SCIENCE

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THE ORGANIZATION OF INDUSTRIAL SCIENTIFIC RESEARCH

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 practise of the

industry and with such theory as was then known; that his successors failed to keep up with the progress of the industry and with the theory of the cognate sciences; and that sooner or later some other genius working on the subject advanced the available knowledge and again gave 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 specialization, the work of investigation and development which used to be performed by an individual has been delegated to special departments of the organization, 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 development 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-organized 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 organized 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 whose owners 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 division 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* of December 2, page 366, it was 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 specialized 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 any one 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 themselves 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 laboratory is 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 manfacture but fundamental developments in the whole subject in which the manufacturing firm is interested; for this purpose it is clear that something very different from the usual works laboratory will be required, and that in order to obtain progress the work of the research laboratory must be directed primarily toward the fundamental theory of the subject. This is a point which seems to be continually overlooked in discussions of industrial scientific research, where much 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 toward 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 can not 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 organization of scientific industrial research is really the problem of obtaining satisfactory cooperation 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 can not 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 can not 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, 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 cooperation 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 from the mind completely 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 cooperate 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 in 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.

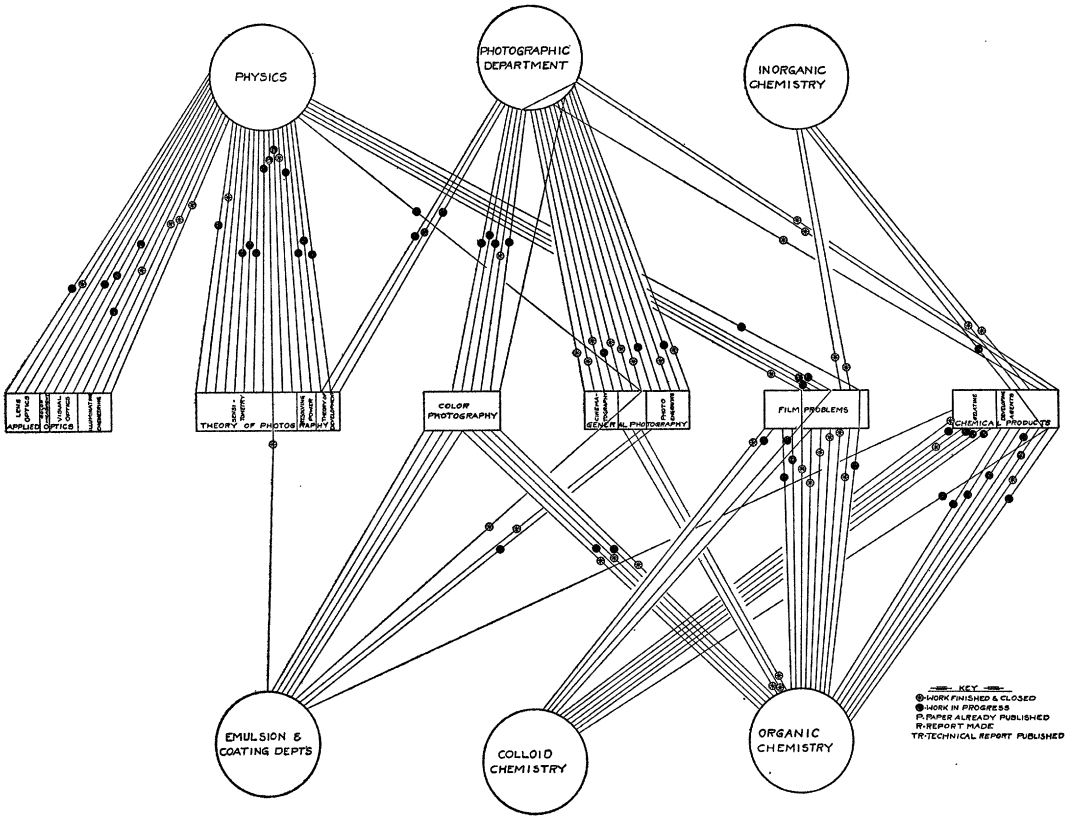
From these causes, then, the efficiency of a laboratory increases very greatly with its size provided that there are good arrangements for cooperation between the different workers of the laboratory so that they are kept informed of each other's problems.

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.

It is the common opinion of those who have to deal with the organization of research that only a small percentage of all the investigations started are likely to be successful, the great majority being either dropped before they come to an end, or being carried through, and filled simply as records, without any results having been obtained which would justify the expense of the investigation; that is to say, industrial research is justified only by the great value of the successful attempts, and these must bear the burden of a great number of unsuccessful attempts which may have been quite as costly as the successful ones themselves. The object of organization is to attempt to reduce the proportion of unsuccessful investigations which will be undertaken, as has already been shown. This can be done by increasing the size of the laboratory, by increasing the specialization of the workers, and especially by increasing cooperation between workers in different fields.

Naturally, the most important step which could be taken to increase the efficiency of industrial research would be to increase the likelihood of correct choice of a promising investigation, but, unfortunately, very little can be done in this direction. Those with the most experience in research work are all agreed that it is almost impossible to say whether a given investigation will prove remunerative or not. The only general conclusion that can be drawn is that the deeper a given investigation goes towards the fundamentals of the problem the more likelihood there is that the results will be of value, and the more superficial an investigation is, even although it appears more promising at first sight, the less likelihood there is that it will finally prove of real worth, so that the choice of investigations must necessarily be made largely at random and will be influenced to a great extent by the ideas of the scientific workers themselves; if any worker has a desire to take up any particular line of work, provided that it is associated with the general trend of work in the laboratory, it is usually wise to let him do so, but the expedition with which a decision can be reached as to the probable value of the investigation after it has been started is very greatly enhanced by complete cooperation of workers in the different branches of science in consultation on the problem.

At this point it might be well to discuss the organization of a large research laboratory. Such a laboratory should be established in charge of a director who has had some actual manufacturing experience in the work processes but at the same time he must have a considerable sympathy with purely scientific work and an interest in the advancement of scientific theory. *Both* these qualifications are desirable, but if such a director combining the two can not be found, then a man of full scientific training should be chosen and put into a position of responsibility in the manufacturing side of the industry until he has become fully acquainted with the technique of the industry. It is most inadvisable to take a man from the industry who has not had a full scientific training, including advanced research work in academic problems, since he will generally be lacking in sufficient knowledge of and sympathy with the more academic investigations of which he will be in charge and if the two necessary qualifications can not be found united in one man, it will be necessary to take a man with the scientific qualifications and give him the



practical training, which is just as essential for the director of a laboratory as scientific knowledge.

These necessary qualifications in the director are reflected in the division of the laboratory itself into manufacturing and scientific sections, since the manufacturing section should be able to carry out on a small scale all the chief manufacturing operations so that any investigations made in the laboratory can be carried through to the practical works scale without interfering with the production departments. In the research laboratory of the Eastman Kodak Company the manufacturing department includes emulsion-making and plate, film and paper coating departments, the capacity being very considerable, the plate department being able to make 300 dozen 8×10 in. plates a day. These departments are used not only for systematic experiments on emulsion suitable for various purposes, such as different kinds of plate emulsion, color sensitive emulsions, especially for color photography, and experimental printing papers, but they are further used to make on a small scale products which are required for special purposes in very small quantities, such as special plates required by astronomers or spectroscopists or special film required for experimental purposes by those working on color photography or attempting to develop other photographic processes. Requests for such special materials are received by every large manufacturing company, and the execution of the orders in the production departments frequently involves much delay and loss, whereas the manufacturing section of the laboratory can carry out the

work with a full understanding of the use to which the materials are to be put and can often materially assist the purchaser in working out his idea. Cooperation of this kind between the general public and the laboratory can not but be of advantage to both parties.

The manufacturing departments should be in charge of skilled foremen who have had previous experience in the works and be run in exactly the same way as the production departments themselves, being under the general supervision of the director of the laboratory and of any assistants that it may be necessary for him to employ. The foremen of the departments should, however, cooperate very fully with the scientific departments.

There is always some difficulty in a laboratory in getting the scientific departments to make full use of the special knowledge of the manufacturing division and at the same time to realize the practical difficulties which occur in works processes, but this difficulty can be overcome much better in the case of the manufacturing division of the laboratory than it could if an outside production department were involved without the laboratory division acting as intermediary.

The scientific division of the laboratory should be divided into departments dealing with the special subjects, but every care should be taken that these departments do not become at all isolated from each other and that they cooperate with each other in the most complete way on the solution of the problems on which the laboratory is engaged. In order to insure this the main lines of work under investigation may be suitably discussed at a morning conference at the beginning of the day's work, one day of the week being assigned to each subject. The laboratory organization will then resolve itself into a number of different departments engaged in dealing with a number of different lines of work, and the total work of the laboratory during the year may be suitably represented, as is shown by the chart (see figure), which is that actually devised for the research laboratory of the Eastman Kodak Company.

The departments of the laboratory are represented as circles on the outside of the chart, the main divisions in which problems group themselves being represented by the rectangles, subdivided in some instances, occupying the middle of the chart. Each of these rectangles will correspond to a morning conference; thus, a conference will be held on general photography, at which there will be present members of the photographic department, the physics department, the department of organic chemistry and the emulsion and coating or manufacturing departments. There will be present at the conference, in fact, every scientific worker of the laboratory, whatever his rank, who is directly engaged on the subjects which are included under the head of general photography, and in some cases, or on special occasions, members of the staff of the company external to the laboratory may be invited to these conferences, although as a general rule in the case of a large company it will not be possible for them to be regularly present. All the main lines of investigation should be laid down at these conferences and the progress from week to week carefully discussed. This procedure will enable a great saving in time to be made, since it will avoid the loss of time which continually occurs in laboratories from the wrong man doing a specific piece of work; and the economy can be much increased by suitable arrangement of the building and equipment itself.

The building should be so arranged that all the laboratories are open to everybody in the scientific departments but that in

each laboratory involving special classes of apparatus there are specialists continually working who are available for consultation and assistance to all other workers in the laboratory. In this way single operations which become necessary in the course of an investigation may frequently be transferred from the man who has carried on the main line of work on the subject to some other specialist in the laboratory. In the Kodak laboratory, for instance, electrical measurements, photometric measurements, spectrophotography, lens optics, photographic sensitometry, work involving dyestuffs, and all strictly photographic operations, such as copying, lantern-slide making, printing and enlarging, making up developers, etc., are in the hands of specialists, and whenever any of these operations become necessary in the course of an investigation, the conference directs that they be carried out by the specialist on the subject. In this way an organic chemist, for instance, will have the absorption curve of his products measured not by an instrument in the organic laboratory but by the physics department, while the preparation of photographs, lantern slides and prints which are often involved in publication are carried on by the photographic department and not by the man who did the work, these arrangements relieving specialists in one subject from having to acquire technical skill in another. It is in such complete cooperation that the greatest economy in scientific investigation is to be found.

It must be remembered that such specialization as this is not at all suitable for use in a university, where the object is the broadening and education of the students; it is one of the many differences between research work in a university and in a set research laboratory, whether it be industrial or not, that in a university the primary object is the training of the worker, while in the research laboratory the primary object is the carrying out of the investigation.

The best utilization of the results obtained in an industrial research laboratory is only second in importance to the organization required to obtain them. All results of general scientific interest and importance should undoubtedly be published both in the public interest, and also because only by such publication can the interest of the laboratory staff in pure science be maintained. It is doubtful if the importance of maintaining the full interest in theoretical science of a laboratory staff has been fully realized. When the men come to the laboratory they are usually interested chiefly in the progress of pure science, but they rapidly become absorbed in the special problems presented to them and, without definite effort on the part of those responsible for the direction of the laboratory, there is great danger that they will not keep up to date in what is being done by other workers in their own and allied fields. Their interest can be stimulated by journal meetings and scientific conferences, but the greatest stimulation is afforded by the requirement that they themselves publish in the usual scientific journals the scientific results which they may obtain. Another reason for publication is that when a piece of work is written up for publication the necessity for finishing loose ends becomes manifest and that work which is published is therefore more likely to be properly completed.

With some laboratories publication is rendered difficult by the industrial organization; while nominally manufacturing companies are usually willing that results of scientific interest should be published, the organization of the company frequently requires that they be passed on by the heads of several departments, such as the

sales, patent, advertising, manufacturing, and so on, and the heads of these departments, possibly not understanding the subject and being afraid of passing material which might prove detrimental, frequently err very much in the direction of withholding entirely harmless information from lack of sufficient knowledge. It is much more satisfactory, if possible, for one responsible executive to pass on all matter submitted for publication, and this will inevitably result in a much more liberal policy than where the responsibility is delegated to a number of representatives of different departments of the company.

In addition to these scientific papers special technical reports for the information of the staff of the company itself should be circulated by the laboratory, and in the case of the Kodak laboratory an abstract bulletin is published monthly giving information as to the more important papers appearing in the technical journals associated with the photographic industry and also of all photographic patents. It is often advisable, also, to prepare special bulletins dealing with the application of scientific investigations, which have already been published, to the special needs and interests of the company.

Since the evidence points, therefore, to the establishment of really large research laboratories as the most economical and efficient way of increasing the application of science in industrial work the question arises as to how these large laboratories are to be supported. In the United States the great manufacturing corporations, who can afford the necessary capital and expenditure for maintenance, and are willing to wait for the results, have already undertaken the establishment of a number of large research laboratories. Such concerns as United States Steel, General Electric Company, United States Rubber, du Pont de Nemours, and many others are supporting large and adequately equipped research laboratories whose staffs are engaged in work on the fundamental theory of the industries in which they are interested, and undoubtedly more and more such laboratories will be established in the course of the struggle for increased industry which the United States is preparing to wage. There are a large number, however, of smaller firms who can not afford the great expenditures involved but who are anxious to benefit by the application of science to their work, and it seems that the only solution to the problem of providing for such firms is in the direction either of cooperative laboratories serving the whole industry, as has already been done in the case of the National Canners' Association and the National Paint Association, and no doubt in some others, or in the erection of national laboratories devoted to special subjects connected with industry and corresponding to such institutions dealing with special branches of pure science as the geophysical laboratory of the Carnegie Institution. Schemes for industrial scholarships tenable at universities do not meet the case at all, since work done under such arrangements must necessarily be limited in respect to time and directed towards a definite practical end rather than towards the general acquisition of knowledge connected with the underlying principles on which an industry rests. In the same way consulting laboratories, like industrial scholarships, are interested in the development of results for immediate practical application, and both these methods of work are substitutes for the practical industrial laboratories belonging to my second general division rather than for the large laboratories here discussed.

In England the coordination of industry has not proceeded as in the United States

and there are very few corporations who would be willing to maintain a large, fully equipped research laboratory of the type discussed, although a few such laboratories are well known to be in existence, but British industry has been brought very much together during the past eighteen months and the organization of industry is already a familiar phrase. Why, then, should England not establish a National Industrial Research Laboratory to assist all British manufacturers and to develop the theory underlying the great fundamental industries on which British work depends? Such a laboratory could take the theory from the universities, or where the theory was lacking, develop it and apply it to the separate industries, working out the results on a semi-manufacturing scale and finally passing it on to the manufacturer. It may be of interest to glance at the possible size and scope of such an organization and I have attempted to formulate a scheme which will represent the minimum which would be required.

A laboratory on the smallest scale adequate to British industry would, at the beginning, require a staff of about two thousand men, one thousand of them scientifically trained and the other thousand assistants and workmen. It should have about three or four hundred men of the rank of professor or assistant professor in the universities or of works manager or assistant manager or chief chemist in the factory. It would require land and buildings costing about $3,000,000 and its annual upkeep with allowance for expansion would be about $4,000,000.

Vast as these figures are, they are infinitesimal compared with the value of the industries whom they would serve. They represent a charge of less than one per cent. and probably not more than one fifth per cent. of the net profits of British industry; moreover, after the initial period has been paid for such a laboratory might be self-supporting and might, indeed, finally, make a very handsome profit on the original investment.

Suppose that such a laboratory patented all inventions and licensed manufacturers to use them, then, it is not too much to expect that after the first five or six years it would be paying for itself, and that five years later it would be able to establish a great many subsidiary institutions from its profits; at any rate, such a vast laboratory would produce far more results at lower cost than would result from any other expenditure of a comparable sum of money on industrial research by the British industries.

I believe, however, that within the lifetime of most, if not all, of us we shall see such extensions of industrial research as will make all that we now have in mind seem insignificant, and it is because I believe so strongly in the importance of the subject that I have endeavored to collect some impressions on the subject and to present them in this paper.

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BENJAMIN FRANKLIN AND ERASMUS DARWIN: WITH SOME UNPUBLISHED CORRESPONDENCE[1]

IT is not generally known that Benjamin Franklin and Erasmus Darwin were correspondents and personal friends. They first met, as far as can be learned, some time during Franklin's second mission to England, between 1764 and 1775, and, attracted to each other by their common scientific interests, a

[1] I wish to acknowledge my deep thanks to Mr. I. Minis Hays, secretary of the American Philosophical Society, for his kind permission to transcribe and publish the correspondence here given.