Enclosure reduces the rate of consumption of the carbons.

Colour Resources of the Arc.—As the sun gives a colour temperature of about 6,500° K., and the positive-carbon arc a colour temperature of about 3,700° K. it can readily be seen why the light of the arc is more yellow in colour. The A.C. carbon arc is more yellow than the D.C. arc because of the lower average temperature of the craters, as each crater is a positive only half of the time. The addition of chemicals to the arc greatly extends the range of colours obtainable. In Table II the best materials for producing various colours are given.

TABLE II.
Colour of Light in Relation to Material in the Arc

Colour of light	Material in the arc
Red	Strontium, yttrium
Yellow	Calcium fluoride
Green	Erbium, thallium, mercury
Blue-white	Rare earths, uranium, iron, titanium
Ultra-violet	Uranium, iron, mercury

Conductivity of Arc Vapours.—The conductivity of arc vapours increases very rapidly with the temperature. This is one of the factors that tend to force the current toward the centre of the arc and thereby further increase its temperature and conductivity. The electrical conductivity of elements in the arc depends largely on the ease with which they give off electrons. In carbon arcs, it is common to use alkali salts, which are called arc supporters, for the purpose of improving the arc steadiness and the ease of its control.

Relation of Arc Voltage to Arc Length.—The relation of arc voltage to arc length is that of a linear function. The minimum voltage below which the arc is inoperative is called the "starting arc voltage." For the carbon arc this is about 40 volts, for the flame arc about 20 volts. The great increase in the length of the flame arc over the pure carbon arc makes it less sensitive to mechanical deficiencies in the drawings of the arc.

Relation of Current to Efficiency.—With the pure carbon arc, on either direct or alternating current, the light increases with the current as the 1.4 power. With flame and magnetite arcs, the visual light increases with the current to the 1.6 power. With flame arcs of the tungsten type, data indicate that the light increases as the square of the current.

Series Arrangement of Arc.—The ideal circuit for arc lamps is the constant-current or series circuit, in which all the power can be utilized in the arcs themselves. In American cities, series circuits operating with several thousand volts are common, while in Europe the multiple arrangement of arc lamps predominates. Low voltage of the arc has the advantage, sometimes of great practical value, of increasing the number of lamps per series circuit of fixed voltage.

Multiple Arrangement of Arcs.—The multiple arrangement of arcs for street lighting has been extensively used in Europe with flame arcs but has not been developed in America. The objection to the multiple arrangement is the loss of energy in the ballast of the arc lamps.

Importance of Arc Control.—Since the arc is characterized by a marked decrease of its resistance with an increase in current, the arc voltage also decreases. Hence, the maintenance of a stable arc depends very much upon the kind and amount of external resistance in series with it. This feature of the arc is an advantage from the standpoint of wide regulation but it is a disadvantage from the standpoint of the power lost externally to the arc in its current-regulating apparatus. On a multiple circuit the arc ballast may consume 1 to 30% of the total electrical energy used, while on a series circuit this loss is avoided because constant current is supplied by the generating apparatus.

Arc Ballast.—On direct current the arc ballast is usually a resistance wire with a low temperature coefficient of resistance so that, as the resistance heats up, the arc regulation will not change. If the resistance is arranged on a magnetic core, the steadiness of the arc is improved. On alternating-current circuits, reactance may be, and usually is, employed instead of the steady resistance, and the waste of power is thereby greatly de-

red. An important aspect in determining the kind of ballast which should be used in an arc is its effect on the efficiency of the arc itself. In the case of the carbon arc the use of a reactance decreases slightly the lumens per arc watt. The reverse results with the flame arc.

GASEOUS VAPOUR LAMPS

About 1890 Dr D McFarlan Moore tested a large number of gaseous lamp designs containing all possible gases and a great many vapours. The ones most commercially successful have been the relatively low-voltage, long-tube nitrogen or carbon-dioxide filled lamps. The former yield yellow-orange tinted light, the latter, white. With the former efficiencies of 6 lumens per watt are attainable, with the latter 2 lumens per watt. With the attainment of efficiencies of the order of 10 lumens per watt in the tungsten lamp the lamps were doomed as commercial sources for general illumination. However, where accurate colour matching of objects is of interest, the carbon-dioxide filled tube still finds a commercial application.

The Mercury Vapour Lamp.—The Cooper-Hewitt mercury-vapour lamp was first exhibited in 1901. The present standard lamps range in size from 200 watts to 1,600 watts. They consist of a tube of glass containing mercury, mercury vapour and wires sealed into the ends of the tube and attached to a cathode electrode of metallic mercury and a cup-shaped anode electrode of iron to conduct electricity to and from the current-carrying vapour.

TABLE III

	Sensation value		
	Red	Green	Blue
	%	%	%
Black body (perfect radiator)	33.3	33.3	33.3
Blue sky	26.8	27.2	25.0
Afternoon sun	57.1	37.3	25.0
Carbon (gen) lamp	50.9	40.6	8.5
D.C. carbon arc	41.0	36.3	22.7
Mercury-vapour arc	29.0	30.3	40.7
Hefner lamp	54.3	39.5	6.2
Carbon incandescent lamp	51.1	40.5	8.4
Acetylene	48.0	40.8	10.6
Tungsten incandescent lamp	48.3	40.8	10.0
Nernst	49.2	40.7	10.1
Incandescent gas mantle, 3/4% cerium	42.5	40.8	16.7
Incandescent gas mantle, 1/2% cerium	45.4	42.0	12.6
Incandescent gas mantle, 1 1/4% cerium	47.2	41.8	11.0
Yellow-flame arc	52.0	37.5	10.5
Moore carbon-dioxide tube	31.3	31.0	37.7

The arc current may be considered as a continuous drift of electrons from the cathode to the anode and a relatively much slower movement of positive ions toward the cathode. The whiteness of the mercury-vapour light is due to the combination of the nearly complementary hues of the yellow-green lines with the blue and violet lines. On the basis that white light is one-third each of red, green and blue, the mercury arc light gives the effect of being 29% red, 30% green and 41% blue. Green and red produce the sensation of yellow. This excess of blue and green is quite apparent. The variation from whiteness in comparison with other commercial illuminants and for sunlight is shown in Table III.

The Alternating Current Mercury Vapour Lamp.—The construction of the A.C. mercury-vapour lamp is identical with that of the D.C. lamp except that there are two anode electrodes. The current in the lamp tube is a pulsating direct current of a frequency twice that of the alternating current. The mercury arc is essentially an unidirectional conductor because it is dependent upon the existence of a so-called cathode "hot spot" which forms on the mercury electrode but not on the iron electrode.

Neon Lamps.—A development of a gaseous conductor tube employing neon gas, which dates back to about 1911, has in recent years come into some prominence for certain special applications. By applying a high voltage to tubes fitted with electrodes and containing neon gas the electrical discharge through the gas causes

a luminous glow. The neon lamp consists of a section of glass tubing varying in length from 10 to 20 ft and when used for electrical displays is bent to form the desired letters or pattern. Neon produces a characteristic reddish-orange glow at a fairly high efficiency (12 to 20 lumens per watt). This colour is quite distinctive and is effective for electrical display even in daylight. Because of the fact that red rays penetrate fog and heavy atmosphere better than the other colours, some application of neon for signal purposes and for aviation beacons have been made. By the addition of slight amounts of mercury a light blue colour is obtained. By adding other gases in conjunction with neon or by using coloured glass for the tubing other colours are obtained, usually, however, at some sacrifice in luminous efficiency. The further development of theory of electric discharges in vacuum as well as in the rare gases are likely to produce far-reaching results in the practical application of illuminants of this character. Some work which is still in the experimental stage, is being done on the so-called "hot cathode" tube which operates on standard 110 volt circuits.

INCANDESCENT LAMPS

Because of their flexibility of use and convenience incandescent lamps have become the most important of all illuminants. Since the last major development in incandescent lamps the gas-filled bulb in 1913, there have been many improvements that have increased their field of application. Their size ranges from the so-called "grain of wheat" of a half of a watt consumption such as used in surgical instruments, to commercial types of 30 kw lamps and above. In 1885, five years after the introduction of the incandescent lamp, there were approximately a million lamps sold. The lamp consumption in 1928 for the world was more than 1,000,000,000 lamps, an increase of more than 1,000% since 1885. In 1928 lamp prices in the United States were only about 40% of the pre-war prices of 1914, in spite of the fact that labour and material costs had nearly doubled. As late as 1920 lamp manufacturing was largely a matter of many hand operations. About that time automatic machines replaced a score of hand operations in the assembly of the stem, leading-in-wires and filament support mounting.

Lamp Development.—Important developments on "getters" have been made. These are chemicals, principally of the halogen group which react to perfect the vacuum in the bulb, and unite with the disintegrated particles of tungsten to produce a white deposit on the inner surface of the bulb, thus helping to maintain the candle-power. Developments in coiling the filament methods of inspection of wire drawing and coiling processes have accounted for great advances in uniformity of life and efficiency. The tipless process of lamp manufacture perfected by Mitchell and White of the General Electric Company, not only improved the physical aspect of the lamp, but made for more economic lamp production. Pipkin's invention of the inside-frosting process in 1925 was a major development in so far as it cleared the way for standardization of lamps.

Actual Efficiency of Lamps.—While vast improvements have been made in the incandescent lamp from its inception the lamp is still relatively inefficient as a transformer of electrical energy into light. In a vacuum lamp about 92% of the energy put into it is radiated, the remaining 8% being conducted away as heat through the leading-in wires and anchors. Of the 92% radiated only a small part appears as energy within the visible spectrum, corresponding to about 6% of the total energy put into the lamp, so that the lamp as a lighting device may be considered as having an "optical" or actual efficiency of 6%, that is, in a 40 watt 115 volt vacuum lamp only about 2 1/2 watts appear in the visible spectrum. In a gas-filled lamp the "optical" efficiency is about 8 to 10%. These figures for both the vacuum and gas-filled lamps are only general, the actual values depending on the operating temperature of the filament, which in turn largely depends on the size of lamp. In practice the efficiency of lamps is expressed in "lumens per watt" (LPW). If all the energy put into a lamp came out as a radiated energy within the visible spectrum, the LPW of such a lamp would depend upon the amount of energy

In each wave length that is a criterion as to predominating colour of the light.

"Visual" Efficiency of Lamps.—The efficiency of a lamp expressed in LPW compared with maximum efficiency at which light can possibly be produced (620 LPW) is called the "visual" efficiency of the lamp. Thus an incandescent lamp operating at 20 LPW has a visual efficiency of about 3.2% (20 divided by 620). It should be noted, however, that the colour of the light of this incandescent lamp is different from that of the light produced by a wave length of 556 μ , having a maximum efficiency of about 100 LPW.

Characteristics of Incandescent Lamps.—Increasing the voltage of a lamp results in higher filament temperature, a higher light output, a higher wattage input and a shorter life. The light output increases at a higher rate than the wattage input and therefore a higher lumens per watt is obtained. The variation of amperes, watts, ohms, lumens (candlepower) and lumens per watt with varying volts can be determined experimentally on a photometer.

Life Performance.—As a lamp burns the filament vaporizes condensing on and darkening the inside of the bulb. This darkening cuts off some of the light given by the lamp. Chemicals called getters are put inside the bulb to convert this deposit into a lighter shade so that there will be less absorption of the light. There is a further reduction in lumens of a multiple lamp during its life due to the evaporation of the filament, which becomes thinner as the lamp burns. This increases the resistance of the filament so that it consumes less watts, hence operates at a lower temperature and so gives less light.

Size of Filament.—The wattage input in a lamp is greater than the amount radiated due to the energy in the heat conducted away by the leading-in wires and anchors, the rate at which energy is radiated from the filament at these points due to their lower temperatures, is less than that from the main body of the filament. In a gas-filled lamp an even greater wattage input is necessary, due to the heat conducted away by the gas. Thus, in order that a filament may operate at a certain temperature, its surface area must be taken into consideration. There is but one possible filament length and diameter which has the right surface to operate at the desired temperature. The 50-watt, 115 volt lamp has a filament length of 17.4 inches and a filament diameter of 0.0016 inches.

Filament Operating Temperature.—It is desirable to operate the filament at as high a temperature as possible in order to get the most light for the energy put into the lamp. The limiting temperature is, of course, the melting point of the filament material. However, the material evaporates at temperatures below the melting point, the lower the temperature the lower the rate of vaporization. The filament becomes thinner as its surface vaporizes until it finally burns out if it has not been broken beforehand. Thus the higher the temperature the shorter the life of the filament, so the operating temperature must be considerably below the melting point in order to obtain a reasonable life. Filament temperatures range from 2400° K to 3100° K for lamp sizes from 25 to 1000 watts (K = Kelvin).

The Vacuum.—If the bulb were not exhausted, the oxygen of the air in the bulb would chemically combine with the hot tungsten filament. This would produce a white smoke and the filament would immediately burn out. The absence of a gas in the bulb eliminates the loss of heat by convection and conduction.

Inert Gas Bulbs.—By filling the bulb with an inert gas which will not chemically combine with the filament, the rate at which the filament material evaporates is retarded. The use of gas increases the loss of energy put into the lamp owing to the conduction and convection of heat by the gas from the filament. In order to reduce the amount lost by conduction, the gas used should have as poor a heat conductivity as possible. Originally nitrogen was used, but argon with a small percentage of nitrogen is now used.

Bulb Temperatures.—The melting point of glass is within the range of 2,200 to 2,700° F depending on the kind of glass. The temperature at which an ordinary bulb will soften is about 600° F. The size of the bulbs used for lamps of various wattages

must therefore be such that they will radiate the heat from the filament and operate at sufficiently low temperature so that they do not soften. The actual operating temperature of the bulb is of the order of 150° to 400° F depending on the lamp wattage.

Bulb Finishes.—Since 1926 all bulbs up to and including the 100 watt size have been regularly supplied inside frosted. This process accomplishes diffusion of light from the intensely brilliant filament with little sacrifice in efficiency. In the past it was necessary to resort to outside etching, spray coating or special white glass bulbs with a loss of 5 to 25% of the light by absorption and at the same time such lamps collected dirt readily and were hard to clean. Above 100 watt lamps are supplied with either clear or white bowl bulbs. The latter differ from clear bulbs only that the lower part of the bulb is sprayed with a superficial coating of white enamel. Coloured lamps are made either in natural coloured bulbs or with coatings consisting of finely-ground pigment mixed with a permanent vehicle and sprayed on the bulbs, either on the outside or in more recent practice on the inside. Lamps may be obtained also with special blue-green glass bulbs producing a whiter quality of light and are designated as "daylight" lamps.

Types of Bases.—In the United States the matter of base standardization was taken up early so that to-day there remain but four standard types in general use aside from those used for miniature lamps. These are designated as mogul, medium, intermediate and candelabra, indicating the type of socket in which each base will fit. Mogul bases are used on lamps above 200 watts, medium bases used on all sizes below 200 watts. The intermediate and candelabra are used only on certain types of small wattage lamps for special decorative service. (W. M. SK; C. E. W.)

LIGHTING IN PRACTICE

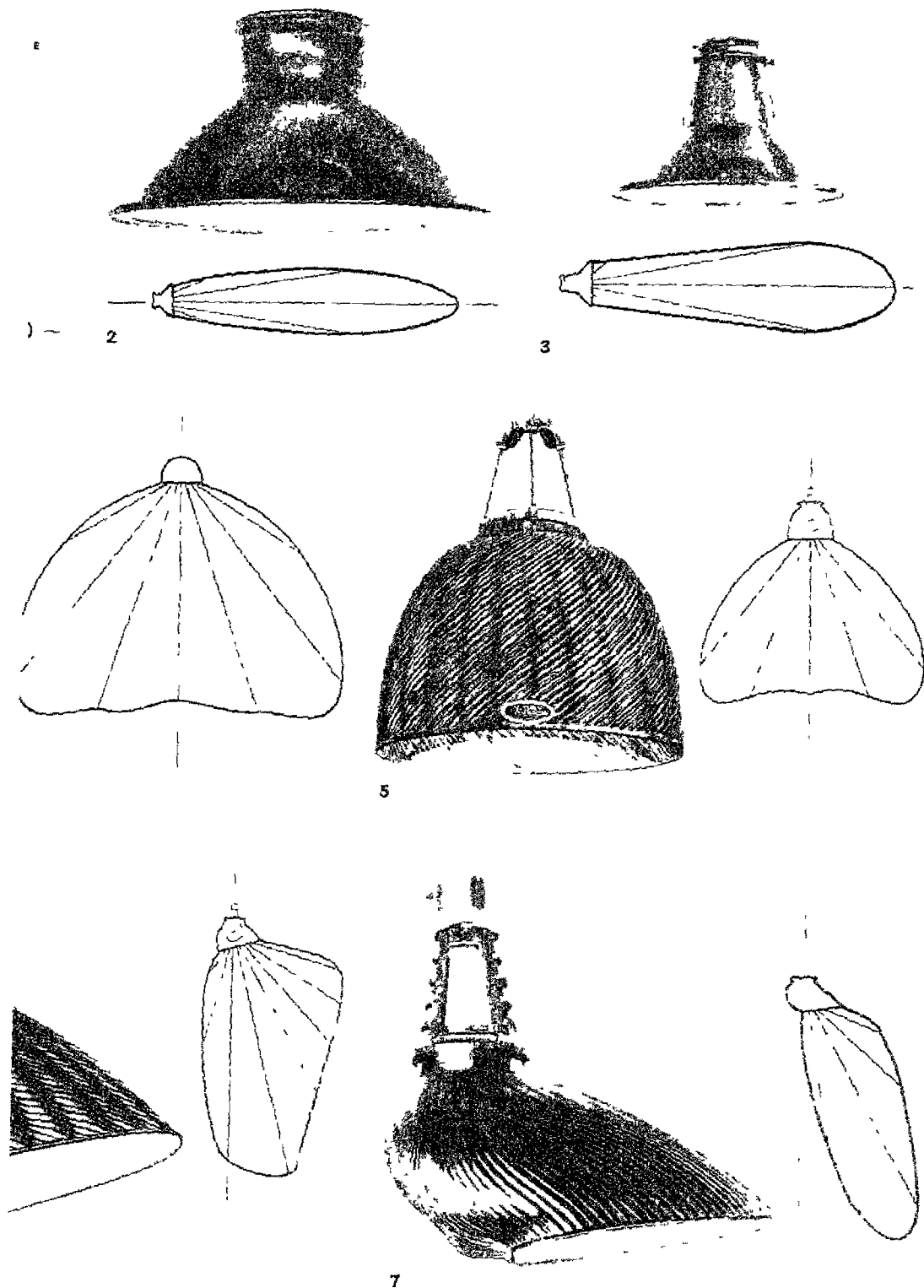
Since the phenomenally quick development in the efficiency and the low cost of electric light there has been a natural trend on the part of the public toward the use of too much light. For a comparatively small amount enough light can be had in any modern home to become dangerous to the eyesight of the occupants. Like the dangers attendant upon other discoveries in electricity, such as those of the X-ray, this new condition will undoubtedly result in much that is harmful before sufficient information is gained and generally understood concerning it.

GENERAL THEORY

In order to acquire an understanding of lighting practice, it is necessary to consider various phases, such as glare, the direction from which light enters the eyes, the use of highlights and shadows, and the relationship of colour to mood.

Glare.—Glare, direct or reflected, must be avoided by the use of one of two methods. (1) a proper diffusion of the concentrated lighting source through a shade; (2) a proper diffusion obtained through reflection upon some surface or surfaces. Even when candles or oil-lamps were in use, unpleasant glare was encountered, and many designers provided them with shields or shades. The light of one candle flame, as ordinarily placed for reading, creates glare and it is proportionately necessary that modern units, giving from 15 to 2,000 candle-power, be carefully considered.

Avoidance of Light Above Eye-level.—Since the beginning of civilization man looking downward using his eyes in reading, writing and in other activities, has caused the axis of the eye to be developed accordingly, it not being horizontal but actually tipped downward (see fig. 1, EYE, ANATOMY OF), with nerves equipped to receive a strong stimulus from below. Thus when a stimulus, such as strong light, is given the eye from above, strain is likely to result. Protection against a stimulus is one of the functions of the eyelids. For the same reason men, living in latitudes of brilliant sunlight or where the sun reaches a position almost directly overhead, such as is the case with the American cowboy and the Australian worker, wear a broad-brimmed hat. Therefore it is advisable to avoid strong illumination, no matter how well diffused in the upper part of a room. Test of this fact may be made by shielding the eyes with the cupped hand after having been in a room for three or four minutes. If there is any appreciable relief the light in the upper part of the room is too bright.



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ector, 250 watts, an extra heavy gauge steel
 ective and night construction work Has
 th universal adjustment and simple device

y floodlighting reflector for use in ceilings and
 Diagram below indicates area of most
 terminated by photometer experiments

ector, placed within a cove or trough near
 room or display window

ighting reflector for use in small space, conch

5. Large industrial reflector used in deep bay or high-ceiling rooms. This type of reflector gives a wide distribution of light and is used in foundries, gymnasiums and auditoriums. Spiral construction of reflector, together with curves, eliminates shadows.

6. Show-window reflector of angle type used in show-windows where the display extends for a distance up side walls or rear of the window.

7. Unit designed to eliminate back wall splash by reflecting light out from wall. The spiral and vertical corrugations completely break up the filament shadows, resulting in light which is absolutely free of streaked or spotted effects, giving perfect illumination to space.



Light and Shadow.—In the avoidance of glare many systems have been devised for the proper diffusion of high intensities. Among those which have had great popularity are the so-called indirect and semi-indirect methods which project the light either wholly or in part against the ceiling from which it is reflected and diffused. Such systems generally tend to eliminate the desirable variety of light and shadow. If the lighting in a room is absolutely constant the iris of the eye maintains a constant aperture which oculists believe to result in fatigue, just as it is tiring to maintain a constant strain upon any muscle of the body. Some shadows in a room, therefore, are a relief and it is often not wise to eliminate them.

Colour and Mood.—The reaction of all animal and much plant life to the influence of the colour of light is remarkable and this influence is felt very strongly by human beings. Colours of light such as blues and greens near the violet end of the spectrum are depressing or narcotic in their effect, while those near the red end of the spectrum are stimulating. The mood felt in watching a sunset deepen and cool into bluer tones is quite different from that felt while sitting under a brilliant noonday sun. Moonlight has a somewhat similar effect. Often the stimulant of a too warm light, though not a strain to the eyes, becomes distinctly tiring to the whole body and on the contrary, it is difficult to "stay awake" in a too blue light. This fact must be kept in mind and where possible lighting should be made suitable to the temperament of the individual or to the group of individuals, and at all times it should be made suitable to the mood desired in the lighted room. As an instance, the lighting in an office of a nervous, high-strung business man should be somewhat cooler than in that of a phlegmatic type, and the bright warm gay light which is pleasant in a dining-room may too quickly become tiring in a living-room.

AESTHETIC THEORY

Accent of Essentials.—Many modern interiors have their lighting units arranged with an utter disregard for the particular lighting requirements of each room. A living-room may incorporate a beautiful fireplace, above which is an overmantel painting which often cannot be seen because the architect, not having planned for the lighting of the picture, has placed wall-brackets on each side, throwing the light, even though properly shaded only against the wall behind. The result is darkness on the picture and distracting spots of light on each side. Properly designed lighting accents the essentials, illuminates the outstanding features and allows shadow to soften the less important parts just as from a practical viewpoint, properly designed lighting in a factory illuminates that part of a machine which the workman must see clearly. This fact is brought out in Plate I, fig. 4, which shows a lack of properly accented high-light. The rule can, however, be carried too far, as shown in fig. 5 in which the shadows are too marked and the tops of the benches too brilliantly accented. Fig. 6 shows a very pleasing arrangement in which there are some shadows toward the back of the room with a general illumination and a more powerful specialized illumination over each bench. These appear to be non-aesthetic considerations but they serve to point out the practical reasons which undoubtedly underlie the aesthetic principle, and in treating a room it will be found that the result of a strong general illumination of the indirect type is tiresome, while the treatment of a room incorporating highlights drawing attention to essentials and permitting deep rich shadows will make the room more interesting.

Composition.—Not only is it necessary to accent essentials but it is equally necessary if the interior is to be beautifully illuminated, to consider the composition or pattern of the light areas. Thus, the use of a powerful central unit or of a string of equally spaced wall-brackets cannot possibly provide the beauty of composition obtained through a variety of carefully considered units, perhaps illuminating a series of paintings of various sizes, a tapestry and nearby doorway or some other pre-arranged feature of the interior.

Sources.—Many of the more beautifully fitted modern interiors depend for their light upon hidden units such as hollow-cove arrangements around the moulding of a room which shed a soft

illumination upon the ceiling or hidden reflectors in mantel-piece which may throw a light upon ornaments above. It is questionable, however, whether such arrangements disregard an important possibility for the aesthetic enhancement of a room. From the time when a caveman sat and dreamed over the embers of his fire man has thought of light as being beautiful, and there is no doubt but what the source of light can often be made as beautiful as the object illuminated. (See LAMPS, MODERN.)

Sympathetic Colour.—Colour may be considered to consist of only those rays of light which are not absorbed by an object and which are reflected to the eye. Any colour, if illuminated by a light made up of its pure complementary colour will appear black. Pure white light or its approximate, daylight, will show colours in their true valuation. Many beautiful colours which enhance the general effect of an interior in the day-time may be lost at night. Interior colour must be studied therefore from the viewpoint not only of its creation of mood but for the purpose of sympathetic relationships with the colours originally provided. (See LIGHT.)

EQUIPMENT

The equipment with which the foregoing general theories in lighting can be carried out has been partially described in the early section of this article, and further reference will be found in the articles OPTICS, LIGHT, LENSES.

Reflectors and Spotlights.—Modern standard reflectors as shown in Plate III, illustrate the light areas produced in various types. These reflectors can be introduced with proper ventilation into comparatively small areas, making it possible to project light in almost any way. Spotlights can be obtained which will illuminate as desired a given area, flood-lights are designed to throw a practically flat or even value of light over a broad area, other reflectors, such as those often used for shop windows, combine the two functions and throw a broad area of flood-light, as well as a concentrated area. It is well therefore, when planning the lighting of an interior to consult a specialist who has made a study of reflectors and who can meet the necessary requirements. (See REFLECTORS.)

Luminaires or Chandeliers.—Besides these more modern methods of projecting light it is still the custom to rely upon fixtures which with certain modifications are similar to those originally designed for the holding of candle or oil-lamps. Thus in Plate II are shown chandeliers (fig. 2 and 3) closely designed after the old-fashioned oil-burning or candle-holding types. The candles have been eliminated and reflectors so located as to produce a typical indirect lighting system adequate for this use. The question has been disputed aesthetically as to whether the old forms are best suited for the uses of electric light. It is believed by many that modern lighting fixtures should be more scientifically designed than as is done at the present time. However such important ornaments as chandeliers must closely harmonize with the architectural treatment of a room and it is therefore necessary that the designer consider both the new element and the position of the art object which is to hold it.

Sconces or Sidewall-brackets.—While these are used sometimes to provide general illumination the present tendency is to treat them as a source of local illumination. When used they must be properly shaded and the general designs should be such that they fit in with their architectural surroundings. The architect should be warned, moreover, that the little scrolls with which his draftsmen often decorate a plain wall area which seems to need some design in it may unless the sconces so indicated are considered from the viewpoint of light, become unpleasant blots of white illumination which are likely to ruin his scheme.

Lamps.—Under the article LAMPS, MODERN, the general design and use of lamps has been treated, but it may be well to say here that one should avoid the use of too many units of portable lamps just as one should avoid them where possible on the wall and it is well to keep in mind that the primary use for these portable units is that of providing light where it is found to be actually necessary for one purpose or another, such as for reading, for writing at a desk for illumination of the keyboard and

value of the electric light
 brackets are to establish the general atmosphere of
 the room. At times of course the portable units can be impressed
 into the double service of throwing light for some special purpose
 and at the same time of adding to the general illumination. How-
 ever the best reading lamps are those which have shades com-
 pactly heavy for it has been found that a concentration of
 light upon the book or paper one is reading or writing upon
 with a shadow above the eye-level is most restful and conducive
 to study.

Screens.—In the attempt to get light on the more important
 elements of a room and to work out the areas of light as a pleasant
 composition one new development has taken place: that of
 throwing translucent screens or various materials with electric
 lights behind them. Such screens can be beautifully decorative in
 themselves and can often be placed so as to throw an interesting
 and desirable light upon a picture or tapestry behind them.

Dimmers.—Many systems of lighting include the use of dim-
 ming apparatus—slugs constructed with resistance coils which,
 if the system includes red, yellow and blue lamps, can produce
 by various windings a wide range of colours and tints and which
 have the added advantage of a range control of the candle-power
 thus making it possible to acquire different tones of lighting in
 the same room.

Stain.—The colour of light can be governed to a certain
 degree by the colour of the original lamps or by the introduction
 of glass plates in front of reflectors. In the making of reading
 lamps the light of the shade can control to some degree the
 colour of light. The first methods unless employed in conjunc-
 tion with dimmers, are of little value. The latter method is
 limited in scope and has the disadvantage that the shade when so
 treated usually appears quite different from the base for which it
 was designed. Stains, however have been devised which will last
 nearly as long, when properly applied as the electric lamp itself
 and these stains can be obtained in a wide variety of clear
 brilliant colours which can be mixed to any hue desired. The
 application consists simply of thoroughly cleaning the bulb, then
 lighting it until it is warm; after which it is dipped into the stain
 which quickly and evenly dries. It is advisable to keep a quantity
 of the primary hues of colour on hand to facilitate in the mixing
 of the exact tint which may be required. The liquid used for
 frosting may be employed in the making of these tints lighter as
 it is nearly pure white. There are also available on the market
 lamps in a great variety of colours. These are either coloured by a
 superficial spray coating or more recently made with permanent
 colouring on the inside of the bulb. But it is seldom that these
 lamps can be used for the reason that the coloration is so crude
 and often so strong as to ruin the desired effect, though it may be
 hoped at some future time that the electrical companies producing
 these bulbs will improve them and offer on the market such a
 variety that the necessity for the use of stains will be eliminated.

LIGHTING PRACTICE IN THE HOME

In order to give the reader some idea of the application of the
 foregoing principles the various common problems will be treated
 separately. The most complicated problems naturally arise in the
 lighting of the home, as it is here that many hours are spent in
 pleasure labour or in resting. It is during the evening particularly
 that proper lighting has its greatest significance.

The Living-room.—The living-room should be treated with
 two systems of lighting: (1) the *special system* consisting of
 reading-lamps, piano-lamps, desk-lamps, etc., and (2) the *general*
system consisting of side-wall-brackets, chandeliers, general illumina-
 tion of paintings or other features. It may be said that the first
 system is for practical use of the family, while the second is
 used chiefly to brighten and enliven the room when desired. In
 planning the first or "practical" system of lighting, it is necessary
 to develop a floor-plan on which is shown the arrangement of
 furniture. All areas which require "reading light" should be
 carefully marked on this plan and as they are indicated the
 elevations of the room should be considered. Upon these eleva-

tion the lamp should be roughly proportioned with attention
 only to the proportions and masses of that elevation, for, as was
 pointed out in the article *LAMPS, MODERN*, the size of the lamp
 has little or nothing to do with the candle-power or the area of
 light which is desired. After these preliminaries the lamp should
 be carefully designed so as to meet the requirements: (1) as to
 area and candle-power of light required; (2) as art objects in the
 room are proportionate with the table upon which they stand
 and with their surroundings in general. (See *LAMP DESIGN*.)
 It is recognized that the use of a large amount of data would be
 necessary to obtain these results. Some of these data may not be
 available for the particular problem at hand.

The present broad problem is to bring to all homes good light-
 ing that will safeguard the eyesight.

The general system of effective lighting is often more a matter
 of experimentation, although the underlying and guiding prin-
 ciples are the same. On the side elevations of the room or the
 walls as they appear with all the furniture and various ornaments
 and decoration certain important elements of the decoration
 must be noted concerning the intensities of light desired for often
 parts of the decoration will demand more illumination than others.
 When these ideal arrangements have been planned it is necessary
 to devise means for meeting them. Sometimes a painting or tape-
 stry hanging above a table upon which stands a reading lamp can be
 beautifully illuminated by the introduction of a thin or trans-
 parent area in the back of the reading lampshade itself. Small
 spotlight equipment can be employed in the establishment of
 these areas. Even the side-wall-brackets can at times be utilized
 and shades made for them which will divert the light to one or
 another side as is required. In the treatment of the modern art
 rooms much thought has been given to the making of lighting
 areas which are in themselves beautiful. The method of arriving
 at them is the same as has already been described.

It has been stated that the general system of lighting in a
 room is devised for the purpose of generally enlivening it and
 one would suppose that it is therefore necessary to include in this
 general system a considerable candle-power. This confronts us
 with the problem of eliminating the eye-strain which occurs when
 the upper part of the room is too brilliant. The solution lies in
 the application of the rule of colour and mood. By keeping the
 intensity to the minimum and warming the general system
 with amber tones it will be found to be quite as effective in adding
 glow to the room and eliminating eye-strain.

Dining-room.—The problem of properly lighting the dining-
 room, in which people sit near the centre around a table, is a
 difficult one. Any wall treatment is bound to throw the shadows
 of the people sitting around the table upon it. Many modern
 designers have simply evaded the question and the result is that
 many people use candles upon the table. If the table is large
 enough and the candlesticks properly designed, wax candles are
 very beautiful but they are likely to cause a considerable amount
 of glare if near the eye-level of people sitting about the table.
 The simplest method for meeting the problem is through the use
 of a chandelier properly shaded to throw the light downward upon
 the table.

However, the whole tendency of modern decoration is toward
 the elimination of such objects in the decoration scheme. Indirect
 lighting is out of the question as it gives a flat, uninteresting
 result without proper accent to the table. A reasonable solution
 seems to be the introduction of a small spotlight with adjustable
 focus either partially or wholly in the ceiling; covering this may
 be a small ornamental medallion, of plaster iron-work, or other
 material suitable to the architectural treatment. Such a lighting
 unit will throw a beam of light of the required intensity down
 upon the table itself and as the angle of incidence is almost per-
 pendicular there is not likely to be a resultant glare in the eyes
 of those seated about the table. Moreover, the highlights of the
 glass and other table-ware will be brought out in their fullest
 brilliancy. The dining-room light should be somewhat warmer
 in colour and more brilliant than that in the general system of
 the living-room. It can be more brilliant, for many hours are not
 spent in the dining-room and a warm light tending to create a

of a room and edge on

The Kitchen. The problem of the kitchen chiefly one of the removal of shadow and the procuring of adequate light in all places where needed. The sink, the top of the stove and even the interior of the refrigerator and other cabinets must be clearly illuminated. For this purpose a direct or a semi-indirect unit can be used placed in some central position and aided if it does not meet all the requirements, by one or two small units. It is highly desirable that the kitchen walls be white or a very light colour. An interesting comparison of the result of wall treatments is shown in Plate I (figs. 2 and 3) in which the lighting arrangement is identical, but where the wall treatments vary. Aesthetic problems need relatively little consideration in connection with this room as its chief lighting requirements are toward the procuring of sanitation and efficiency. It is not so harmful to use an indirect system in the kitchen as it is seldom occupied for long periods. If, however, the housewife is doing her own kitchen work it is advisable to cut down candle-power and somewhat increase the warmth of the light, and if considerable time is to be spent in this room individual shaded units should be installed where required, in addition to a general semi-indirect unit of low intensity.

The Bedroom.—Even though a special room may be provided as a dressing-room, or the bathroom used for that purpose, it is advisable to have a rather strong general system of lighting in the bedroom as it is here that it may be said one prepares oneself to go out to meet the world and it is often necessary to be able to see the effect of a costume or otherwise aid in dressing. This general system should be of high intensity as it need only be used occasionally for a comparatively few minutes. It is also desirable that this system be a white or nearly white colour and clear as possible. This system often consists of a combination of sidewall-brackets and chandelier the sidewall-brackets perhaps shaded for more general use, and the chandelier being depended upon for brilliancy. In addition, each dresser or dressing-table should have small lamps upon it, often of the candle-stick type which take up little room on the usually congested tops of these pieces of furniture.

These lamps should be provided with shades which either tip or turn so that a clear light may be had on the face of one standing before them. In addition to these arrangements it is often necessary to introduce a suspended reflector above the dressing-table, in case the chandelier does not give a sufficiently clear light properly directed to be able to see the hair. This unit can be adjustable to various heights and angles, and though shaded to permit a pleasant glow through the shade, should direct a clear beam of light. It is well to have the chandelier and this suspended unit on the same switch, with a separate switch for the control of the small lamps upon the dressing-table, bedside lamps, floor lamps and other units. If a floor lamp is used near a chaise-louche it should be small, light and easy to move, and so shaded that one does not see up underneath the shade when reclining. When this problem is difficult it is sometimes necessary to make a circular or half-circular shield which fits up underneath the shade and clamps on to the centre stem of the lamp, allowing its outer rim to meet the lower edge of the shade. These shields can be made in quarter segments and simply turned underneath the shade to shield the eyes of a person reclining.

Makers of lamps frequently make floor-lamps too high and bedside lamps too low. The bedside lamps should be so designed that the lower edge of the shade is a little above the level of a book held in the hands of a person reclining. Tipping a shade is always unsatisfactory, as the shade when rearranged usually sits askew. Moreover, when it is so tipped it throws the full brilliancy of a light against the opposite wall, causing an unpleasant glare both direct and reflected. If the bedside lamps are designed to take up as little room as possible, and to be of the correct height, all that is necessary is to place under the shades the same sort of shield described above so that it can be moved to protect the eyes of the person reclining. One type of bedside lamp is made as part of the head of the bed or another may be attached to the wall above the table. This is a practical feature as it does away with a

bulky one on the bedside table which is one of the smallest and most congested pieces of furniture in the home.

LIGHTING PRACTICE OUTSIDE THE HOME

The Office.—The lighting of a private office should be not unlike that of a living-room or library and should consist of both the special and general systems. There is a strong tendency toward the making of these rooms much more homelike than heretofore with perhaps a more severe and durable aspect. Individual lamps should be so placed to the right or left of the desk-pad as to shed a proper reading light upon it and the upper part of the room should be somewhat in shadow. If the walls are undecorated it is necessary to make use of a simple lighting fixture of the semi-indirect type with not too high candle-power and a warmed light amber being perhaps most appropriate. For large general offices in which many people are working it has been usual to have a more brilliant and natural-hued system supplemented sometimes with special lamps over each desk. Such a system is shown in factory use in Plate I, fig. 6 though perhaps the general over-head system for an office need not be quite so beautiful as is shown in this photograph, as this level of illumination was necessitated chiefly because of the danger of the various machines if not well illuminated. It is more restful if the walls of an office of large dimensions are made a medium dark colour, the loss of efficiency in lighting is not great.

Shop Windows.—In Plate II examples are given of an effective modern shop window, one properly and the other improperly illuminated. The purpose of a shop window is to attract and hold attention to merchandise and this purpose is often defeated by the flood-light systems commonly used. In fig. 4 the dress, coat and shoes are only incidental to a huge sweeping design brilliantly illuminated. In fig. 5 the gowns and other accessories stand out strongly against the dark background. High intensity of lighting in a window, if not properly done, may submerge interest in the merchandise and cause the passerby to react against it. The counteracting of reflections in the glass of shop windows by the use of powerful illumination within, is helpful during the daytime. These reflections are however, likely to be so strong that they cannot be overcome during the brighter part of the day and they are so reduced at night that they are almost negligible. One method coming into use is that of slanting the glass of the shop window inward at the top so that it stands leaning backward about 30° from the perpendicular. If then an awning is employed of an even dark colour on its underside, the passerby looks into the window and sees only this awning reflected in a flat even tone. The effect of windows so constructed is to give the impression of no glass being used and the result is a tremendously increased efficiency.

The Store.—The same principles of concentrated interest and attention by the use of proper lighting apply to the interior of the store. Strong general systems of high illumination while still widely used, are being eliminated in favour of general systems of a subdued and warmer hue. Specially illuminated show-cases have also come into use, as it has been found that they accent the merchandise, showing it off to best advantage. In the lighting of these cases sympathetic colour must be carefully studied, for such merchandise as does not have to be definitely matched can be made to look more beautiful by being shown in the right colour of light. It has been found that silver seems more brilliant and beautiful if displayed in cases in which the electric lamps are alternately arranged, daylight and ordinary tungsten. The rich warm qualities of wood in furniture stores can be shown off to best advantage with an amber-tinted light and it is not impossible to have a furniture store so arranged with booths or alcoves that the effect of specialized lighting is obtained. A beautiful table-top which appears uninteresting in the shop may be surprisingly rich in colour when seen under the library reading lamp. Meat-markets, grocery stores, etc., should present, on the contrary, an aspect of sanitation, and there is nothing so effective as pure white colour for the walls and a brilliant pure white flood-light.

Schools and Libraries.—Biologically it is unnatural for man

The main aim of the concentration upon a single object is a strain. Special care must therefore be taken in the equipment of study-rooms or reading-rooms in schools or libraries. The school lighting codes that are in use throughout the United States specify minimum values allowed and set no upper limit to the intensity of illumination. Local lighting is not recommended. It is however the author's opinion that the general system should be as subdued as possible. The specialized system however should consist of fairly brilliant units with opaque or nearly opaque shades so that it is possible for the student to have a perfect light upon his paper or book without glare and with the possibility of locking up from the printed page into shadow from time to time in order to rest his eyes. Oculists assert that this habit is helpful in elimination of eye-strain. In order to eliminate glare it is well to have the tops of desks finished with a dull mat in a dark tone, and where concentrated study is taking place it is also advisable to "warm" the individual units of lights, thus creating a slight stimulus. When light plays only upon the narrow surface which is of interest it will be found far easier to concentrate the attention. Lecture halls should be considered in much the same way as theatres and there is no real reason for the keeping of the audience under a brilliant illumination which tires the eyes. Where the reaction of the schoolroom class to what is being said must be watched by the lecturer, a soft illumination may be used, but under no conditions should this illumination be kept at the full intensity required for entrances and exits. Many yawns in audiences during lectures have their real cause in a straining lighting system.

Churches.—The problem of lighting churches is largely the same, but as a rule a higher lamp wattage is necessary because the walls are usually darker and more ornamental. Great care must be used to avoid an almost hypnotizing glare which is likely to occur on organ pipes. Various spotlights should be arranged to throw into sharp relief the face and figure of the speaker. Adequate dimming systems must be included in order to obtain all the various effects needed during services and the celebrations of church holiday ceremonials. From the aesthetic viewpoint one must not lose sight of the principle of accenting the main features of the design. Relief carvings must be illuminated by the use of screens or spotlights to bring out the modelling. Stained-glass windows which often appear dead and colourless at night should be equipped with lighting arrangements on the outside so as to show their full beauty during evening services. Other arrangements must also be made on the inside of these windows so that the effect of the building is enhanced by them at night. Altar, pulpit and other equipment must be carefully studied regarding lighting requirements. It will often be found that various coloured lights if not brilliant can be so used as to add considerably to their beauty and dignity.

Hospitals.—Hospitals have been designed as a rule with white or very light-coloured walls and many of them are also illuminated with pure white flood-lights that may result in the constant glare being very tiring to the patient reclining in bed, even though the light is diffused. The general system of a hospital should be, like that of a library, or study-room, almost negligible, and subdued to give a restful effect. Over and above the head of each bed there can be easily arranged on the wall a small lighting unit holding a 25 or 40 watt bulb, so designed as to be adjustable with a shutter to throw the light down upon the bed with shadow falling across the face of the patient. These units if properly shaded with opaque metal shades can also be arranged as to project the light no further than the foot of each individual bed, eliminating all glare in the eyes of the person in bed at the opposite side of the ward. This arrangement provides a restful and yet adequate reading light. If mounted 3 or 4 feet above the head of the bed it is completely out of reach of the patient though a cord or a pull-chain switch makes it possible for the patient to turn it on or off with little effort. For special medical attention upon patients in the ward it is only necessary to introduce a more powerful

bulb of 60 or 75 watt

The general lighting system should be cool in colour so that when the individual lights are off the ward is restful and conducive to sleep. The general system should also be provided on a second circuit with an individual switch controlling lamps of high candle-power so that when required the whole ward can be flooded with a brilliant illumination, though this illumination should never be used longer than necessary. In the treatment of the individual bed lamps, screens of coloured or tinted gelatin should be kept on hand so that they can be slipped into a slot in front of the lamp tinting the light. It will be found that these individual lamps will be preferred by the patients and especially by convalescents in warm amber or rose tones, if the colour is not too deep, as these tones are mildly stimulating and pleasant in their effect. Operating rooms should be equipped with adjustable spotlight units, four or six in number so that they can be arranged to concentrate upon the operating table from different directions. Each one of these spotlight units should have an adjustable shutter so that the beam of light can be cut down if desired. In addition a powerful semi-indirect unit or units should be used so that instrument cabinets, etc., can be easily seen. It is advisable that the walls of the operating room be a pure mat-white and that all light be also white.

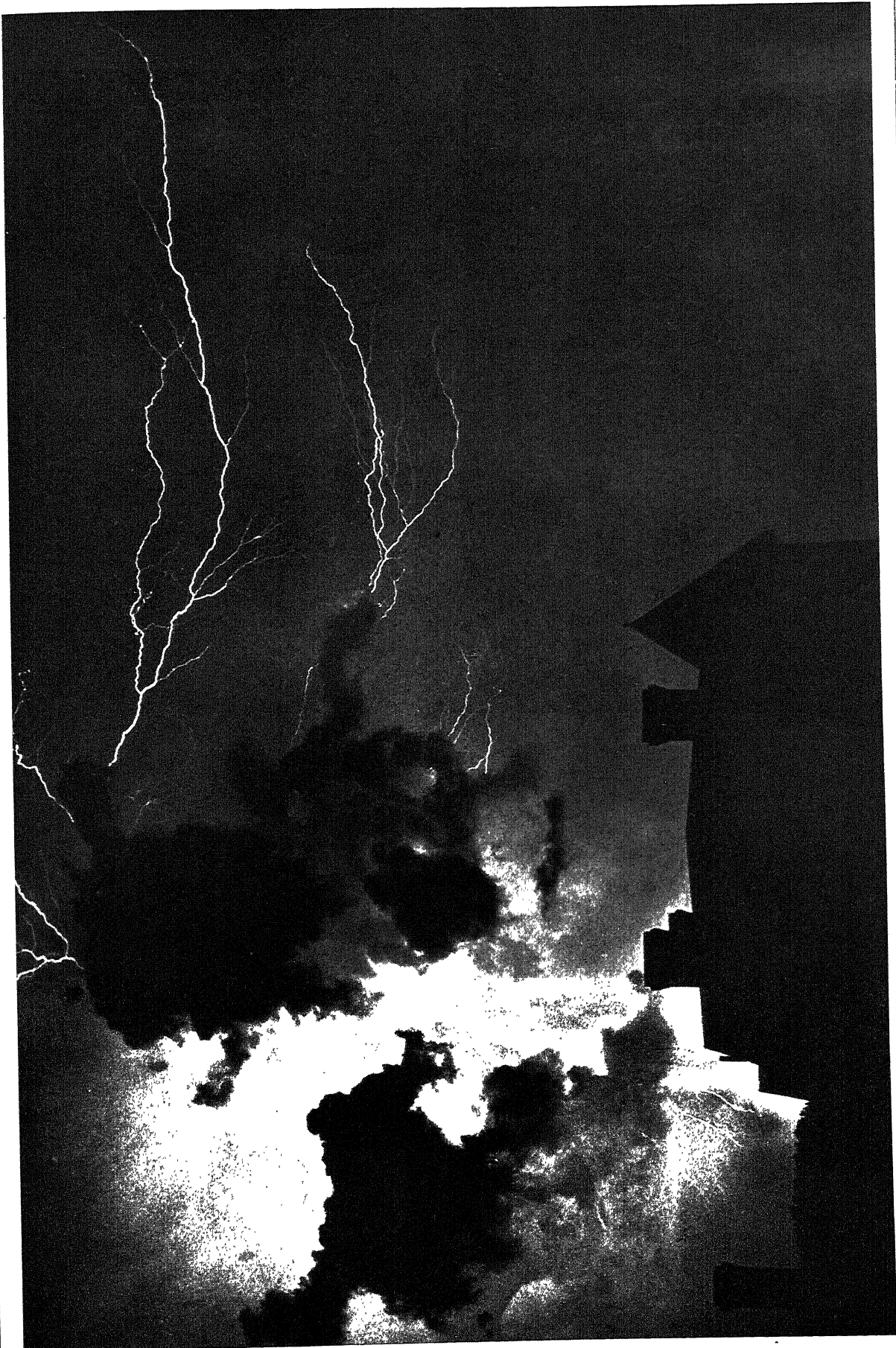
Street-lighting.—It is not possible to go into detail concerning all the various necessary requisites of proper street-lighting. The writer believes that generally street-lighting should be accomplished through units which are placed as high as is reasonably possible from the street level, that these units be sufficiently close together to make it possible to shield them at right angles to the direction in which the street runs, so that the lamp itself cannot be seen more than a block away. This allows the light shed upon an area which is sufficiently large to make use of all of the light which it can efficiently give. Long lines of street-lamps extending into distance and reflected in rainy weather upon the pavements are very confusing. It is also advisable that street-lamps be slightly tinted a warmer shade, for in this way they can be distinguished from other lights along the thoroughfare without any lessening of efficiency. This article has purposely been written without reference to technical measurements of light, as these are of broad use only to technicians who have made a study of illumination and engineering, and even those who are experienced in the work need to do a considerable amount of experimenting in order to meet all conditions.

The Factory.—It was the common practice when electric light first came into use in the factory to install local lighting with individual lamps usually without reflectors arranged at intervals in the room, and systems of this sort are commonly found in industrial plants to-day. The first improvement was that of the addition of opaque (usually metal) or semi-opaque reflectors above these units giving a greater efficiency of concentration below them. It was also found that by making the walls of an industrial plant light in colour a greater efficiency was obtained. A further improvement consisted of perhaps the only legitimate use for indirect and semi-indirect units and there was a distinct advantage in their employment though it was necessary to use a higher wattage at an additional expense. Such a system supplies a uniformly level illumination throughout, eliminating sharp shadows and severe contrasts of intensity and making each part of the room in which they are employed available for productive occupation. However, it has been found that this uniformly flat and necessarily high degree of illumination was tiring to the eyes of the employees in plants so treated, and certainly the most efficient arrangement is the combination of the two systems similar to the combination already described under the treatment of the home, consisting of a series of units in a special system, designed to produce a concentration of light upon the actual work in hand and a general system designed to eliminate all the dangers incumbent upon any plan which admits too dense shadows about the moving machines of the workshop.

The special system should be carefully arranged with attention paid to each unit so that unpleasant and hampering reflected glares are avoided. Care must be taken also so that each unit provides only

LIGHTNING

PLATE I



LIGHTNING FLASH AND SHEET LIGHTNING BEHIND DENSE CLOUDS

BY COURTESY OF THE U.S. WEATHER BUREAU