zons. There are traces in the Trenton (Ordovician); small quantities are obtained from four distinct Silurian series. The largest quantity of oil comes from the Onondaga beds, which are Devonian. The author mentions both the organic and inorganic theories of the origin of petroleum; he expresses no definite preference, but appears to be inclined to the latter, and some of the facts stated in the memoir indicate why some Canadian geologists are firmly attached to that view. The most interesting evidence is based on the uniform composition of the associated natural gas, which is advanced as incompatible with its local origin; but the balance of the evidence stated seems difficult to reconcile with the inorganic hypothesis.

Each of the three memoirs is a useful contribution to Canadian geology. J. W. G.

RADIO-ACTIVITY AND PLANT GROWTH.

FOR some time past Mr. Martin Sutton has been making experiments on the effects of radio-active ores and residues on plant growth. A preliminary account of the experiments was given in NATURE for October 7, 1915, and the detailed report now to hand, issued as Bulletin No. 7, from Messrs. Sutton, of Reading, confirms the conclusions then drawn. The experiments were soundly conceived and well carried out; the results showed that radium compounds have no sufficient effect on plant growth to justify any hopes of practical application in horticulture or agriculture.

The experiments were made with tomatoes, potatoes, radishes, lettuces, vegetable marrows, carrots, onions, and spinach beets; some of the plants were grown in pots, and others in the open ground. Pure radium bromide was used in some experiments, and radium ores in others. In order to eliminate the effect of substances other than radium present in the ores, a mixture of these was made and applied to some of the plants. In certain cases small increases in growth over the unmanured plants were obtained, but nothing approaching the increases given by artificial fertilisers or farmyard manure.

A number of rather extravagant claims are thus disposed of, including one to the effect that radium treatment caused plants to take on certain flavours that they do not naturally possess. Thus a previous investigator had claimed that vegetable marrows grown in presence of radium compounds assume the flavour of pineapples; Mr. Sutton's marrows were cooked and tasted by a distinguished exponent of horticultural science, whose tastes in these matters are recognised as being beyond reproach, and were found to be indistinguishable from the others. Mr. Sutton has rendered good service by disposing of this and other of the hares started in the field of horticulture that were distracting attention from the larger problems with which the horticulturist has to deal.

THE ORGANISATION OF INDUSTRIAL SCIENTIFIC RESEARCH.[1]

I.

IF one attempted to formulate the common belief concerning the origin and development of modern technical industries, it would probably be found that stress would be laid upon financial ability or manufacturing skill on the part of the founders; but if, instead, we were to make a historical survey of the subject, I think that we should find that the starting and development of most manufacturing businesses depended upon discoveries and inventions being made by some individual or group of individuals who developed their original discoveries into an industrial process. Indeed, if the localities in which various industries have developed be marked on the map, they will often be found to have far more relation to the accidental location, by birth or otherwise, of individuals than to any natural advantages possessed by the situation for the particular industry concerned. The metallurgical industries, of course, are situated chiefly near the sources of the ores or of coal, but why should the chief seat of the spinning industry be in Lancashire or of modern optical industry in Jena, except that in those places lived the men who developed the processes which are used in the industry? And, moreover, industries are frequently transferred from one locality to another, and even from one country to another, by the development of new processes, generally by new individuals or groups of workers.

The history of many industries is that they were originated and developed in the first place by some man of genius who was fully acquainted with the practice of the industry and with such theory as was then known; that his successors failed to keep up with the progress and with the theory of the cognate sciences; and that sooner or later some other genius working on the subject has rapidly advanced the available knowledge, and has again given a new spurt to the development of that industry in another locality.

Thus, in the early days of the technical industries the development of new processes and methods was often dependent upon some one man, who frequently became the owner of the firm which exploited his discoveries. But with the increasing complexity of industry and the parallel increase in the amount of technical and scientific information, necessitating increasing specialisation, the work of investigation and development which used to be performed by an individual has been delegated to special departments of the organisation, one example of which is the modern industrial research laboratory.

The triumphs which have already been won by these research laboratories are common knowledge. The incandescent lamp industry, for instance, originated in the United States with the carbon lamp, but was nearly lost to the United States when the tungsten filament was developed, only to be rescued from that danger by the research laboratory of the General Electric Company, who fought for the prize in sight and developed, first, the drawn-wire filament, and then the nitrogen lamp; and we may be sure that if the theoretical and practical work of the research laboratory of the General Electric Company were not kept up the American manufacturers could by no means rest secure in their industry, as, undoubtedly, later developments in electric lighting will come, and the industry might be transferred, in part, if not completely, to the originators of any improvement. Manufacturing concerns, and especially the powerful, well-organised companies who are the leaders of industry in this country, can, of course, retain their leadership for a number of years against more progressive but smaller and less completely organised competitors, but eventually they can ensure their position only by having in their employ men who are competent to keep in touch with, and themselves to advance, the subject, and the maintenance of a laboratory staffed by such men is a final insurance against eventual loss of the control of its industry by any concern.

There was a time when the chief makers of photographic lenses were the British firms, the owners of which had been largely instrumental in developing the early theory of lens optics, but that position was lost entirely as a result of the scientific work of the German opticians, led by Ernst Abbe; in a smaller divi-

[1] An address delivered at Columbia University by Dr. C. E. Kenneth Mees, director of the Research Laboratory, Eastman Kodak Co., Rochester, N.Y.

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sion of optical work, however, the staff of Adam Hilger, Ltd., has been able by its superior knowledge and intensive study of the manufacture of modern spectroscopes to transfer a large portion of the manufacture of such instruments from Germany to England again.

In a recent book review in NATURE (December 2, 1915, p. 366) it is pointed out that the rare earth industry has been chiefly concentrated in Germany. The manufacture of gas mantles, discovered by an Austrian, developed an entirely new chemical industry, which has been carried on almost completely under German auspices. It seems to be suggested at the present time by some of the leaders of British industry that such specialised chemical operations as the manufacture of compounds of the rare earths can be transferred to Great Britain by the application of superior financial methods, or better business foresight, or even merely more intense application. I do not believe that anyone who is acquainted with the business men of several countries will believe that the British manufacturer is lacking either in financial capacity, or in business foresight, or in application, but none of these things by itself will develop a chemical industry. The only thing that will attract and retain the business is the manufacture and development of new and improved products, and this can be done only by the use of more and better research chemists and physicists than the competitor is willing to employ. In fact, at the present time it seems to be clear that the future of any industry depends upon its being able to command a sufficient supply of knowledge directed towards the improvement of the product and the development of the methods of that industry, and that any failure in this respect may involve eventual failure. While this view of the importance of research work to the industries is now obtaining universal acceptance, I feel that many who assent without hesitation to the value of a research laboratory still take far too low a view of the work which it should perform.

Industrial laboratories may be classified in three general divisions :—

(1) Works laboratories exerting analytical control over materials or processes.

(2) Industrial laboratories working on improvements in product and in processes, tending to lessen cost of production and to introduce new products on the market.

(3) Laboratories working on pure theory and on the fundamental sciences associated with the industry.

The first class of laboratories are so obviously necessary that practically all works are so equipped, and frequently each department of a factory maintains its own control laboratory. The second class of laboratories are frequently termed "research" laboratories, and this type has been very largely instrumental in forwarding the introduction of scientific control into industry.

Unfortunately, however, the immediate success of the application of scientific methods to industrial processes has often led the executives of commercial enterprises into the belief that such work along directly practical lines is capable of indefinite extension, and in this belief a number of laboratories have been started, some of which, at any rate, have been sources of disappointment in consequence of a failure to grasp the fact that if the whole future of an industry is dependent on the work of the research laboratory, then what is required is not merely an improvement in processes or a cheapening in the cost of manufacture, but fundamental development in the whole subject in which the manufacturing firm is interested, and for this purpose it is clear that something very different from the usual works laboratory will be required, and that in order to attain progress the work of the research laboratory must be directed primarily towards the fundamental theory of the subject. This is a point which seems to be continually overlooked in discussions of industrial scientific research, where such stress is generally laid upon the immediate returns which can be obtained from works laboratories, and upon the advantage of scientific control of the operations; but in every case where the effect of research work has been very marked, that work has been directed, not towards the superficial processes of industry, but towards the fundamental and underlying theory of the subject. From Abbe's work on lenses, and Abbe and Schott's work on glasses, to the work of the research laboratory of the General Electric Company on the residual gases in lamp vacua, which resulted in the production of the nitrogen-tungsten lamp and the Coolidge X-ray tube, this will be seen to be true, and we must consequently agree that for industries to retain their position and make progress they must earnestly devote time and money to the investigation of the fundamental theory underlying the subject in which they are interested.

Research work of this fundamental kind involves a laboratory very different from the usual works laboratory, and also investigators of a different type from those employed in a purely industrial laboratory. It means a large, elaborately equipped, and heavily staffed laboratory, engaged largely on work which for many years will be unremunerative, and which, for a considerable time after its foundation, will obtain no results at all which can be applied by the manufacturer.

The value of a research laboratory is essentially cumulative; in the beginning it may be of service as bringing a new point of view to bear on many problems; later, accumulated information will be more and more available; but most men acquainted with industrial research work consider that five years is the earliest date at which any considerable results can be expected from a newly-established research laboratory, and that the development of really new material in considerable quantities so that it will have an effect upon the industry as a whole cannot be looked for in less than ten years' consecutive work. This does not mean that a laboratory is useless during the initial period, since it will be of considerable service in many other directions than in that of its main work on the fundamental problems, but when this main line of research begins to bear fruit it will absorb the energies both of the laboratory and of the factory.

It is often suggested that the problem of the organisation of scientific industrial research is really the problem of obtaining satisfactory co-operation between the manufacturers and the universities, possibly with small research laboratories in the factories themselves acting as intermediaries. Various schemes have been suggested for enabling the universities to carry out research work of value to the manufacturers, but if it is believed that the work chiefly required for the development and maintenance of industry deals with the fundamental theory of the subject, it will be seen that this cannot possibly be carried on to any large extent in collaboration with a university; it requires a continuity of application by the same investigators over long periods, with special apparatus, and with the development of special methods which cannot be expected from any university. This necessity for continuous work along the same line is, indeed, the greatest difficulty in making use of the universities for industrial research. The conditions of a university laboratory necessarily make it almost impossible to obtain the continuous application to one problem required for success in industrial research, and, indeed,

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in the interests of teaching, which is the primary business of a university, such devotion to one problem is undesirable, as tending to one-sidedness.

There are also difficulties in obtaining the co-operation of manufacturers with universities and in the application of university work to industry, which I see no hope whatever of overcoming; the universities do not understand the requirements of the manufacturer, and the manufacturer distrusts, because he does not understand, the language of the professor. Moreover, it is quite essential that any investigator who has worked out a new process or material should be able to apply his work on a semi-manufacturing scale, so that it can be transferred to the factory by skilled men who have already met the general difficulties which would be encountered in factory application. This development on a semi-manufacturing scale is, indeed, one of the most difficult parts of a research resulting in a new product, and the importance of it is shown by the fact that all the large industrial research laboratories, however concerned they may be with the theory of the subject, have, as parts of the laboratory, and under the direction of the research staff, experimental manufacturing plants which duplicate many of the processes employed in the factory itself.

All these arguments tend to show that an industrial research laboratory must necessarily be of considerable size, but this requirement is much accentuated by another consideration altogether.

Except in a few branches of pure science small research laboratories are relatively inefficient, in the technical sense of the term—that is, they require more time and cost more money for the solution of a given problem.

When considering this subject it is necessary first to dismiss completely from the mind the idea that any appreciable number of research laboratories can be staffed by geniuses. If a genius can be obtained for a given industrial research, that is, of course, an overwhelming advantage which may outweigh any disadvantages, but we have no right to assume that we can obtain geniuses; all we have a right to assume is that we can obtain, at a fair rate of recompense, well-trained, average men having a taste for research and a certain ability for investigation. The problem, then, is, how can we obtain the greatest yield from a given number of men in a given time? Investigation of the subject shows that the yield per man increases very greatly as the number of men who can co-operate together is increased. The problems of industrial research are not often of the type which can be best tackled by one or two individual thinkers, and they rarely involve directly abstract points of theory, but they continually involve difficult technical and mechanical operations, and most of the delays in research work arise because the workers engaged on the subject do not know how to do some specific operation. In my own experience, I have seen a good man stick for six months at an investigation because he did not know and could not find out how to measure a conductivity with a precision higher than one part in a thousand, a point which was finally found to be perfectly well known to several scientific workers in the country. Again, it took another good man three months to learn how to cut a special form of section, but, having learned the trick, he can now cut sections for all the workers in the laboratory with no delay whatever.

In this connection the advantage of permanent set-ups of apparatus may be pointed out. Among a large number of chemists some one will continually be wanting to photograph an ultra-violet absorption spectrum or to take a photomicrograph, and if the apparatus for these purposes is erected and in charge of a competent man who understands its use, the work can be done without any delay at all, the photography of the absorption spectrum of an organic liquid by a man who is used to the work taking only an hour; but if this point is vital to the research, and the chemist is quite unacquainted with the technique of the subject and has no apparatus available, it may easily take him six months to find out what has been done on absorption spectra, to buy and erect the apparatus and become skilled in its working.

From these causes, then, the efficiency of a laboratory increases very greatly with its size, provided that there are good arrangements for co-operation between the different workers of the laboratory, so that they are kept informed of each other's problems.

When considering the efficiency of research work it must be remembered that the efficiency is necessarily extremely low, since it is very rarely possible to arrange any research so that it will directly proceed to the end required.

(*To be concluded.*)

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

BIRMINGHAM.—Dr. O. F. Hudson has resigned his post as lecturer and instructor in assaying and special lecturer in metallography in order to take up duties as assistant investigator to the Corrosion Committee of the Institute of Metals.

The degree of Doctor of Science has been awarded to the following: Elizabeth Acton (botany), Henry Briggs (mining), George William Clough and Albert Parker (chemistry).

LEEDS.—On the occasion of Degree Day on July 1 the vice-chancellor (Dr. M. E. Sadler) in the course of an address reviewed the position of the university, with special reference to the war. Of nearly fourteen hundred associated with the university who are on active service, fifty-one had received military distinction. The war has found the university able and ready to give the nation unforeseen and many-sided service, and the long vacation is little more than a name for those in the university who are doing scientific or administrative work in connection with the war. The war, Dr. Sadler remarked, has already enriched the university with a deepened tradition of fellowship in public service. In the years to come it will be called upon to prove the power of patient but imaginative investigation, of trained judgment, and of unjealous and patriotic energy in helping forward whatever will impart a finer quality to the social and economic conditions of the national life. Grateful mention was made of the recent benefaction of Sir James Roberts for the endowment of a chair of Russian language and literature—an act of international significance. As important and opportune would be the foundation of a professorship of Spanish language and literature.

Alluding to the future of the universities, Dr. Sadler said, whilst they must continue to work in intimate co-operation with the great local authorities and the Government, it must never be forgotten that the living power of their work will depend on their continuing free from mistaken, however well-meant, kinds of external interference. Germany has failed, in spite of her brilliant endowment of knowledge, to keep unsullied in her universities freedom of moral judgment in respect of some vital questions of duty to mankind and to the State. She has gradually and half-consciously undermined, by subtle pressure of State control and by inducements of official distinctions, independence of moral and political judgment in some of the teachers through whom that higher education is given. This should be a warning to us.

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