number. Thus marine plants (by assimilation) and all marine organisms (by respiration) respectively lessen and increase the concentration of carbonic acid, and so exert considerable influence on the inversely related changes of the hydroxyl-number in any body of water. The carbonic acid is also affected by the carbonates and bicarbonates brought into sea-water from the land or dispersed over the sea-floor. As a result of the successive chemical processes, the hydroxyl-number becomes greater when the sea-water dissolves carbonates from the bottom deposits. Consequently the bottom water should have a larger hydroxyl-number than that of the superjacent layers. Organic life acts on the hydroxyl-number, not merely through the carbonic acid, but also through the carbonates. By removing the calcium and magnesium carbonates from the sea-water it lowers the hydroxyl-number, but gradually, as the organisms die, the organic material and the carbonates are carried down through the deeper layers to the sea-floor. The effect of the atmosphere seems to be confined to readjusting in the upper layers the balance of carbonic acid disturbed by plant assimilation. The chemical changes consequent on an influx of fresh water have as their final expression a reduction of the hydroxyl-number; in other words, the salter the sea, the greater the hydroxyl-number, and the more alkaline the water. The concentration of oxygen in sea-water is, by reason of the vital processes mentioned above, inversely proportional to that of carbonic acid, and therefore stands in direct relation to the hydroxyl-number.

The principles thus worked out by Mr. Gaarder from theoretical interpretation of previous observations have been applied by him to the fjord-waters of western Norway, and have there found both confirmation and extension.

Of the other papers, Mr. J. A. Grieg's inquiry into the age of starfish individuals collected from various localities in the North Sea and North Atlantic is not without its practical bearing. It is found that in any given spot the starfish, like the brittle-stars, are represented only, or in great majority, by the product of a single year. The length of life of a starfish is usually about four years. The species as yet investigated, however, do not appear to include the forms of chief economic importance.

Dr. J. D. Landmark contributes a well-illustrated discussion of the valley system at Dale, in Bruvik; and Prof. G. O. Sars describes, under the name *Urocopia singularis*, a new member of the Copepod family Lichomolgidæ, which, unlike its confamiliars, lives, not near the shore, but in the open sea at some distance from the bottom, and, presumably for this reason, has its caudal rami broadened into oar-blades

RESEARCH ORGANISATION IN INDUSTRIAL WORKS.[1]

Introduction.

NO plans for the future development of industry are now considered complete unless they provide for scientific research, and although this is necessary to a greater or less degree in all industries, in no industry is there such scope for research as in the highly technical electrical industry.

During the past few years there has been a great deal of research directly controlled by or associated with industry. For instance, while universities and technical colleges have in the past conducted research, only a fraction of which has been directed to industrial requirements, the tendency is for an increasing proportion of the research carried out in such institutions to be of an industrial character. Various other laboratories and organisations, together with scientific and engineering societies, have either conducted or financially supported research in connection with their interests.

In a national sense, the Department of Scientific and Industrial Research with its large Treasury grant is endeavouring by the establishment of research associations to develop means whereby co-operative research can be established in various industries, with the initial assistance of Government funds.

Many of these laboratories will provide new industrial knowledge for the common use of those able to make use of it, and, while there is need for them, the individual manufacturer invariably has his own immediate problems, for which he requires special provision directly under his control. In such cases he has to consider whether he should establish his own research organisation or whether he can be efficiently and suitably served by research associations, university or other laboratories. Whatever facilities are available, it is clear that in many instances it is advisable for firms—particularly large ones—to establish research organisations in connection with their own factories.

I.—*Functions of the Organisation.*

The function of an industrial research organisation in its broadest sense is to acquire and to apply all the knowledge and experience which can assist the advancement of the industry, since it is only by the application of new knowledge and experience that progress is made.

It is necessary to draw a clear distinction between research work in pure science and industrial research. Both are essential to industrial progress, the former being directed towards widening the boundaries of knowledge, formulating principles, and revealing relationships that are the raw material of the latter, which is generally directed towards the solution of some specific industrial problem or towards meeting some industrial need

The justification for undertaking research in pure science in a research laboratory associated with an industrial concern lies in the almost inevitable industrial applications which follow rapidly in the wake of a new scientific discovery, and it should be noted that the functions of the man of science, industrial worker, and manufacturer are equally necessary in rendering the ultimate product of a new discovery available to the public. It is questionable from the economic point of view, however, whether the majority of works laboratories should undertake such research, since only a fraction of the new knowledge produced is likely to be of value to one particular works. Much of this work, therefore, must be carried on, as hitherto, by men of science working in private, university, co-operative, or national laboratories. On the other hand, in very large laboratories in complex industries, particularly where special products resulting from discoveries can be manufactured, the undertaking of research in pure science may be of very great value.

Research laboratories partly or wholly supported by industrial firms may be broadly classified according to the particular interests they are intended to serve, as, for example:—

(1) Industrial research laboratories self-contained and serving one particular works.

(2) Central industrial laboratories each forming the scientific focus of an industrial organisation comprising several works, often in different industries, and linked up by control laboratories at the individual works.

[1] From a paper on "Planning a Works Research Organisation" read before the Institution of Electrical Engineers on January 23 by A. P. M. Fleming.

The function of the central laboratory is to conduct research bearing on the manufactures of all the works, and that of each control laboratory is to serve the immediate requirements of the works to which it is attached.

(3) Laboratories planned to serve a wide range of interests in various industries in connection with isolated problems, such as the Mellon Institute of Industrial Research, Pittsburgh, or ordinary commercial laboratories such as that of A. D. Little and Co., Boston.

(4) Laboratories designed to serve the needs of one particular industry working on a co-operative basis, such as the laboratory of the National Canners' Association, U.S.A. The laboratories of the proposed research associations in Great Britain would fall into this class.

(5) State laboratories carrying out researches occasionally of an industrial character, but not necessarily for any particular firm, such as the National Physical Laboratory, the Bureau of Standards, U.S.A., and various university laboratories.

The majority of firms, particularly when commencing research work, find it expedient to combine necessary routine testing with research work, at any rate in the initial stages of development. There are many reasons in favour of this course. Both routine testing and research have much in common, and can make use of the same building and much of the same equipment. The routine testing department serves as a training ground and nursery for some members of the research staff. Further, through the work involved in routine testing the research department is kept in close contact with other works departments.

In the later stages of development, however, and especially in large and complex organisations comprising several works each requiring routine testing, it becomes desirable to establish a separate and, if possible, central laboratory for research work alone.

The laboratories referred to in this paper are considered to comprise both routine and research work, as their combination is the policy most likely to be adopted by manufacturers initiating research organisations.

The functions of such a works research organisation, which involve the arrangement of the department in a number of sections, may be classified thus :—

(1) Testing of raw material supplies and the establishment of a suitable technical basis for purchasing.

(2) Production of new materials or substitutes for those already in use, as, for instance, high-speed tool-steels, improved magnetic sheet-steel, etc.

(3) Investigation of difficulties arising in the manufacturing organisation.

(4) Investigations necessary for controlling and maintaining at their proper level technical processes in manufacture.

(5) Development of new and improved processes and their establishment on a manufacturing scale on most economical lines.

(6) Development of methods for the treatment of factory waste and scrap for by-products.

(7) Investigation of phenomena required in the compilation of fundamental data for designing new apparatus.

(8) Development of new tools, appliances, and methods of testing; improvement and standardisation of those existing.

(9) Investigations of operating troubles and service for customers.

(10) Investigations for the information of financiers of the possibilities of new projects of a scientific character.

(11) Physiological and psychological investigations relating to vocational selection and for determining the most efficient means of employing human services

(12) Research in pure science.

II.—*Divisions of the Organisation.*

The character of the industry determines mainly the scope and nature of the work to be done and, consequently, the number of sections of the laboratory. In rolling mills, for example, sections devoted to chemical, metallurgical, microscopic, and physical testing are sufficient to meet the main requirements. In the electrical and allied industries the number of sections is perhaps as great as will be found in any industry. These are given below, together with a brief statement of their functions for the general kinds of electrical and mechanical engineering works. In the case of a small works, some sections, such as the workshop, may be provided in the manufacturing departments. It will be noted that some of these sections deal wholly or largely with routine testing, and that they are subsidiary to other sections.

Chemical (Organic and Inorganic).—Co-operating with all other sections and undertaking routine analysis of incoming materials, ferrous, non-ferrous, and organic, for works use, and of materials in process of manufacture, and investigating and standardising speedy methods of routine testing.

Mechanical Testing.—Dealing with all routine tensile, transverse, compression, hardness, and torsion tests on metals and alloys in sheet, rod, or wire form; tests on textile fabrics, papers, fibre and other insulating materials, cements, etc.; destruction tests on assembled parts, and the testing of scale models.

Metallurgical (Ferrous and Non-ferrous).—Responsible for advising on the suitability of metals and their appropriate treatment for use in apparatus and in works equipment and tools; for supervising annealing and other heat treatment processes; for the conduct of investigations for the production of improved metals and alloys; for investigating failures in metals.

Photomicrographic.—Co-operating with the metallurgical and other sections in preparing specimens for microscopic examination and in photographing them.

Electrical.—Responsible for special tests on insulators, conductors, and resistances, both when received and as required during manufacture; for special tests on finished machines, oscillograph investigations, etc.

Magnetic.—Responsible for tests on steel forgings and electrical sheet-steel for permeability, hysteresis, and eddy losses, and on permanent magnets for remanence and coercivity.

Optical.—Dealing with investigations and tests of an optical character, such as the examination of large forgings by optical and X-ray methods; the application of colour testing to routine work, optical examination of screw threads and gauges.

Illuminating.—Undertaking investigations in connection with lamp manufacture.

Physical.—Undertaking all investigations of a physical character not optical or electrical, such as investigations connected with standards of measurement, heat transmission, acoustics, etc.

Pyrometric.—Responsible for the standardisation repair, regular checking, and supervision of works pyrometers; selection and installation of appropriate instruments where required, and manufacture of spare parts for works use; advising on thermostatic control, methods of high-temperature measurement, refractory materials.

Materials.—Responsible for the standards of size and quality of materials used in the works, and for the acceptance of materials purchased after appropriate chemical, mechanical, electrical, microscopic, and in-

spection tests. This section draws up specifications to define the limits of variation of sizes and properties of standard materials where required, and secures uniformity of practice throughout the works. It undertakes investigations into defective materials for which special provision is not made.

Technical Processes.—Dealing with the development of new or the improvement of existing processes, particularly those giving trouble in the shops, and requiring the services of expert engineers in a suitable laboratory. Technical supervision may also be exercised over works processes, such as electro-plating, galvanising, sherardising, electric arc, resistance, and spot welding, insulating processes of various kinds, casting, painting and varnishing, and the modes of procedure crystallised in specifications. The development of new processes requires the employment of plant of a semi-manufacturing scale after preliminary small-scale laboratory experiment before the process can be placed in the shops. A most important function of this section is to remove, so far as is practicable, all experimental work from departments the true purpose of which is manufacturing.

By-products.—Responsible for recovering usable products from factory waste and scrap such as oils, metals, and insulating materials. In addition, this section may conveniently be equipped for the preparation of oils, solders, cements, fluxes, special insulating compounds, paints and varnishes where these are special to the works or where they can be prepared more cheaply than they can be purchased outside.

Psychological and Physiological.—Modern methods of engaging employees, particularly juveniles, and of determining a basis for promotion involve the development of psychological tests of intelligence. The evolution of tests of proved validity involves continuous investigation in a laboratory of applied psychology.

Workshop.—For the manufacture of small parts, instruments, etc., and for the preparation of specimens for physical testing, a small workshop is required, fitted with the commoner types of machines, lathes, drilling, milling, and shaping machines, and hand-tools.

Intelligence and Information Section.—It is important in a research organisation to prevent the expenditure of time and money on investigations which have been carried out previously, either inside or outside the organisation, the results of which can be made available for reference. Information of this character may be collected much more economically and thoroughly by a small trained staff than through the promiscuous efforts of the research workers themselves. The information thus collected would form the research library, also under the control of this section. Such a section would serve as a focus and a co-ordinating centre for the research department, and would also facilitate relations between the works and the department and between the department and outside institutions. The section further becomes a repository for the reports of work done in the research department. Too much stress cannot be laid on the importance of keeping adequate records, setting forth not only the causes bringing about the need for research, but also full details of the investigations, the methods employed, the apparatus used, the deductions drawn from results, and a special note of any further researches arising out of the particular investigation reported. It may not be possible to carry out subsidiary investigations at the time, but they may be of sufficient importance to be considered later. In preparing a report, a standard plan is desirable.

Administrative.—Accommodation must be provided in the laboratory building for the staff dealing with the administration of the research organisation. It will be the duty of part of this staff to maintain a proper record of costs of investigations. In some laboratories it is usual for a sum to be set aside for each major investigation; in others, an overall sum is voted each year for the maintenance of the laboratory. Where routine work is done the cost of this may be charged against the works department on behalf of which the expense is incurred. In any case, a systematic record of all costs, stores, breakages, and wages, subdivided according to the various investigations, is of great importance.

III.—*Administration.*

The internal organisation of an industrial research laboratory depends largely upon the nature of the work undertaken. Where it comprises routine testing for works departments the nature and number of the tests carried out form a series of sections each having a departmental chief responsible to the director, and a staff of senior and junior assistants to carry on the work and to provide for continuity in case of transfer or promotion. Where research work of a kind not immediately related to works practice is concerned, each major investigation should be placed in the hands of a competent research man, working with or without assistance, but directly responsible to the director. Where work is combined, as will generally be the case, both methods may be combined.

In either case, the work of the staff is greatly facilitated by regular conferences of the departmental chiefs and research workers, as in this way the progress of work of interest to more than one section can be discussed and the cumulative experience of the whole staff brought to bear on new problems. Overlapping and duplication of work can also be avoided, a possibility which may frequently arise when every part of a problem has to be analysed and different aspects minutely studied by different workers.

IV.—*Staff.*

The most important feature of a research organisation is that of the staff. This country has for centuries produced a succession of distinguished men of science, especially physicists, and at the present time there is no lack of gifted men who are able to extend the boundaries of knowledge. It has, on the other hand, been repeatedly emphasised that there has been a lack of technically trained young men who are able to apply the results of scientific research in industry. The demand was not sufficient to stimulate a suitable supply. The experience of the war period has changed the attitude of industry considerably in this respect, and the inducement offered to university men to enter research work is much greater than hitherto. So far as the limited supply of students permits, the universities have endeavoured to respond, and the scholarships now being awarded, together with the assistance offered by the Department of Scientific and Industrial Research, should do much to encourage students still further. For a considerable time to come, however, the supply of men will be totally insufficient for the needs of industry.

It is an error to suppose that industrial research cannot be carried on without men of genius of the type which has been responsible for many brilliant advances in the past, frequently under considerable personal difficulties and without adequate experimental equipment. Such a type, indeed, is generally not at ease in an industrial works, where research can be reduced to the character of a business, where procedure can be organised on systematic lines towards a clearly defined objective, and where progress can be

made by co-operative effort of resourceful, energetic, well-trained, but otherwise ordinary men.

With the exception of those actually engaged in directing research, the staff should comprise comparatively young men and women capable of distinguishing cause from effect, able to observe keenly, and possessing sound technical training, preferably of university standard in the faculty pertaining to the industry they propose to enter, followed by some practical experience. Graduates who have shown during their university career that reasoning capacity, knowledge, resource, and skill in manipulation which comprise aptitude for research might proceed to a works for a period of practical training and then return to the university for a post-graduate course in research before entering the works organisation. Alternatively, students may enter the works for practical experience on concluding a post-graduate course, afterwards being placed in the research department.

In addition to serving as a nursery for research workers, the laboratories should undertake part of the training of all those young men who in a large organisation are being trained for higher industrial positions, as, for instance, many of those on the designing, commercial, and works management sides. In this way the industry becomes permeated with men having a keen appreciation of the value of scientific method. In connection with the section dealing with works processes, some of these men, promoted possibly from the trade apprentice course, may ultimately be permanently employed. Others would be transferred to the works, where they could utilise their experience in the direction of such processes.

In view of the limited supply of research workers, it is essential that the research department should work in close contact with the educational portion of the organisation now becoming an essential feature in industrial concerns, since the latter would control the selection, training, and promotion of all grades of apprentices. Every possible step should be taken to reveal latent talent, and to provide opportunities for the acquisition of the necessary education and experience.

The universities can only partially complete the training of the staff required for industrial research. This may be illustrated by the procedure adopted at the Mellon Institute of Industrial Research, Pittsburgh, which was founded for the express purpose of conducting researches for manufacturers, the work being undertaken by research fellows selected principally from the universities. These men co-operate closely with the works concerned, and frequently become absorbed into its staff at the conclusion of the research.

The staff of an industrial research organisation, comprising sections as indicated above, will generally include a director, sectional heads, senior and junior assistants, with possibly a number of individual research men responsible to the director. The function of the director calls for special consideration. He must appreciate the possibilities of applying new knowledge to industry to commercial advantage, and be able efficiently to direct specialised research workers, avoiding aimless research having no utilitarian objective. While he requires a wide scientific knowledge to be able to follow intelligently and appreciate the trend of scientific development, he must have, in addition, considerable organising capacity, commercial instinct, and a thorough knowledge of the manufacturing processes of this industry. He must have sufficient breadth of view to be willing to employ expert assistance whenever occasion for this arises.

The sectional heads will, in general, be men of high scientific standing, especially in their particular branch of science. These and the senior staff should be men of university education and training. It is essential that every position in the department should be filled by the best available man for the post, and the research staff should be considered to offer the most highly prized positions, unsuitable men being transferred to other parts of the works organisation.

Conclusions.

No hard-and-fast rule can be laid down as to the amount of money that should be expended on research. Every undertaking must be considered on its own merits, and research expenditure based on the economic needs of the moment and the probable requirements of the future. In many cases it is the impoverished industry which stands in the greatest need of research. Similarly, the small concern, though it may not be able to afford expensive research facilities, can make considerable use of those afforded by universities, national institutions, and private or commercial laboratories. Then, again, the wealthy firm or prosperous industry can maintain an unassailable position through improving by research its methods of production, this being ultimately the only effective method of securing monopoly.

It is an economic error to assume that the best method of increasing profits is, through trade combinations or other means of protection, to increase the selling price. A much more logical method is to bring about the difference between manufacturing cost and selling price by reducing the cost of manufacture, and it is in this connection that the possibilities of research are unlimited.

Apart from its value in assisting economic manufacture, the advertising value of research should not be overlooked. The knowledge that a manufacturing firm employs scientific methods establishes in the public mind a feeling of confidence in the firm's products. Similarly, this may be a by no means negligible factor in favourably influencing investors.

It is to be hoped that firms undertaking research on a large scale will adopt a broad-minded policy in regard to the publication of a great deal of the results of their work. The tendency towards secrecy on the part of most British firms has been weakened to a considerable extent during war-time, when many otherwise rival firms have been engaged upon similar kinds of new work, in which each firm could benefit by exchanging its experience with other firms engaged in the same production. This exchange of experience and information is of the greatest importance in keeping all sections of an industry up to date, and in this way an industry becomes much more potent in international competition, and at the same time individual firms through differences in organisation are no less able to compete among themselves. Moreover, the preparation of work for publication and discussion is of great educational value to a research worker.

In staffing a research organisation, the highest economy is secured by obtaining the very best brains in the various positions, and posts in the research department should be looked upon as those most highly prized in an industrial organisation.

It is to be hoped that the great industrial organisations having well-established research facilities will extend their hospitality freely to those workers in universities and elsewhere to conduct important investigations which they have leisure, but not equipment, to undertake, and that considerable freedom of interchange of ideas and experience with other research organisations will be practised.