THE ORGANIZATION

OF

INDUSTRIAL SCIENTIFIC RESEARCH

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BY

C. E. KENNETH MEES, D. Sc.

DIRECTOR OF THE RESEARCH LABORATORY
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“There is danger in an organization chart—danger that it be mistaken for an organization.”

A. D. LITTLE.

PREFACE

There is no subject concerning which scientific discussion is more active at the present time than the relation of science to industry, and especially the development of research in science which may be applied to industrial ends. Hitherto, this discussion has been concerned chiefly with an exposition of the advantages to industry of participation in scientific research and of the importance, national and economic, of an increase in the volume of research work of all kinds.

But together with propaganda in favor of research there is necessary a study of the best methods of organizing research work for industrial purposes and of the conditions under which such work should be conducted. This book is intended as a contribution to this latter question, and, while general principles have been discussed throughout the book, every effort has been made to be as definite in statement as the nature of the subject will allow.

One can imagine the head of a large manufacturing corporation answering the plea that his firm should undertake research work both for its own sake and for that of the community, "Very well, I am convinced, I am ready to start a research department. What will it cost? To start, to support? Where shall I get the men? What should it do? What may I expect to get from it, and when? What position in my organization should it occupy? What should be its own organization?" It is to answer these questions that this book has been written, and it is with the hope that it may be of value in promoting the great cause of scientific research that it has been published.

Thanks are due to many friends for helpful criticism and advice; their suggestions, freely offered, have been gladly accepted and incorporated in the text.

Rochester, N. Y.
December, 1919.

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CHAPTER I

INTRODUCTION

The present development of human knowledge has been produced by investigation of the relationship between cause and effect in natural phenomena. This is termed *scientific research*, which may take many forms according to the branch of knowledge with which it is concerned. The equipment necessary for scientific investigation also depends upon the field in which it is pursued. Some branches of research require no apparatus and can be carried on by an individual investigator without any special equipment; mathematical research, for instance, demands only writing materials and the ability of the investigator; but most forms of scientific research involve the use of apparatus, which may be very simple or may be extremely complex, and for convenience research is therefore carried on in special laboratories equipped with the necessary apparatus.

Before an investigation can be commenced with profit, it is necessary for the worker to become acquainted with what has already been done by other investigators in the same field, and after the work is completed it must be utilized in such a way that it becomes available as a stepping stone toward further work and is applied to the practical purpose of industry. Research laboratories therefore necessarily contain a library, and the proper use of this library and the proper utilization of the work produced by the laboratory is as necessary a function of its organization as the experimental work itself.

The purposes for which research may be undertaken are diverse. A research may be started with the object of advancing pure knowledge or, on the other hand, with the purpose of facilitating industrial production and making commercial profit, yet the methods and results will be similar in the two cases, and it is usually impossible to predict whether the value of any projected research work will be greater in its industrial applications or in the advancement of knowledge. In many cases those very researches which have been undertaken in the interests of pure science have proved to be of the greatest value to industry.

Some forms of scientific research are applicable only in the smallest degree to industrial production. The work of the astronomer or of the comparative anatomist would appear to have very little possibility of application, but other branches of science closely allied to these are of the greatest industrial importance. Thus, the work of the illuminating engineer, who requires photometric apparatus designed on exactly the same principle as that used by the astronomer, or of the entomologist, whose work is closely related to that of the comparative anatomist, has the most direct application to industrial lighting or to agriculture.

The difference between a pure and an applied science is therefore merely one of intention. An investigator in pure science desires primarily to advance knowledge, while an investigator in applied science desires to obtain a financial advantage from his work, but the purely scientific work may eventually prove of great financial value while that of the industrial investigator may have much value for the theory of the subject

It is often stated that industrial laboratories must select those researches which will pay financially, while laboratories devoted to "pure" research are not under any such limitation, but, as Dr. Steinmetz points out,[1] this is really no limitation at all, since

"there is no scientific investigation, however remote from industrial requirements, which might not possibly lead to industrially useful developments.

Experience, indeed, has shown that it is rare that sooner or later some industrially valuable results do not follow, no matter how abstruse and remote from apparent utility a scientific investigation may appear, and any scientific research whatsoever is thus industrially justified. To illustrate, when research work was undertaken by the Consulting Engineering Laboratory of the General Electric Company on the electrostatic corona and, in general, on dielectric phenomena in the air, no immediate or direct benefit could be seen for the industrial company which financed the work, but it was justified by the consideration that a greater knowledge of these phenomena may extend the economic limits of long distance power transmission and thereby increase the industrial demand for transmission apparatus. Nevertheless, before the research was completed—if research can ever be considered completed—it had led to a redesign of practically all high voltage transmission apparatus and thus proven essentially valuable in industrial design."

[1] C. P. Steinmetz, Scientific Research in Relation to the Industries, *Jour.* Franklin Institute, December, 1916, p. 712.

The great value of scientific research both to the industries and to the nation at large is now generally recognized throughout the world, and the last few years have seen a remarkable increase in the efforts made to stimulate the production of scientific knowledge. In 1914 the American Association for the Advancement of Science appointed a Committee of One Hundred to inquire into the steps which should be taken for the increase of scientific research in the United States, and the work of this committee has been continued and greatly extended by the National Research Council. The British government has appointed a Committee of the Privy Council to deal with the subject, and it is announced that in France a new national laboratory on a very large scale has been projected. In Australia the government has appointed a special department to consider what steps should be taken for the organization and development of research work in the Commonwealth, and in Canada the matter has been the subject of government inquiry and solicitude.

Among the industries themselves there has been a similar awakening to the value of research. Many industrial corporations which were not provided with research facilities heretofore are making such provision, while small corporations which cannot afford to support extensive laboratories themselves are combining to maintain laboratories doing work for the whole industry. Research is being supported by governments, by private gifts, and by the industries, and while at the present moment the intention of most of this research is toward applied science, there is no doubt that the movement will be accompanied by a great awakening and extension of research for the increase of knowledge in pure science.

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, we should find that the starting and development of most manufacturing businesses depended upon discoveries and inventions 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 these industries? 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 progress and with the theory of the cognate sciences; and that, sooner or later, some other genius working on the subject rapidly advanced the available knowledge and gave a new impetus 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 growth in the amount of technical and scientific information necessitating greater specialization, the work of investigation and development formerly 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 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 organized companies who are the leaders of industry can, of course, retain their leadership for a number of years against 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 to advance the subject, and the maintenance of a laboratory staffed by such men is a final insurance against 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 their 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, Limited, 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.

The rare earth industry was, prior to the war, concentrated chiefly in Germany; the manufacture of gas mantles, discovered by an Austrian, developed an entirely new chemical industry which was carried on largely under German auspices. It seems to be suggested 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. No one who is acquainted with the business men of different countries will believe that the British manufacturer is lacking in financial capacity, 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 toward the improvement of the product and the development of the methods of that industry, and that any shortcoming in this respect may involve eventual failure. While this view of the importance of research work to the industries is now obtaining universal acceptance, undoubtedly many who assent without hesitation to the value of a research laboratory still take far too limited 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, processes and product.

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. Laboratories of the second class 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. 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. 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 has sometimes been overlooked in discussions of industrial scientific research, much stress being 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 toward 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 if industries would 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.

Let us consider some graded examples of theoretical work in relation to their application in industry.

First, let us take the case of such work as that done by Abbe on the geometrical laws which govern the formation of images by lenses. The connection between this and the manufacture of lenses is so obvious that it is at once manifest that the discovery of any new principle in the theory of lens optics will react immediately upon construction in some way, either in the form of a new product or in cheaper forms of construction.

Next, let us consider work on improved methods of testing, such, for instance, as the work done by the various bureaus of standards or research on analytical methods. Here it can be seen that only the possession of an accurate method of testing will enable the manufacturer to improve his product and to guarantee the similarity of product made at different times. Consider, for instance, the improvements in electrical measuring methods and instruments which have made available the standardized electrical equipment which is now so familiar to every one.

In the third place, we may take as an example such research work as the study of the relation between inductance and capacity and the properties of alternating electrical circuits, which has had such an immense influence upon the design of alternating current electrical machinery. At the present time, of course, this is a recognized fundamental portion of electrical engineering.

Lastly, let us consider such work as that of the universities on the photo-electric effect, the diffraction of X-rays by crystals, or the emission of electrons by hot bodies. Of these, the last has already found extremely important commercial application, the second one is being adopted by several industrial research laboratories in studying the structure of metals, alloys, and other crystalline substances, while the first has not, up to the present, found any industrial application; yet it may safely be prophesied that it will be of importance to industry within the next ten years.

It is almost impossible to name any class of physical or chemical scientific work, from the physics of the atom to structural organic chemistry, which may not sooner or later have a direct application and importance for the industries.

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 mainly 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. Such a laboratory will have a value which will be cumulative as its work is continued. At the beginning it will be of service to the industry in bringing a new point of view to bear on many of the problems; it will be of value especially in establishing standard methods of testing and standard specifications connected with the purchase of raw materials, while much of its energy may profitably be devoted toward the investigation of the use of the products of the industry. Many large industrial laboratories, indeed, are maintained as much in the interests of the customers of the manufacturing company as on behalf of the production departments. A research laboratory of this type will be of value also in ascertaining the merits of new industrial propositions of which the value has not been commercially established, but all these uses of the laboratory will finally prove subsidiary to its main work on fundamental problems, and when this main line of research begins to bear fruit, it will absorb the energies both of the laboratory and of the factory. This, however, will take many years.

While a large laboratory, fully equipped for fundamental research, represents the most effective means of prosecuting industrial research, such a laboratory can only be maintained by manufacturing companies of the largest kind, as the cost of maintenance is very heavy and only a large company can afford such an expenditure.

Since it is obviously undesirable that industrial research should be confined to the largest manufacturing concerns, it is necessary that substitutes for the large research laboratory should be provided which are available for the smaller manufacturing undertakings. This need is met by laboratories of two different types: co-operative laboratories and consulting laboratories.

Co-operative laboratories may be arranged either for an industry as a whole, the different firms in the industry joining together to support a research laboratory fully equipped and organized for the prosecution of research relating to the industry or, on the other hand, manufacturing concerns interested in various industries may combine to support a laboratory for the investigation of some specific subject in which they have a common interest.

In many countries the government is proposing to aid manufacturers to carry on research work, the most noteworthy example being that of Great Britain, where in 1915, the government undertook the encouragement and organization of scientific research by direct State action. The activities of the Department of Scientific and Industrial Research are summarized by its secretary as follows:[1]

"First, it seeks to encourage the worker in pure research by looking for him in the places where he is most likely to be found, through the eyes of individual men and women who are themselves engaged in research and teaching others how to begin. When the man or woman has been found who needs assistance, they receive it in liberal measure, with no restrictions beyond the necessity of showing that they are continuing their work. Secondly, the Department is helping the firms in different industries to co-operate with a view to raising the funds necessary for employing first-rate men of science in the solution of the problems with which they

[1] Sir Frank Heath, *Jour.* Royal Society of Arts, 1919, p. 214.

are faced and in the scientific development of the industry in question. In this connection the Department is building up a clearing-house of information for the benefit of all concerned. Finally, the Department is offering its assistance, on the one hand, to other Government Departments who desire to have research undertaken on a scale and for purposes which they cannot themselves easily compass. On the other hand, it is organizing research into problems of practical utility, which are of such wide importance that they cannot be handled by any one section of the nation. In both regards it proceeds by delegating the responsibility for the conduct of this work not to officials but to boards of experts, who are entrusted with the preparation of the scheme of work, the employment of the workers, and the control of its execution."

It is a matter of some doubt as to how far governmental organization of industrial research work is likely to be successful. The tendency of work done under governmental control is to be too academic, needlessly expensive, and insufficiently in contact with the practical conditions of industrial life. Probably, however, these tendencies will be less dangerous to research than to other departments of industry, and arguments against governmental organization of research are merely arguments against any direct control of industry by the State, a question with which this discussion is not concerned.

One of the great problems in the organization of research work is the effective utilization of the facilities of the universities. On the one hand, some demand that the universities should be prepared to take up problems in applied science of direct value to manufacturing corporations, while others consider that the research work done in universities should always be strictly subsidiary to and directly connected with teaching.

The primary function of the university is the education and training of its students and everything tending toward this end is therefore a necessary and proper function of the university. For the development of advanced technical and scientific experts a training in the methods of scientific research is agreed by all to be absolutely necessary, and for this reason alone research work must be undertaken in university laboratories. But, further, training in the methods of research can only be given by teachers who are themselves expert research workers, and for this reason the professors and instructors of the university *must* be engaged in research work if they are to fulfill their duties properly. The laboratories of the universities must therefore always continue to be most important agencies for the extension of scientific knowledge.

There remain to be considered, however, two questions:

1. Should universities engage in research work of direct industrial value undertaken with a view to the assistance of industry rather than for its value as training?

2. Should laboratories for the prosecution of research in pure science be attached to universities when they do not propose to undertake teaching at all, or should they be constituted as independent institutions? On the whole, it is probably undesirable that those departments of the universities which are concerned with the teaching of pure science should continuously undertake industrial research. Should they do so, it would be likely to militate against the effective prosecution of their own work and even to affect the

value of the teaching of the institution. At the same time, the universities will be centers of scientific knowledge unbiased by manufacturing considerations and containing large numbers of specialists whose knowledge is necessarily of the greatest value to the industries, and the industries should properly be in a position to make use of the specialized knowledge of such men.

In the departments of applied science, work on problems of importance in industry is often of value in training students, since it gives a feeling of reality to their studies, which is too often absent when no application can be seen. In this connection Dr. Steinmetz makes some very pertinent remarks:[1]

"Some research work can be carried out more efficiently by educational institutions, others by the industry. In general, for industrial research, better facilities in materials and in power are available, but high class skilled labor, of investigators and research men, such as is available in university research by the graduate students, is expensive in the industry. Thus researches requiring little in facilities, but a large amount of time and attention of research men, are especially adapted to educational laboratories, while investigations requiring large amounts of material or of power rather than time of the investigators, are specifically adapted to the industry, and often beyond the facilities of the educational institution. Efficiency thus should require a division of research between educational and industrial laboratories in accordance with their facilities, and where this is done, the results are splendid. Thus, for instance, the phenomena of the dielectric field beyond the elastic limit, or in other words those of the disruptive effects in air and other dielectrics under high electric stress, were almost entirely unknown a very few years ago, and it was even unknown whether there is a definite dielectric strength

[1] C. P. Steinmetz, Scientific Research in Relation to the Industries, *Jour.* Franklin Institute, December, 1916, p. 712.

of materials, analogous to the mechanical strength. This field has been completely cleared up, and a comprehensive knowledge of the phenomena of the dielectric field gained, not only under steady stress, but also under oscillating stress, and under the transient stress of sudden electric blows or impulses, ranging down to the time measured by micro-seconds, as the result largely of the work of an industrial research laboratory—The Consulting Engineering Laboratory of the General Electric Company under Mr. F. W. Peck—and an educational laboratory—Johns Hopkins University under Professor Whitehead—both laboratories working independently and devoting their attention to those subjects for which they are specifically fitted, though naturally often overlapping and checking each other.

"Unfortunately, this limitation of research work in accordance with the available facilities is not always realized, and especially educational institutions not infrequently attempt research work, for which industrial laboratories are far better fitted, while research work for which the educational institution is well fitted, which the industry needs but cannot economically undertake, is left undone. It is usually the desire to 'do something of industrial value' which leads universities to undertake investigations on railroading and similar subjects, in which the probability of adding something material to our knowledge is extremely remote, or to undertake investigations on industrial iron alloys in competition with the vastly greater and more efficient research of industrial laboratories in this field of magnetism, while all other magnetic research is largely neglected, our knowledge on the phenomena of magnetism is therefore still very unsatisfactory, and it is obvious that a material advance can be expected only from a comprehensive study of the entire field of magnetism, and the little investigated non-ferrous magnetic materials thus would be the ones most requiring study."

A question of some importance in this connection is that of the remuneration which should be paid by the industry for the scientific assistance which it receives. Only too often industries consider that they have a right to the services of university professors without charge or for a merely nominal fee. There seems to be no justification for this and there is no reason why the fees charged by university professors for consulting work should be any lower than those of any other professional man of equal grade. The charging of such low fees by university teachers is further open to the criticism that it lowers the standard of charges for scientific consultations and consequently makes it difficult for scientific men unconnected with universities to obtain adequate compensation.

There is the danger that a professor might be tempted to do so much industrial work that he could not attend adequately to the duties of his post. This difficulty is met in other professional positions by a rule preventing a man from doing outside work, and if this rule is to be relaxed in the case of university professors, means for meeting the danger must be devised, since every one with much university experience must have met cases where the work of a department was neglected as a result of the outside interests of its head.

Closely associated with this difficulty, of course, is the low rate of payment at present received by university professors, a rate so low that men are constantly tempted to enter industrial work altogether or to supplement their income by a large amount of consulting work, and an increase in the standard of payment of university professors is urgently necessary if the universities are to retain good men in competition with the industries. It is not necessary for a university to pay as much as a business corporation, since the amenities of university life, the considerable vacations and the standing of the university professor will always be advantages compensating some disadvantage in payment, but it will certainly be necessary for the universities to pay their scientific staffs far more generously than has been the case in the past.

It is possible that the difficulties of industrial research in universities may be met by the university departments acting as consulting research laboratories for those industrial concerns which require such assistance, the fees received going to the department and not to the individual men, and being used for the increase of salaries and for the support of research work generally. In one interesting experiment in industrial research conducted by a university, that of the Engineering Experimental Station of the University of Illinois, cost fees only are charged even for such directly industrial work as the testing of materials. The University is supported by the State of Illinois and considers it to be its duty to serve the industries of the State without profit. Most of the work of the Station is carried on by graduate research assistants, fourteen such assistants being paid a stipend of $500 a year by the University to devote half their time to research work, the other half being spent in post-graduate study.

The desirability of organizing research in pure science in the form of research institutes attached to universities seems to be generally considered to be beyond question, but this is not quite the case

For the proper development of research in pure science there is necessary the establishment of positions in which men can devote their whole lives to the study of scientific problems, unhampered by the need for their application or by financial embarrassments.

For creative work in fundamental science there is perhaps necessary an atmosphere of detachment and concentration upon a specific problem, which can only be obtained in a university or other academic sphere, and it is essential that a man who has the capacity for original thought should be able to attain to a position where the development of his ideas for a long period, unhampered by external disturbances, may be possible. The need for such opportunities has often been pleaded, notably by J. J. Carty[1] and W. R. Whitney.[2] It does not follow, however, that such research positions should necessarily be established in connection with universities. The advantages of a university connection are the academic atmosphere, the contact with minds working in other fields of knowledge, and the stimulus provided by a strictly limited amount of teaching. On the other hand, the university connection may easily absorb much of the time of the research workers for academic or administrative duties, may vex their souls by restrictions and red tape, and may limit the extension of the work which would otherwise come as consequence of success. It is certain that in future much research in pure science will be done by the universities, but it is possible that the establishment of research institutes for work in pure science having no direct academic connection might prove a profitable experiment.

However the provision for research work in the universities may be extended, it is undesirable that

[1] J. J. Carty, The Relation of Pure Science to Industrial Research, Presidential Address to Amer. Inst. E. E., 1916.

[2] W. R. Whitney, Eng., 1917, v. 123, p. 245.

the industries should rely upon the universities to do the fundamental work required for the development of the industry itself. The application of science to industry is essentially a function of the organization of industry and cannot effectively be transferred to other agencies such as those suitable for teaching or for the creation of original knowledge. It is moreover vital to the future of research that the universities should be strengthened and supported for their own work, and that any diversion of their energies should be resisted.

As F. B. Jewett says,[1]

> "The matter of an adequate supply of properly equipped and trained investigators and directors of research is absolutely vital to the growth of industrial research, and I am as sure as one can be of anything in the world that all of our visions of the benefits to be derived from a large expansion of industrial research will come to naught if we fail to realize or neglect the fact that in the last analysis we are dependent absolutely upon the mental productivity of men, and men alone, and that we must, in consequence, provide adequately for a continuous supply of well trained workers."

It is possible that the supply of trained men may best be increased and the universities strengthened by direct financial support from the industries and by the maintenance at the universities of advanced research workers studying problems of general fundamental interest of which the results are freely published. It is, of course, necessary that such support of the universities by industries should not degenerate into any form of control for commercial purposes.

[1] F. B. Jewett, *Trans.* Roy. Can. Inst., 1919, p. 117.

CHAPTER II

TYPES OF RESEARCH LABORATORIES

The agencies engaged in scientific research are of several kinds. In this, as in other fields of human activity, the work has been undertaken by those who felt the need for the results which it was hoped to achieve; and the degree to which research work has been associated with other institutions has always been due to the fact that those institutions felt the need of research work for their own essential duties.

The earliest scientific men were ecclesiastics, who regarded the knowledge which they derived from their inquiries as a means of developing the fullness of the religious belief both of themselves and of those whom they taught, and who felt that the disclosing of the marvels of natural science was a fitting part of worship. As the advance of knowledge came to demand greater and greater modification of creeds and dogmas, so that the increase of knowledge, instead of being an advantage to any particular religious body, became a danger in that it might introduce dissension and doubt, the ecclesiastical world abandoned the pursuit of natural science; and the mantle which the church dropped fell upon the university.

The readiness of the university to accept the burden of being responsible for the advancement of knowledge was due essentially to the fact that the results obtained were immediately applicable to the purpose of teaching, and that, indeed, only by assiduous investigation and discovery could the facts of natural science be sufficiently correlated to make it possible to present them in orderly manner so that they could be understood by the immature minds with which a university has to deal. This necessity for continual investigation on the part of a teacher was so marked, and the success of teachers who themselves were engaged in investigation was so pronounced, that it was generally recognized that the best advanced training in science could be obtained only under a man who was himself actively engaged in promoting the science which he taught.

At the present time, however, science has advanced in all directions to such wide boundaries that the teacher cannot expound to his students the matters which are under investigation at the time at which he is teaching, and, indeed, the matters taught, even in advanced classes, are often those on which the investigation has been carried ten or fifteen years beyond the point at which the teacher must deal with the subject. While the teacher must, therefore, continue investigation both for its beneficial effects upon his own habits of thought and for the advantage which his students will gain from close association with original investigation, it is no longer the duty of the universities alone to provide for the expansion of knowledge. That expansion is no longer required primarily for the assistance of the teacher; it is required for the development of civilization as a whole and especially of industry, and the provision for its expansion would therefore seem to be incumbent upon the leaders of industry themselves, and in the case of knowledge which has no direct application to industry at the time, upon the leaders of the people as a whole, that is, upon the governments of the world.

There are seven principal types of research laboratories which have been developed hitherto:[1]

1. University laboratories.
2. Government research laboratories.
3. Foundation research laboratories.
4. Industrial research laboratories maintained by individual firms.
5. Co-operative research laboratories.
6. Industrial fellowship laboratories.
7. Private consulting research laboratories.

If we consider the work undertaken in these various laboratories we find that the above classification, which is based on the nature of the agency supporting the laboratory, has little relation to the work done. Neither does the object with which research is undertaken form a definite guide to the nature of the work done in the various types of laboratory, since there is little distinction between the work done in some university laboratories and some industrial laboratories, and the work of the government and institutional laboratories again overlaps that of the two former classes.

The research work on photometry done at Nela Park and at Cornell University is of the same kind, and work on physical chemistry or on the structure of chemical compounds is of the same type, requires the same class of workers and produces the same results, whether it be done in a university, in a laboratory of

[1] See P. G. Nutting, Institutes of Applied Science. J. Franklin Inst., 1919, p. 487.

the Carnegie Institute or in such an industrial laboratory as that of the General Electric Company.

A classification of laboratories which is sometimes useful is obtained from consideration whether the problems investigated in a laboratory are all connected with one common subject or whether the problems are of many kinds, having no connecting bond of interest. The first type of laboratory might be called "unipurpose" or "convergent" and the second "multipurpose" or "divergent."

In the divergent group of laboratories are included all research institutions which are interested in science in general or in science as applied to industry and which will attack any problem which may seem to promise progress in knowledge or, in the case of an industrial laboratory, financial return. Most university laboratories are of this type. When they devote themselves to special problems it is usually because of the predilection of some professor, and as a general rule, a student or instructor may choose any problem in the whole field of the science in which he is working, and may carry out an investigation on that problem, if he be interested in it, without regard to the relation of his work to the other work of the laboratory.

Correspondingly, in most industrial laboratories the problems investigated are those which present themselves as a result of factory experiences or of suggestions from the men working in the laboratory and which promise financial return, the different problems carried on in the same laboratory not necessarily being related in any way whatever.

The greater number of university and industrial laboratories are necessarily of this type. It would be a disadvantage for a university laboratory, whose primary business is training students, to be too narrowly specialized. Specialized university laboratories are desirable only in the case of post-graduate students, and it would be inadvisable to allow the laboratories responsible for the general training of scientific men to specialize in one branch of science, since as a result the students would acquire a proper acquaintance with only a limited portion of their subject.

Industrial laboratories, on the other hand, must necessarily be prepared to deal with any problems presented by the works, and as these will be of all kinds, covering generally the whole field of physics, chemistry and engineering, it is impossible for many works laboratories to specialize except in so far as they deal with the works processes themselves.

In the "convergent" laboratories, however, although the actual investigations may cover as great a range of science as those undertaken in a divergent laboratory, all these investigations are directed toward a common end; that is, toward the elucidation of associated problems related to one subject. Thus, the staff of the Geophysical Laboratory, which includes physicists, geologists, crystallographers, mineralogists and chemists, works on the structure of the rocks and their manner of formation; and although the field of the actual investigations ranges from high temperature photometry to study of complex solubility diagrams and their interpretation on thermodynamical principles the results of all the work carried out are converged on the problem of the structure and formation of the earth's crust.

The Nela Park Laboratory, in the same way, is studying the production, distribution and measurement of illumination, and all its work, which may involve physiology, physics and chemistry, is related to that one subject. Such convergent laboratories sometimes develop in universities owing to the intense interest of a professor in a single subject and to the enthusiasm which inspires students and assistants to collaborate with him and to concentrate all their energies on the same group of problems. Among examples of such laboratories may be named most of those which have become famous in the history of science. Emil Fischer's laboratory, which for some time was concerned with the sugars and later took up the study of the proteins, Ostwald's laboratory at Leipzig, Kayser's laboratory at Bonn, the laboratories of Curie, Ramsay and Rutherford, dealing with radio-activity, the Cavendish laboratory at Cambridge, the Wolcott Gibbs laboratory at Harvard, dealing with the determination of atomic weights and with the physico-chemical properties of the elements, and the low temperature research laboratories of Kammerlingh Onnes and of James Dewar, are but the better known cases selected from a great number.

Astronomy furnishes us with an example of a science in which not only is intra-laboratory co-operation complete, since almost all the great astronomical observatories are working on some selected group of problems, but inter-laboratory co-operation has also been developed, since, by means of the International Union for Solar Research, and other institutions of the same kind, the astronomical observatories throughout the world co-operate and exchange results to a higher degree than obtains in any other science. The great progress which has been made recently in astronomy is due not only to the munificent foundations which have facilitated research in this subject but also to the well organized co-operation both inside and outside the observatories which is characteristic of this branch of science.

As a rule, therefore, institutional and foundational laboratories will be of the convergent type, since they are established to deal exhaustively with a special field of science. Many industrial research laboratories will also tend toward the convergence of their work, and co-operative laboratories serving an industry or engaged in a specific field of research will be of the convergent type. On the other hand, university, governmental and consulting laboratories will be divergent rather than convergent in their aims and organization, and most works laboratories will necessarily be of this type.

The national research laboratories supported by the governments are of the greatest value and importance. The governments of the large countries have already recognized that the maintenance of standards of length, time and mass, standards of quality, specifications of materials, standards of performance, and the determination of physical constants which are required for the whole commerce of a nation must be undertaken by some laboratory which shall have the authority given by government sanction. The Reichsanstalt in Germany, the Laboratoire Centrale d'Electricité in France, the National Physical Laboratory in England, and the Bureau of Standards at Washington represent the four great national laboratories maintained for this purpose, while the Bureau International de Poids et

Mesures at Sèvres has resulted from the co-operation of all countries for the maintenance of one international laboratory where the primary standards of the world are maintained.

The work of these national standard laboratories is extended to cover many branches of scientific research which have developed from their original fields of investigation. The Bureau of Standards, for instance, is now a very large laboratory, the total cost considerably exceeding $1,000,000, and its annual maintenance cost being about $600,000.

Another function of these government laboratories is to act as consulting laboratories for the government departments, advising them as to specifications for materials and making tests on the materials purchased. The need for such a laboratory, indeed, was the cause of the establishment of the National Physical Laboratory, the greater part of its work on standards being transferred to it later. Recently, these laboratories have still further extended their fields of work, and are now doing research work for government departments comparable with the industrial research required by manufacturing corporations; thus, some time ago at the National Physical Laboratory there was installed a water tank for testing the properties of ship models, this being intended partly for warship design but more especially for the assistance of private ship builders; and the laboratory erected aero-dynamical tunnels for experiments on the design of aircraft and the properties of aircraft propellers, engines, etc. Under war conditions these national laboratories have, of course, assumed great importance, many of the problems arising from the war being referred to them. The

National Physical Laboratory, especially, has grown very greatly since 1914.

In the United States, certain branches of industry are of such importance that separate sections of the government have been formed to deal with them, and in some cases these have established laboratories which are supported by the federal government. Thus, the Bureau of Mines, which has for its object the welfare of workers in the mining industries and the improvement and prevention of waste in procuring and utilizing mineral resources, carries on a large amount of research work, especially as regards fuel research and the testing of mining explosives. Recently, this bureau, in co-operation with the National Radium Institute, has undertaken the extraction of radium from carnotite ores found in the United States, developing some new methods for the process and successfully preparing large quantities of radium salts which have been applied to medical work. The largest research institution in the world is that maintained by the United States Department of Agriculture, which has experimental stations in various parts of the country supported partly by the individual states and partly by funds from the federal government. These stations are usually associated with the State universities and undertake all kinds of experimental work, from pure chemical and biological research to the training of agriculturists and the dissemination of information in the simplest and most practical form to the farmers. In connection with the forest service section of the Department of Agriculture there is established in co-operation with the University of Wisconsin a Forest Products Laboratory which carries on investigations in connection with the wood-using industries, a large amount of work being done on the manufacture of paper and the production of alcohol from waste timber.

Next to the government laboratories the most important agencies outside the universities for the promotion of research in pure science are the laboratories supported by benevolent foundations. In the United States there are two such great foundations, the Rockefeller Institute, which is distinguished especially for its research in preventive medicine, and the Carnegie Institution, noted particularly for its investigation in certain branches of pure physics and of some fields of biology. These institutes are models of well administered research in pure science. The organization of the Carnegie Institution consists of a number of convergent laboratories, each devoted to some very important group of scientific problems on which the whole energy of the laboratory is centered. These laboratories are directed by capable research men, and their staffs contain men of the highest scientific distinction. The whole of their energy is devoted to scientific research, the only purpose of the institution being the promotion of knowledge, and the results which have been obtained completely justify the greatest hopes which the donor may have entertained. The chief laboratories supported by the Carnegie Institution are the Solar Physics Research Laboratory at Mount Wilson, the greatest observatory in the world; the Geophysical Laboratory, devoted to the investigation of the structure of the rocks and the earth's crust; the Laboratory of Terrestrial Magnetism, which operates in connection with a non-magnetic ship of sea-going capacity; laboratories for experimental evolution, for botanical research, for embryology; and an important station in the Tortugas for the study of marine biology. There are also departments for research in history, economics and sociology; and the Institute further aids in the promotion of scientific work outside its own organization, and especially in the publication of papers of scientific importance for which a limited circulation is expected.

If the governments of the world ever really come to believe that the promotion of scientific knowledge is a function of government, it would seem that some such scheme as that of the Carnegie Institution—magnified in extent, of course—would furnish the best starting point for the establishment of a national system of research in pure science. This may seem utopian until it is realized that the income of the Carnegie Institution is only about $1,000,000 per annum, and, in comparison with national expenditure, an expenditure of many times this amount for the development of scientific knowledge would not seem a very rash experiment. Such a national institute would be of the utmost value to the universities on the one hand and to industrial research on the other, partly as forming a reservoir of men but especially as forming a reservoir of knowledge from which both these important sections of the communal life could draw.

In addition to the Rockefeller and Carnegie Institutes there are a number of endowed observatories in the United States; it is, in fact, the readiness of wealthy Americans to endow observatories which has placed the United States in the first rank in astronomy in the world; and there are a certain number of other funds from which grants can be made to investigators.

In Germany, until recently, scientific research was left in the hands of the universities, which were very fully endowed for the purpose and which it became the ambition of all other nations to rival in the mass and quality of their production. In 1910, however, the scientific men of the German empire decided that an even more intensive effort to support scientific research and especially research in pure science should be made, and this took the form of the foundation of the Kaiser Wilhelm Gesellschaft, which was endowed by the commercial magnates of the German empire in order to carry on scientific research on a very large scale. The financial support for this institute was derived from the subscriptions of the members, the entrance fee to membership being $5000, and the annual subscription $250. At the beginning there was founded a chemical institute, under the directorship of Professor Beckmann, and several biological and archæological institutes. The president of the Kaiser Wilhelm Gesellschaft was Dr. Harnacke, the first vice-presidents Herr Krupp von Bohlen and Dr. Delbrück.

Industrial laboratories in some form or other are maintained by a great number of manufacturing concerns, but for the purposes of this discussion we may ignore all those laboratories which are not concerned with pure research and which deal only with the testing of raw material or the control of product.

Industrial research laboratories in the true sense of the term may be created and maintained for the following objects:

The elimination of manufacturing troubles;

The investigation of possible new products;

The development of standard methods of testing or specifications for the purchase of raw materials;

The investigation of new industrial propositions of which the value has not been commercially established;

The investigation of new methods of using products or of improved methods of operating for the benefit of the customers of the firm;

Fundamental scientific research having an important bearing on the technique of the subject with which the industrial corporation is concerned.

These industrial laboratories are of many different sizes and types. There are in some firms very small laboratories operated by only one or two men, which nevertheless are doing important scientific work; there are very large laboratories which are doing equally important scientific work; and on the other hand, there are laboratories which do practically no work of general value, concerning themselves only with the specific problems of direct commercial importance to the corporations which support them.

The number of research laboratories doing industrial work is probably far greater than is generally realized. A very useful résumé of the chief industrial laboratories of the United States is given by Mr. Fleming in his paper on industrial research in the United States of America, but there are necessarily a considerable number of laboratories which did not come to his notice, since the work done in them is not published and little mention is made of their investigations.[1]

Judging from the British scientific press, it is commonly believed that research laboratories on a large scale do not exist in the British Isles, or did not exist there prior to the war. This is, of course, an error. For many years some of the British firms have been doing scientific research of a very high order, but as a general rule, although much of the work was published in the scientific journals and many of the products of that work have been of value to British commerce, the firms were not anxious to advertise the work of their laboratories. It is only when a firm considers that the possession of a research laboratory is of advertising value that its existence is likely to become widely known to the general public. Some of the American firms have conducted publicity campaigns informing their customers of the existence of their research laboratories and of the value that they should be to their customers as well as to themselves, and the fact that this has not been done by many British firms has probably led to an underestimate of the value of the work already done in Great Britain.

The laboratories which are supported by a number of co-operating industrial firms with or without assistance from governments, promise to become so numerous and important that it has seemed better to consider them separately in the next chapter.

[1] Much more complete lists are given by A. D. FLINN, *Proc.* Am. Soc. for Test. Mat., vol. xviii, Part II, 1918 and by A. GREENE, *Proc.* Am. Soc. Mech. Eng., June, 1919.

CHAPTER III

CO-OPERATIVE LABORATORIES

Since the support of a research laboratory by a manufacturing company involves a considerable expenditure, it seems natural that a number of firms having common interests should combine to support such a laboratory and should thus form a co-operative research association.

Three forms of co-operative laboratory have been developed.

Co-operative laboratories supported by a group of manufacturing firms interested in a common industry, the financial arrangements being operated by means of a trade association, either pre-existent or formed for the purpose.

Research institutes maintained by an independent body such as a university but in which the research work itself is financed by industrial firms to whom the results obtained belong, this financing usually taking the form of industrial fellowships founded for specific investigations.

Consulting research laboratories maintained as private ventures and carrying on research work at fixed rates or on a percentage basis.

The first form of laboratory has been represented for some years by the laboratory of the National Canners' Association, which was established in Washington to study the problems of the canning industry and which has been so successful that it is now considered one of the assets of the industry. This type of laboratory has been adopted by the British Department of Scientific and Industrial Research. The proposals of that department will be considered later.

The original research institute in which research work could be carried on by a number of industrial firms was founded by Professor R. K. Duncan at the University of Kansas and transferred by him to the University of Pittsburgh, where the Mellon Institute was erected and endowed to form a permanent home for the work. This institute has been copied in several places and the Research Institute proposed by the Research Council of Canada is based on it.

Consulting research laboratories, such as that of Arthur D. Little, Inc. in Cambridge, Mass., or the Electrical Testing Laboratory in New York and others, have been very successful in special fields and meet a need for which no other form of laboratory is adapted.

In addition to these types of laboratory it seems probable that a fourth form, which would differ in that it would be strictly *convergent* in type, may have a considerable future.

In this chapter these four types of laboratory are therefore discussed, and since the British Department of Scientific and Industrial Research has made an exhaustive study of the subject and has finally adopted a definite type of research association, it will be well to study their work first.

In July, 1915 a committee of the Privy Council was established to promote scientific and industrial research in the British Isles, and at once appointed an Advisory Council of eminent scientific men, which has since been the active agent in organizing the work. In the first report[1] the Advisory Council refer to the establishment of the committee thus: "The State had thus recognized the necessity for organizing the national brain power in the interests of the nation at peace. The necessity for the central control of our machinery for war had been obvious for centuries, but the essential unity of the knowledge which supports both the military and industrial efforts of the country was not generally understood until the present war revealed it in so many directions as to bring it home to all."

The directions to the Advisory Council were "to frame a programme for their own guidance in recommending proposals for research and for the guidance of the Committee of Council in allocating such State funds as may be available."

As a commencement, the Advisory Council undertook to give aid to the existing researches, to hold conferences with professional and other societies, to form standing committees to deal with special branches of research work and to complete a register of researches to aid research in educational institutions, this, however, being limited by the provision that such aid should not result in the funds of the educational institution ordinarily available for education or research being relieved.

In December, 1916 the work of the Committee of the Privy Council was established as a separate department entitled "The Department of Scientific and In-

[1] Report of the Committee of the Privy Council for Scientific and Industrial Research, 1915–1916, p. 9. (These reports will be referred to hereafter as "British Report, 1915–1916," etc.)

dustrial Research," and an Imperial Trust for the Encouragement of Scientific and Industrial Research was created to hold the funds allocated to research, the expenditure of which was to be controlled by the new department. The principal part of these funds consisted of the sum of one million sterling voted by Parliament.

In the report of the Advisory Council for 1916[1] it is pointed out that there is room in the industrial world for three methods of financing research. The report continues:

"There is research which the individual firm finds it remunerative to undertake at its own expense. Secondly, there is research which is financed on a co-operative basis, and lastly, there is research which must be financed by the State, if it is to be done at all.

"Is any distinction in kind to be drawn between these three classes of research which would justify this difference of treatment? If there is, and if it can be clearly stated, it should greatly assist the sound administration of public funds and be a useful guide to our own policy. We suggest that the distinction is to be sought in the probable nature of the results to be obtained from an investigation. If the research is one which a single firm can finance and which, if successful, will yield results that a single firm can exploit to the full, there is no case in normal circumstances either for co-operation with other firms or for assistance from the State. The more powerful the firm and the greater the variety of its activities, the more far-reaching will be the nature of the research it will be justified in undertaking. But as we pointed out in our last report, British manufacturing firms are not as a rule at the same time both large and complex. In the great cotton industry, where some of the firms have capital funds to be reckoned in millions, the organization is 'horizontal,' not 'vertical,' and manufacturing success has been obtained by specialization in a narrow range of processes. Far-reaching scientific investigations which

[1] British Report, 1916–1917, p. 16.

are likely to affect several sections of the industry are accordingly more suitable for co-operative than for single-handed attack. There will still be ample room for private research by individual firms on the lines of their own special work. Indeed, they may be expected to gather many suggestions for this from the results of the co-operative investigations.

"On the other hand, the German chemical industry with its powerful firms engaged in handling the primary raw materials through all their intermediate stages up to the manifold but closely related final products, explosives, dyes, essences, drugs, antiseptics, would not be suited for co-operative research, though it may be prepared to go far in the direction of financial fusion—a mere continuation of the previous line of development.

"If, as in this country, conditions are in many respects specially favorable to co-operation in the conduct of research, the State is, we think, justified in encouraging development along these lines by means of monetary and other assistance. We find the justification for our proposals for Research Associations in these considerations. But when the firms have done all that it will pay them to do in the way of both private and co-operative research, there still remain lines of investigation which will either be sufficiently fundamental to affect a range of interests wider than any single trade, however large, or else they will clearly have a direct bearing on the health, the well-being, or the safety of the whole population. The two types are not mutually exclusive, but research of either kind falls, we think, into the third class and must be undertaken by the State itself."

The research associations referred to in this extract were designed by the Advisory Council to make use of the funds at their disposal for the promotion of research. These research associations are formed as follows:

The manufacturers in each industry combine to form a limited liability company operating without making profits. This research association undertakes to initiate researches, collect information, and generally be at the disposal of the manufacturers supporting the association.

When the Advisory Council commenced its work it found a strong movement in England toward trade associations, and after the Whitley report of 1917 the standing joint industrial councils recommended in that report were invited to co-operate in the formation of the research associations, thus giving a representation to labor in their organization. Many scientific industries, however, were found to be completely without any trade association, and in these cases it was necessary to form the research associations as separate bodies.

It was not held essential that research associations should organize laboratories of their own, since existing laboratories attached to universities might be utilized. Each association, however, has a research director as executive officer. The research associations are entitled to receive from the Department for the first five years, funds equivalent to the amount subscribed by the manufacturers, the limit, however, being £5,000 per annum.

The advantages accruing to each firm subscribing to a research association are set forth by the Department as follows:[1]

1. "It will receive a regular service of summarized technical information which will keep it abreast of the technical developments in the industry at home and abroad. To do as much for itself any firm would have to employ more than one man on its staff reading and translating the technical press.

2. "It will be able to obtain a translated copy of any foreign article in which it may be specially interested and to which its attention will have been drawn by the periodical bulletin.

[1] British Report, 1916–1917, p. 50.

3. "It will have the right to put technical questions and to have them answered as fully as possible within the scope of the research organization and its allied associations.

4. "It will have the right to recommend specific subjects for research, and if the Committee or Board of the research organization of that industry consider the recommendation of sufficient general interest and importance, the research will be carried out without further cost to the firm making the recommendation, and the results will be available to all the firms in the organization.

5. "It will have the right to the use of any patents or secret processes resulting from all researches undertaken either without payment for licenses, or at any rate on only nominal payment as compared with firms outside the organization.

6. "It will have the right to ask for a specific piece of research to be undertaken for its sole benefit at cost price, and, if the governing Committee or Board approve, the research will be undertaken.

Sir Frank Heath[1] says:

"The Department acts as a clearing-house of information for the association, and gives all the assistance and advice in its power, whether the association is in receipt of a grant or not. The association has full control of its own income, whether from Government or from its members, and all the results of research are the sole property of the association held in trust for its members. The Department asks to be kept informed, acts as the go-between when an association seeks to sell its results to another industry or association, and reserves the power to prohibit the communication of results to a foreign body or person. But this is the limit of Government interference. The Advisory Council laid stress upon the representation of science as well as capital and management on the board of directors, and they think it desirable that there should be some representation, if possible, of skilled labor. They also lay great stress upon the appointment in each case of a responsible technical officer as director of research, in order to ensure the unity of direction, which is as necessary in research as in the battlefield."

[1] *Jour.* Roy. Soc. Arts, 1919, p. 210.

The plan thus adopted by the Department was well thought out and the manufacturers have displayed great interest in the scheme, but it will undoubtedly require great tact on the part of the executive officers of the Department to make the arrangement work smoothly. While the Department protests that it is prepared to make the research associations entirely self-governing, the restrictions imposed by the articles of association, the model draft of which is provided by the Department, are such as to leave a considerable amount of control in its hands. The draft of these articles published by the Department is indeed a document which does not tend to inspire confidence in any one who has had experience in industrial research. It has evidently been drawn by an expert in company law who knew nothing of the difficulties in direction which arise in all forms of industrial research, but, above all, in research undertaken in the interests of a combination of competing and probably suspicious and jealous manufacturers.

The great problems in such an association will be the choice of the researches to be undertaken and the disposal of the results obtained from the work. The only provision in the articles dealing with the choice of work is one enabling a member of the association to appeal to the Department to prevent work being undertaken which may prejudice his personal interests, and in the specific directions for the powers of the Council no mention of research work is made at all, the difficulties which are certain to arise in such research associations being therefore entirely ignored in the Articles of Association and left to the decision of the Council assisted by the executive officers of the

Department. It would seem that the most urgent requirement for the success of this scheme for research associations would be the drafting of a set of regulations dealing with their research work. This will probably be done before long, and it may be hoped that the regulations will be drawn up by a committee composed of the heads of industrial undertakings and of scientific men experienced in actual industrial research rather than by either the legal or scientific experts of the Department. There are certainly more men available in Great Britain with years of experience in actual industrial research than would be suggested by reading the names of the members of the Advisory Council or even of most of its committees.

The list of research associations to which licenses were issued up to July 31, 1919 is as follows:

British Photographic Research Association
British Scientific Instrument Research Association
British Research Association for the Woolen and Worsted Industries
British Portland Cement Research Association
British Boot, Shoe and Allied Trades Research Association
British Motor and Allied Manufacturers' Research Association
British Empire Sugar Research Association
British Cotton Industry Research Association
British Iron Manufacturers' Research Association.

The list of those approved at the same date is:

Research Association of British Rubber and Tire Manufacturers
British Music Industries Research Association
Linen Industry Research Association

Glass Research Association

British Chocolate, Cocoa, Sugar Confectionery and Jam Manufacturers' Research Association.

Scottish Shale Oil Trade Research Association

British Non-ferrous Metals Research Association

British Refractories Research Association.

The Advisory Council recognized from the beginning that there were important fields for industrial research which could not be covered by means of research associations, and where the conditions made it unlikely that any particular industry would undertake necessary research the Department was prepared to take action itself with the help and assistance of the industries concerned.[1] In the report for 1917 it is stated that the attention of the Department had been devoted in growing measure to the organization of those fields of research which are unsuitable for research associations, and that the work on fuel research had progressed so far that it was determined to erect a special research station at a cost of about $800,000 on a site loaned by the South Metropolitan Gas Company. This station was completed at the end of 1919.[2] This fuel research station corresponds to a considerable degree to the convergent laboratories for specific branches of research discussed later in this chapter, and it is quite possible that eventually the activities of the Department of Scientific and Industrial Research may be concentrated upon such convergent laboratories, and that the co-operative laboratories which were at first proposed may be limited to those industries for which they are particularly suitable.

[1] British Report, 1916–1917, p. 15.

[2] British Report, 1918–1919, p. 20.

It does not seem probable that co-operative laboratories will be successful in all industries. The success of private industrial laboratories has led to a belief that co-operative laboratories would be equally successful, but this belief ignores certain essential aspects of the matter.

When an industrial research laboratory is supported by a single manufacturer it will be part of the competitive system of the industry, so that the manufacturer will be stimulated by competition against rival manufacturers in the same industry to use his laboratory to the utmost extent. Moreover, to a single manufacturer a laboratory has a considerable advertising value, and its possession is commonly used to instil confidence among his customers in the products of the factory. It also serves as a school for the training of skilled technical employees who can be transferred to other branches of the business when necessary. Even when employees are not so transferred the presence of a number of men acquainted with the industry, but with specialized scientific training, in daily close association with the other employees of the company cannot fail to be of value. Finally, a private laboratory can be entrusted with trade secrets of great value and can often take a valuable part in the executive direction of the business, especially where new products or methods are being considered.[1]

None of these advantages exist in the case of a co-operative laboratory. It cannot by its very nature aid one manufacturer in competition with another, it has an advertising value only for the industry as a

[1] See Chapter IV, p. 61.

whole and not for the individual firm, it may train men for the industry but this is as likely to assist his competitors as any individual manufacturer. Furthermore, great difficulties attend the carrying out of work which involves trade secrets in any co-operative laboratory, and few manufacturers would care to discuss their plans for the future with the officials of such a laboratory.

The conditions, therefore, under which we may expect co-operative laboratories to be successful are those in which all the members of the industry have a common interest in the results.

The work of an industrial research laboratory may be divided into work on fundamental theory, on raw materials, on the design of products, on processes of manufacture, and on applications of and uses for the products. Ignoring for the moment the question of fundamental research, work on raw materials and on the applications and uses of products cannot fail to be of interest to all manufacturers in an industry apart from the jealousies which are inevitable among competitive firms and which any scheme for co-operative research must overcome if it is to succeed.

Work on processes can be carried out co-operatively only if the processes of an industry are matters of common knowledge among all those engaged in it. In some industries this is the case, and competition is confined to superior efficiency in manufacturing, organization or selling, but in many industries this is not so, and many of the processes are held as trade secrets. Under such circumstances it is difficult to see how a co-operative laboratory could effectively study those processes.

As regards the design of products, there seems little opportunity for co-operative research; for where there is a possibility for varied design this is usually the most competitive aspect of the industry, and it is difficult to see how the results of work on new products in a co-operative laboratory could be allotted among the subscribers.

At first sight, it may seem that work on fundamental theory would naturally be common ground and that any co-operative laboratory might study this to the satisfaction of its supporters. It is somewhat doubtful, however, whether any but the largest industries will eventually be successful in carrying out research in fundamental theory.

Consider a small industry in which the charge for the research laboratory amounts to perhaps 2 per cent. of the profits, and in which most of the firms are small and make small profits. Now, suppose a research association is formed with the intention of studying the fundamental theory and that the more immediately remunerative branches of research cannot be undertaken because of the nature of the industry. As is frequently emphasized in this book, fundamental research is a difficult and slow business, from which little can be expected for many years, and the only product from such a laboratory at the beginning would therefore be a number of papers published in the scientific press and written in language which would quite possibly be incomprehensible to many of the business men who had each year to pay their assessment for the support of the work. At first, no doubt, they would feel a certain amount of pride in the publications from their own laboratory, but this feeling is much less than would be the case if the work had been done in a private laboratory rather than in a co-operative one, and one cannot help feeling that before long there would be a strong demand from the industry that the laboratory should do something "practical," and that work on theory should be left to somebody else.

Co-operative laboratories, however, are likely to be of the greatest value in some industries, especially in those on which little scientific work has been done and where no strong feeling of exclusiveness and secrecy prevails. It is by no means necessary that we should consider co-operative and private laboratories as mutually exclusive alternations. A manufacturer's membership of a Research Association is perfectly consistent with the existence of his private laboratory, for while the Association laboratory carried on work of common interest to the whole body of members the laboratory of an individual company might use that work as a basis for particular investigations of direct value to itself. In any case co-operative laboratories must tend to weaken and eventually destroy the "trade secret" bogey, which does so much to retard progress and prevent increased production.

One method of enabling small firms to carry on their scientific work when they cannot afford to support an adequate private laboratory is undoubtedly to be found in a laboratory of the type of the Mellon Institute, which provides the necessary conditions for secrecy and individual control while supplying the organization and directive ability which is beyond the resources of many small firms. Another solution may be found in convergent laboratories supported by users of materials rather than by producers.

Common interests are much more frequent among users of materials than among producers, since all users of a given material or process have an interest in its improvement. They have an interest in the lowering of its cost, and they have a common interest in its replacement by a superior material or method.

It may be, therefore, that for many purposes laboratories might be supported by associations of users as well as by the co-operation of producers. It is obvious that the number of users of the materials or method who would be interested in research on a given subject may be very large indeed.

Consider a laboratory devoted to research on non-ferrous alloys for instance. Few manufacturers who are using alloys would care to support an adequately equipped laboratory even on a small scale. For research on alloys a laboratory requires a very extensive plant, involving metallographic microscopes, strength-testing machines of different kinds, furnaces, etc., and also a specialized staff of experts—difficult to get and expensive to maintain. Moreover, in the case of most users of alloys it is only occasionally that problems present themselves, though when those problems occur it is frequently very vital to get a rapid solution of them.

It would seem, therefore, that research on alloys would be a most suitable subject for an association laboratory, and that firms of all kinds who use alloys might subscribe sums for its support, according to the interest they have in the scheme. Even an industry having a well equipped laboratory for its own work would probably prefer to contribute to an alloys research laboratory rather than install a special department for alloy research in its own labcratory. For a moderate contribution it could have the privilege of referring problems to the general laboratory and of obtaining their reports, bulletins, etc., on new alloys. When a problem of special interest to itself appeared it could maintain in the alloys laboratory a man supported by an industrial fellowship to work on its special problem, paying only the cost of the research while the man would have available the special equipment and directing knowledge of the whole specialized laboratory. Such a method of conducting alloys research would certainly be far more economical than a large number of small laboratories, each attempting to cover part of the field, and would probably be much more likely to succeed than an attempt to get the conflicting interests of the miners and smelters of the various metals reconciled sufficiently to support a co-operative laboratory for research on alloys. The establishment of such a laboratory is now being considered by the Research Extension Division of the National Research Council.

Another possible example of the same thing is a laboratory for research on metal cutting. Only the largest industries could afford to do any adequate research on the subject, but very few of them would refuse to contribute toward the support of a central laboratory which would study the subject as a whole and to which they could refer their own problems for solution.

In addition to co-operative laboratories formed by associations of manufacturers a type of laboratory which is particularly valuable to small firms is that in which the researches are carried on by means of industrial fellowships, the laboratory organization being maintained by some institution such as a university or government department.

The prototype of these industrial fellowship laboratories is the Mellon Institute at the University of Pittsburgh, which was founded to carry out the scheme of industrial fellowships originally introduced by Professor Robert Kennedy Duncan at the University of Kansas. Professor Duncan founded this scheme partly in order to train students in industrial research and partly because he felt that such research work as was attempted in small factories was often undertaken under very bad conditions.[1] He felt that often the manufacturer has neither the knowledge nor the experience requisite to establish successful research, that he is not willing to allow sufficient space or equipment, and that a man working alone in a small industry is hampered by lack of the stimulation which arises from association with other scientific workers, and also by want of proper skilled direction of the work.

In such a laboratory as the Mellon Institute the manufacturer can arrange to have the work done by a man employed by himself, thus insuring that the manufacturer alone obtains the result of the work, and yet the research man will have the advantages of the Institute, contact with other scientific workers, the availability of sources of information such as a reference library, and direction of the work by experienced ad-

[1] R. K. Duncan, Industrial Fellowships, *Jour.* Soc. Chem. Ind., v. xxviii, p. 684.

ministrative officers of the laboratory. According to the system in operation at the Mellon Institute a manufacturer having a problem requiring solution may become the donor of a fellowship, which provides the salary of the fellow selected, the Institute supplying free laboratory space and the use of all ordinary chemicals and equipment.

In the first five years of the Institute 105 one-year fellowships were supported by 47 concerns, the total amount contributed being $360,000. During this period the Institute itself expended $175,000 in overhead charges, and the building and equipment represent an investment of over $300,000. About 40 fellowships are generally in operation with about 70 fellows at work. The first fellowship founded was on baking. In 1917 the most important fellowships dealt with bread, yeast, synthetic organic products, glue, copper, gas, coke, oil and illumination.

Such laboratories as the Mellon Institute are certain to be of great value for training men, and it has been found that in many cases manufacturers who have endowed an industrial fellowship eventually establish research laboratories of their own, employing in them the men who have carried on the work as fellows. These institutes will thus serve as nurseries for private industrial research laboratories in addition to the work which they do directly and to the training which they give. The weakness of such industrial fellowship laboratories is that the conditions of their operation produce a tendency to demand immediate results, and the work undertaken tends to be of an extremely "practical" nature.

It would seem to be difficult for such an institute to take up really fundamental work in applied science, and consequently the great danger of all work in such an institution is that it will tend to be too superficial. This is recognized to some extent by the Mellon Institute itself, which has founded a laboratory for research in pure chemistry, intended to keep the fellows in closer touch with theoretical science. Also, it is probable that the work of the Institute would be improved if it were extended to cover a greater amount of physical research instead of being almost exclusively chemical in its organization. Physics is so often of importance in industrial research that its absence from a research institute must be a source of weakness.

A number of universities have drafted schemes for institutes similar to the Mellon Institute, but the most interesting proposal along these lines is that of the Research Council of Canada for the establishment of a Canadian National Research Institute, which is to be a combination of a national physical laboratory for physical determinations and the maintenance of standards and of a fellowship research institute in which the fellowships are to be maintained by trade guilds for research formed by the industries.

A similar national research institute forming a combination of a physical standards laboratory and a fellowship research institute is in course of organization in Japan, a fund of 8,000,000 Yen being proposed for its endowment. A national research institute on somewhat similar lines has been proposed in France. These latter institutes are subject to the difficulties which have already been indicated as attaching to co-operative industrial laboratories and especially to those to which governmental assistance, and consequently governmental control, is extended. They must be of advantage to industry, they may be of the greatest value to science, but their value will depend very largely upon the ability of their directors and especially of the director of the laboratory itself. Only if the direction is of the wisest, and if it is unhampered by red tape and officialism to an extent which can scarcely be expected, will the proposed institutions fulfill the hopes which are expressed by those responsible for their organization.

Such a consulting laboratory as that of Dr. A. D. Little in Boston is very valuable for the promotion of research in the case of industries who do not care themselves to undertake the direction of the work. A firm can refer a problem to such a consulting laboratory, which will study the problem, undertake the necessary investigation, erect a model plant and finally supervise the installation of the process in the factory, charging a fee for its services and undertaking the responsibility for the whole operation. Such an arrangement provides the maximum security for secrecy and, if the laboratory is efficiently organized and managed, makes the development of new processes possible to firms who could scarcely undertake them in any other way.

There is little doubt that a research laboratory on a very large scale would be a successful commercial venture, especially if the capital were sufficient to enable the founders of the laboratory to patent inventions and to exploit those patents for their own benefit. The difficulty, of course, is that the return from such a laboratory is very small for a number of years, and that the successful establishment of such a laboratory would require a large amount of capital, a considerable amount of faith in the value of scientific research, a good deal of experience in the direction of research, and, finally, capable business judgment. It is, perhaps, not to be expected that such a combination will be found.

CHAPTER IV

THE POSITION OF THE RESEARCH LABORATORY IN AN INDUSTRIAL ORGANIZATION

The success of an industrial research laboratory depends to a considerable extent upon its position in the organization and upon its relation to the other departments of the company with which it is associated.

If industrial enterprises had been organized afresh with the research laboratory as a definite part of the organization it is probable that by this time some general opinion would have been formed as to the position which it should occupy, but in fact nearly all industrial research laboratories have been added to already formed organizations and their relations to the other departments of the organization are usually closely associated with their origin.

Laboratories have been established in many different ways:

If an executive of the manufacturing company is a technical scientific expert he may have felt the need of a laboratory and become its director, and in this case the laboratory will necessarily be very closely associated with the work of the executive who initiated it.

A laboratory may also have been established under a separate director, not himself associated with the executive officers of the company, but as a reference department for the executives, and in this case also it will be very closely associated with the officers of the company and will tend to be concerned more with questions of policy and the introduction of new products than with any other of the problems of the company.

In a large company a research laboratory may have been established as a separate department, having its own organization and being available as a reference department for all sections of the company, in which case its activities will cover a very wide field, but at the same time it will not have as direct an influence upon the policy of the company as will happen if it is closely associated with one or more of the executive officers.

The earliest research laboratories grew out of the works testing and control laboratories and were therefore responsible directly to the works manager. More recently, laboratories have generally been established as independent departments of the company responsible to the general manager only.

In order to understand the proper relation of the research laboratory to the organization the general nature of any organization must be considered briefly. As a general rule, the functions of an organization can be divided into two distinct classes, which, to borrow a military term, may be termed "line" and "staff" functions. Staff functions are concerned with planning, line functions with operation.

In an army the line organization is paralleled throughout by staff organization. The Commanding Officer, who is the head of the line, has at his General Headquarters the Headquarters Staff, each Army Commander has his own Army Staff, each Divisional

Commander a divisional staff, each brigade a brigade staff, and the staff functions of each battalion are carried out by officers to whom they are assigned. In operation, the line officers are supreme; it is their duty to be responsible for the execution of the work; in planning, the work is done by the staff, and once approved the plan is put into operation by the line.

Now, in industry there has not often been any clear separation of these two functions. The founders of industrial enterprises have usually taken staff functions on themselves, creating a line organization to carry them out. And even when businesses have grown beyond the point at which any one man can be responsible for all the planning necessary, a definite staff organization has very rarely been created; men have simply been employed with definite functions of a staff nature, but without any interlinking organization.

The oldest definite staff function in industry is that of accounting. In its nature the accounting department is a purely staff department, touching the sales department in its bookkeeping accounting, and the production department in its cost accounting. It often creates a branching organization permeating the whole business, each works having its own accounting department and even each department having one or two clerks who attend to its accounts and who are responsible to the accounting department of the works.

In an industry which is not primarily concerned with engineering, a chemical industry for instance, the engineering and maintenance department occupies a similar position. It is a staff department responsible for the supply of power, for the construction and maintenance of buildings, and for the production, supply and maintenance of the machinery with which the producing departments carry on their work. The efficiency department is another staff department, its function being essentially planning. In an engineering works the efficiency department should be a part of the engineering department as a whole, concerned with the design of product and the planning of operation. The employment and welfare department is another staff organization which may undertake also the educational work, which is now becoming so important in all industries.

The production and distribution of technical knowledge, which is the function of a research laboratory in an industry, is a staff function, and the research work must therefore be organized along lines parallel to those of the accounting department. Like the accounting department the research laboratory will often develop two sections, one dealing with manufacturing questions, and having its closest relations with the production department, and the other concerned with the use of the products, taking the form of service to the customer and having its relations with the advertising and selling departments. It is not unusual for new products developed by the aid of the research laboratory to require a certain amount of assistance from the scientific staff for their introduction to the public.

A staff department can be attached to the line organization at any point; a manufacturing department, for instance, may have clerks attached to it for accounting, mechanics to keep machines in order, engineers to plan the sequence of operations, and a laboratory to control chemical processes. The point to which the staff organization shall be carried will therefore depend upon the nature of the work to be done. There may be industries in which research work is required for only a single department, and in this case the research workers should be responsible to the head of that department; there are others in which the interest in the research is confined to the works, and in such cases the laboratory should be responsible to the works manager; but in most technical industries research work will have a great bearing not only on the methods of production, but even on the general policy of the industry, and in such cases it is necessary that those who direct research should be in touch with, and responsible to, the executives who control policy.

It is often felt that, while the question of the products to be manufactured and their method of manufacture should be under technical and scientific control, the policy of the business as a whole is a matter which should be under the direction only of men specially trained in finance and in that variety of branches of knowledge which is loosely classified under the heading of "business." But in the technical industries the question of policy is so intimately bound up with the scientific aspects of the subject that its right direction demands immediate supervision by directors acquainted with the technical side of the business as well as with the financial side. Consider, for instance, the board of directors of a dye manufacturing company. Suppose that the board wished to introduce a new dye belonging to a different group from those manufactured at the time. This would involve not only questions of the supply of raw material, but the question of the by-products obtained in the proposed manufacture, and the displacement of other dyes and incidentally of other by-products by the new dye when introduced—questions of such a technical nature that their ramifications could be understood only by a chemist. If such a decision is to be made with the best possible judgment, it is obvious that the chemists must have a controlling voice in the matter, so that the board of directors of a dye manufacturing company should contain a considerable representation from the scientific staff. As a matter of fact, in the German dye companies the directors are generally expert chemists of international reputation for their purely scientific work.

The position of the research laboratory in an industrial organization is perhaps best determined by the criterion that the research department should be responsible to the officer of the company who is in charge of the development of new products. If the introduction of new products is in the hands of the works organization, then the research department should be responsible to the works manager; if there is a definite development department, or, if new products are introduced through the agency of some definite executive, then it is to that executive that the research department should be responsible. The research laboratory, in fact, should be associated primarily with development.

The different fields of activity of an industrial research laboratory may be classified into the fundamental work of the type which is its special province, the development of new products, and work on manufacturing problems submitted from the works. It is a matter of some doubt as to how far manufacturing problems should be dealt with by the same laboratory as that which is responsible for original work leading to new progress; it may be urged that if a research staff engaged on fundamental research is called upon frequently to deal with works troubles, the more fundamental work is subject to interruption and cannot be carried on so efficiently.

On the other hand, it is doubtful whether it is desirable to divorce a research laboratory from the works problems, since the study of works problems must suggest many important lines of work to the laboratory staff, and anything which tends to separate the research staff from the other departments of the company must be considered disadvantageous. It cannot be too strongly urged that the success of the research laboratory depends upon how far the work done in it can be applied, and since the application will naturally depend to a very large extent upon co-operation with other departments of the company, everything that tends to such co-operation is to be encouraged and everything that tends in the opposite direction is to be discouraged. Nothing stimulates the co-operation of manufacturing departments with the laboratory more than the successful solution by the laboratory of problems submitted to them by the works departments. It is sometimes difficult for the laboratory to solve such problems; very often the practical solution depends upon minute knowledge of the working process, and a laboratory is expected to solve in some supernatural way problems which have baffled men thoroughly acquainted with all aspects of the process. But even if the laboratory fails to solve a given problem to the satisfaction of the department concerned, the study of the process itself is quite likely to result in suggestions which may be of more value than the solution of the problem submitted.

If the manufacturing organization is of sufficient size, however, it may be desirable to have a separate laboratory for the more fundamental problems, while those dealing with the works are undertaken by special departments of the laboratory more acquainted with manufacture; thus a link is formed between the purely scientific research and the manufacturing departments.[1]

A scientific division to cover the whole of the scientific requirements of a manufacturing concern may therefore be organized in three divisions: (1) the routine laboratory, (2) the manufacturing developments laboratory, (3) the research laboratory proper. Although this classification is fairly useful, it is difficult to draw any hard and fast line between manufacturing developments and pure research, and yet it is often convenient to keep the two separate if possible.

The routine laboratory will undertake all analyses and testing of raw materials, semi-manufactured and finished products. In so far as this work is done in connection with the actual manufacture, the routine laboratory will act as an inspection department, but in addition to this it should carry out the analyses and testing required by the departments devoted to development and research, since work in the routine laboratory should cost less than the same work

[1] See P. G. Nutting, Research in the Industries, *Scientific Monthly*, August, 1918.

done in the other laboratories, and it is consequently advisable to concentrate it in the routine section. The reason for the lower cost is that the routine laboratory carries out analyses according to routine or printed instructions, originality not being desired. The origination of new methods in analysis should be reserved for a small separate department dealing with research on analytical methods. The whole of the work of the routine laboratory can therefore be carried out efficiently by a staff of laboratory assistants working under the supervision of one or more qualified chemists who are in training for positions in the manufacturing departments or for the research laboratory. The routine laboratory as a whole will, of course, be in charge of an experienced analyst. In this way there will be a greater proportion of junior staff and of laboratory assistants in the routine laboratory than in the other sections of the scientific department, so that it is economical to concentrate routine testing there.

The staff of the three sections will require different mental equipment for the proper discharge of their respective functions. In the analytical laboratory the first consideration is accuracy, patience and care in the carrying out of routine operations. In the development laboratory the work will range from the simplest and most obvious alterations to problems of extreme difficulty involving scientific knowledge of a high order. The qualities pre-eminently essential for men of this order, in addition to a thorough professional training are common sense and tact. These qualities will be required at all times and perhaps only occasionally will a man have an opportunity of bringing his more theoretical knowledge to bear on his problems. In the pure research section, on the other hand, a high degree of scientific ability is one of the first essentials for the proper carrying out of the work.

The development section will collect ideas from all sources and apply them to manufacture, and those investigations of the pure research section which result in new products or methods will pass through the development branch to the manufacturing departments. The man who has been in charge of an investigation in pure research should be enabled to follow his work through the development branch into the manufacturing departments until it becomes a recognized and established feature of manufacture.

An interesting organization is that of the Westinghouse Electric & Manufacturing Company.[1] In this, the research division is a section of the engineering department, which is a staff department, carrying on the planning function and being responsible for development. The research division is divided into sections and embraces work from the purely theoretical side of the problem presented to the practical application of principles and materia's in the factory and in the field. It has under its control various laboratories, such as an electrical laboratory, a process laboratory, a molded-material laboratory, a materials testing laboratory, a chemical laboratory, a ceramic laboratory and a more recently acquired research laboratory proper especially set aside for work of a more theoretical nature. This laboratory has provision for studies in organic chemistry, electrometal-

[1] C. E. Skinner, Industrial Research and Its Relation to University and Governmental Research, *Jour.* A. I. E. E., 1917, p. 765.

lurgy, metallography, illumination, general physics, electrochemistry, insulation, etc., etc. The theoretical and the practical research men, while in separate sections of the same unit, work in close harmony. The result of a theoretical research, such as the production of a new device or material or the application of a new principle, can be tried in a practical way in another section of the division.

"The division does all the engineering in connection with the purchase of materials and carries on the experimental work in connection with the establishment of shop processes. The men working on materials' specifications keep in the closest possible touch with the method of production of these materials, their characteristics, their engineering application and their shop use. The process men work between the engineering department and the shop in connection with processes of every sort, and prepare all specifications with the co-operation of the shop men under whom the process is carried out. The division has the technical direction of the brass foundry, the scrap recovery plant and the copper refinery and is thus in daily contact with the multitude of metallurgical problems arising in these processes. The control laboratory as well as the theoretical laboratory for these processes being under the direction of the division, the best possible co-operation between the two is ensured.

"The above clearly shows that the division has been so organized that it can be a leader in the development of new things and at the same time keep in closest possible touch with their application and use. Problems for solution come to it from every possible direction and not the least fertile source of theoretical problems is the grist of troubles from the daily routine work in the factory. We believe that the research division should both lead and follow the practical end of the work."

Where a single manufacturing corporation controls a number of different factories—possibly situated in different localities and dealing with different products, the question arises as to whether the research department should be situated at one of the principal factories of the industry or should be located without reference to local distribution of the factories in a center under conditions most favorable to the successful development of the proper research spirit. It might seem that the research department should certainly be situated at the main factory of the corporation in order that the relationship between the research and the manufacturing departments should be of the most intimate nature possible. One,[1] however, who has had much experience of research work under these conditions states:

"My experience has been that the result of such an arrangement, in the case of a large organization of many and varied interests, is that research—which after all provides more for future prosperity than present profits—is hampered in its proper development through the sacrifices of its requirements to considerations affecting the manufacturing departments. It is clear that nothing should be allowed to interfere in any way with the repair and development of running plant. If the total building and engineering resources of the locality are required to keep the manufacture in an efficient state, then the research department must remain at a standstill or remove its sphere of activity to another locality. In many other directions also is research hampered by a too close association with manufacture. The 'sturm und drang' of everyday manufacturing life is not calculated to encourage the growth of such an atmosphere as the research spirit requires for its adequate nourishment. The result is that many men, especially among those possessing marked ability for research, drift off into other lines rather than submit to being tied down to factory conditions. Again, intercourse with other scientific workers is a valuable source of inspiration and this can be had only to a limited extent if intercourse is limited to the members of one staff.

"The manufacturing developments section of the research

[1] Wm. Rintoul, Manager Research Section, Nobel's Explosives Company, Private communication of February 11, 1919.

center must, of necessity, be so placed as to bring about the closest possible association between it and the manufacturing departments wherever situated; but this condition is not so necessary in the case of pure research, and the degree of association with manufacture which is necessary in this case can be provided in other ways than through the close juxtaposition of the departments. By a small sacrifice in this direction we are able to obtain the much greater advantage of being in a position to locate the center for pure research at or near the center of scientific thought for the country, where the staff will have the benefit of being able to meet and confer with other scientific workers in various allied and diverse fields. It would still, of course, be the duty of the head of the department to see that a regular system of intercourse was maintained between the pure research laboratories and the various factories of the industry. This could be done by correspondence and by visits and conferences at the various centers. Some industrial laboratories attempt to attain this end by arranging for a certain number of their staff to work in university laboratories under the direction of the professor. This system may be successful in some of the smaller laboratories, but severence from the industry is too complete to yield the best results.

"The scheme outlined, would, of course, be applicable only to organizations above a certain size. In smaller concerns dealing with a single branch of an industry the research work would probably be most largely of the nature of manufacturing developments and sub-division would not be desirable."

Whatever the position of the laboratory may be, it is necessary that it should have facilities for carrying the development of new products through to the stage of production, and, indeed, in most laboratories it is considered necessary not only to produce some products on a small experimental scale but even to place them on the market, only transferring production to the works when the demand is such that a full scale manufacturing organization is required to meet it. This is particularly useful in the case of those products which are quite new to the industry and which require novel and difficult manufacturing methods, and at the same time the development of a new market.

Where a research laboratory does not occupy a closely co-ordinated position in the organization of an industry, it may be very successful in the development of such radically new products if efficiently directed by investigators of great ability. The research laboratory of the General Electric Company furnishes a number of notable examples of this. This laboratory is not concerned primarily with the solution of works problems or with investigations on the manufactured products of the company; it has deliberately sought entirely new discoveries, new applications of materials and new developments in the art of electricity. To mention only a few of its triumphs, from it have come the metallized carbon and the drawn wire tungsten filament lamp, the nitrogen filled high efficiency lamp, the magnetite arc lamp and the Coolidge *X*-ray tube; and all of these were not only discovered and developed in the laboratory but were manufactured there and sold from it until the business grew to the point where it was necessary to build vast factories to meet the demand.

Such a success of an individual laboratory, however, should not blind us to the fact that the primary business of an industrial research laboratory is to aid the other departments of the industry and that for that purpose it should work in the closest harmony and relation with them and should not be tempted to develop an isolated line of work, which might yield it a greater direct triumph but yet leave the business as a whole the poorer for lack of its assistance and co-operation.

Few laboratories can be founded on such an independent footing as that of the General Electric Company, as possibly few investigators could justify such an independence as have Dr. Whitney and his colleagues, and, on the whole, it is probably best that the research department should be closely associated with the manufacturing departments and should transfer its products to them as soon as they have passed the experimental stage.

In order to obtain good co-operation between the laboratory and the manufacturing departments it is often necessary for the laboratory staff to display a considerable amount of tact, especially if the laboratory has been added to an already pre-formed manufacturing organization. The same is true of the efficiency department, and it is sometimes held that the primary qualification for an efficiency engineer is tact. This is unfortunate, since tact is not directly correlated with ability, and research men must more often be chosen for their ability than for other characteristics.

In promoting co-operation the management has a responsible part to play, and it is by no means reasonable for the management to evade its responsibilities and throw the burden of obtaining co-operation entirely upon the staff department.

The authority of staff departments is derived from the management, and it is a direct function of management to promote co-operation and harmony between the staff departments and the line operating departments. A wise and efficient manager will act as a check on both staff and line men, insisting on each carrying out their own functions without trespassing on the other's territory.

While it seems to be generally accepted that small industrial undertakings cannot afford to support scientific research, it is very doubtful indeed whether this is really true, and whether any small business of a technical nature would not do better to undertake its own research rather than share in a co-operative laboratory. The co-operative laboratory will certainly cost less but it offers much less hope of profitable return and advantage over competing firms. Indeed, the argument that small industries cannot afford to support scientific research is exactly as if it were suggested that small industries cannot afford to support advertising. The object of spending money on research, for a small industry at any rate, is not to support the research but to be supported by it, and it is scarcely an exaggeration to say that the smaller a business the more important is it that it should make use of scientific research to the greatest possible extent.

A small business is at a disadvantage in comparison with a large one in regard to all its cost charges. In the purchase of raw materials, in manufacturing, and in selling, its cost per unit of output tends to be larger than in the case of big business, but, on the other hand, it is at a real advantage in regard to flexibility and enterprise. Any large business must necessarily be cautious and conservative. The amount at stake is so large that the penalty of error is heavy. Consider, for instance, the mere cost of allotting half a page in a catalogue of which three million copies are to be printed.

It is clear that no business man will allow the introduction of a new article into a catalogue for which such an edition is necessary unless he has reason to believe that the demand will be sufficient to pay the cost involved. That is, the machinery of a large business is adapted to the sale of things for which there is a large demand, but it is difficult for it to introduce articles for which the demand will probably be limited and doubtful. Every large business is anxious to improve its goods, since it knows perfectly well that the penalty for failure to do this is extinction, but it necessarily moves with greater caution and more slowly than a small business can. It is this very fact, rightly grasped, which enables the small business to get its start and grow in spite of the advantage in regard to cost possessed by its larger competitor, and the growth of a small business will depend upon its supply of ideas for new products and new methods to a far greater extent than will that of the big manufacturing concern making staple products. Small businesses can therefore make far more use of a research laboratory and get a much bigger percentage return for the expenditure than any big company can hope to do. In the small business, in fact, a research laboratory closely associated with one of the high executive officers should begin to return a profit within a short time whereas in the case of a large company it may be years before a research laboratory can be considered to be completely successful financially.

The greatest difficulty in the establishment of a research laboratory in a small business is that any research laboratory will depend for its value upon the quality of the men at the head, or, if the laboratory is really small, of the *man* at the head, and a small business often feels that it cannot afford to pay even one good scientific man. The solution of this in a technical business might be that the research man should also be an officer of the company, so that his cost is borne not only by the scientific work but also by the value of the executive position which he holds.

It may be objected that an investigator would not as a rule prove a capable business man, but there really seems to be no particular evidence for this common belief, and there are many examples of men trained in science who have proved extremely good administrators. The classic example is, of course, the organization of the great Zeiss works under Professor Abbe, but in many cases it will be found that the technical industries are directed by technical men who were themselves directly concerned with development and manufacture rather than with financial or business direction.

CHAPTER V

THE INTERNAL ORGANIZATION OF INDUSTRIAL RESEARCH LABORATORIES

Since the laboratory is a staff department of an industry its organization must be such as to enable it to carry out staff functions related to all other departments of the industrial organization. The chief of these staff functions are as follows:

1. The provision of information regarding the technical and scientific matters in which the industry is interested, and the supply of this information in a form suitable for the education of the employees, of the customers and of the general public.

2. Service in the form of the provision of specifications and standards for materials, the making of analyses and tests, assistance to the works in regard to difficulties, and to customers in relation to problems arising from the use of the product.

3. The development of new processes or products, utilization of by-products, and the development of new departments of the industry.

These functions may be expressed by means of annular diagrams such as those shown in Figs. 1, 2, and 3.

In Fig. 1 is shown the information diagram. The information originating from the library and from the research staff is issued in the form of abstracts,reports, scientific publications and monographs, and goes to the executive, manufacturing, purchasing, and sales

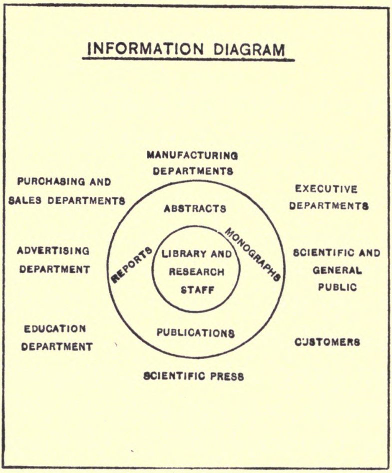
INFORMATION DIAGRAM
MANUFACTURING DEPARTMENTS
PURCHASING AND SALES DEPARTMENTS
EXECUTIVE DEPARTMENTS
ABSTRACTS
MONOGRAPHS
REPORTS
LIBRARY AND RESEARCH STAFF
ADVERTISING DEPARTMENT
SCIENTIFIC AND GENERAL PUBLIC
PUBLICATIONS
EDUCATION DEPARTMENT
CUSTOMERS
SCIENTIFIC PRESS

FIG. 1.

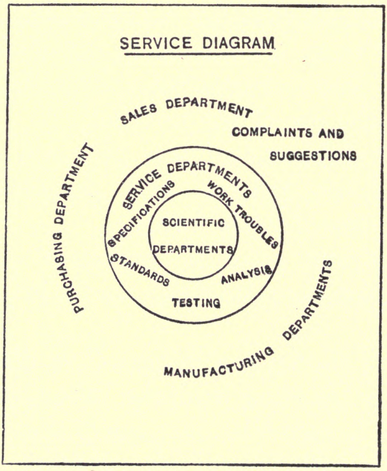
SERVICE DIAGRAM
SALES DEPARTMENT
COMPLAINTS AND SUGGESTIONS
PURCHASING DEPARTMENT
SERVICE DEPARTMENTS
SPECIFICATIONS
WORK TROUBLES
SCIENTIFIC DEPARTMENTS
STANDARDS
ANALYSIS
TESTING
MANUFACTURING DEPARTMENTS

FIG. 2.

departments for their information; to the advertising and educational departments to be utilized by them as required; to the scientific and the general press, and thence to the public.

In Fig. 2 the service diagram shows the scientific departments as the operating center, each supporting and controlling the necessary service departments which prepare specifications and standards, undertaking testing and analysis, and investigate works troubles, complaints of customers, and suggestions from the sales department, the results being communicated to the departments interested.

The service work which the laboratory carries on for other departments of the industry is best done by men working especially for each department or group of departments. The real problem in taking care of the difficulties of a manufacturing department is to provide good assistants as regards knowledge, and at the same time to have them continually at the disposal of the department. The ideal thing would be to have a first-class chemist or physicist attached directly to the department, since only a man working continually in the department can become acquainted with its problems. This is, of course, impracticable since it would cost too much, but an entirely satisfactory solution can be obtained by having a man in the laboratory who deals with the problems of a particular department and spends a great deal of his time in that department, doing his experimental work, however, in the main research laboratory under the supervision of one of the senior executives of the research laboratory. As soon as he meets a difficulty which requires greater knowledge than he possesses or knowledge in a different branch of science, the problem can be taken up by his chief and transferred to another section of the laboratory, where it can be studied and a solution found, the solution then being given to him to be taken back to the manufacturing department and put into operation. In this way a junior chemist, if possessed of the necessary

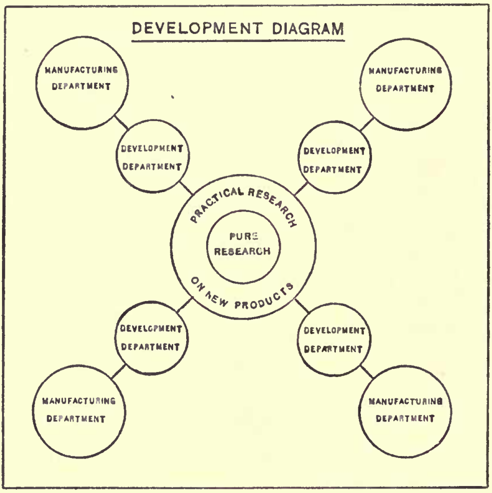

FIG. 3.

temperament for dealing with manufacturing problems and for co-operating with other people, can make use of the whole of the facilities of the research laboratory and apply them to the problems of a particular department, the application of this principle making it possible to utilize the scientific facilities of the laboratory very economically, and to cover effectively the whole of the work of the manufacturing divisions.

The organization of the development work is shown in Fig. 3. Here the work is shown to be founded upon pure research done in the scientific department, which undertakes the necessary practical research on new products or processes as long as they are on the laboratory scale, and then transfers the work to special development departments which form an intermediate stage between the laboratory and the manufacturing department.

These development departments are really small scale manufacturing departments which may be operated either by the works departments or by the laboratory, but which are controlled, as regards the work done in them and the methods used, by the laboratory itself, being run as experimental departments in order to develop a new process or product to the stage where it is ready for manufacture on a large scale.

The commonest mistake is to transfer laboratory work to the manufacturing department too soon; experimenting in a manufacturing department is a costly matter, and the experimental work should be done on a small scale under control of the laboratory before any attempt is made to transfer it to a full scale manufacturing department.

The development department itself should have an organization separate from the research laboratory, though under the same general direction. It will study all proposals for new methods, processes, or products which may be submitted to the company, and will report on them, these reports bearing at their conclusion definite recommendations on which the executives of the company can act.

In addition to this study of material presented from outside, the development department should take up one branch after another of the industrial field, and study those branches exhaustively, preparing a general report in which is outlined the policy to be followed with regard to those fields, the developments to be aimed at, and the work to be done in research and in production to meet the needs which each field is seen to present.

The development department should be of sufficient size to be able to survey the whole of the industry every few years, thus keeping fully in touch with all the developments which are taking place, and directing the flow of invention and experimental work into those channels which seem most likely to be profitable. In many ways the control of development is more difficult than the control of scientific research itself, since large commercial interests are generally involved, and an impartial survey of the whole field is necessary if a correct decision is to be reached.

The laboratory organization will, therefore, consist of a section of administration, which will be responsible for the direction of the work, the control of accounts and the issuing of reports; a section of information, which will operate the library, prepare abstracts of the literature, keep in touch with the patent department and constitute its technical wing, and prepare reports and publications of all kinds; and the scientific section, which will carry on the operation of the laboratory work.

Whether a laboratory is of the convergent or of the divergent type there are two forms of organization possible for the whole of its scientific work. For brevity these may be spoken of as the "departmental" system and the "cell" system.

In the departmental system the organization is that familiar to most businesses. The work of the laboratory is classified into several departments; physics, chemistry, engineering, and so on, according to the number necessary to cover the field, and each of these departments has a man of suitable scientific attainments in charge. In a large department each of these men will in turn have assistants responsible for sections of the department, all the heads of departments finally being responsible to the director of the laboratory.

Under the alternative or cell system the laboratory consists of a number of investigators of approximately equal standing in the laboratory, each of them responsible only to the director, and each of them engaged upon some specific research. Each such investigator, of course, may be provided with assistants as may be necessary.

Each of these systems has advantages and disadvantages. Under the departmental system the advantages are strict organization, good co-operation throughout the departments, a plentiful supply of assistants for the abler men who form the heads of departments or sections of the departments. The chief disadvantage is that the system tends to stifle initiative in the younger men. While it is true that research men require to serve a considerable apprenticeship to older investigators, there comes a time when every man wishes to try to develop his own line of research on his own initiative and to carry out work by himself, and while it is quite possible to provide for such men in a departmental organization, there is some danger that men who are really capable of original work may not get the opportunity to carry it out.

The cell system, on the other hand, provides a good arrangement for men of original initiative and of the self-reliant type; it enables a man to continue a single line of work by himself for a long time and patiently to bring to a conclusion work which in a departmental organization might have been abandoned because of its apparently unremunerative character. On the other hand the cell system tends to exaggerate the vices of such men. They tend to become secretive, to refuse co-operation, to be even resentful if their work is inquired into; while if a man who has developed a line of work for himself in a cell leaves the laboratory it may be very difficult for anybody else to take up the work, in which case a great deal of time and money is lost, and work which should have been carried forward is left unfinished. Another objection to the cell system is that men who are good organizers and who are of the type that can carry on work requiring many assistants do not easily find a place in it.

In practice, a balance between these two systems of organization is essential and will develop in any laboratory. It is not possible to work a rigid departmental system, and on the other hand no cell system in its most definite form could be effective. The form of organization which is the easiest in administration is undoubtedly some modification of the departmental system, since only by this means can young students fresh from college acquire adequate training and at the same time keep in touch with different branches of their subject and avoid the danger of immature specialization. A laboratory should therefore be organized in departments with an intra-departmental section in which a young man who develops the ability to carry out his own work may be able to take up work on his own initiative, still retaining his position in the department and carrying on his work under the general supervision of the chief of his department. There will always be a tendency in the departmental organization for men to desire to split away from the department to which they are attached and become semi-independent in the laboratory, and this tendency must be resisted in the organization and by the director of the laboratory. At the same time, it is important that the control should not be so rigid that men feel that they are prevented from exercising their own initiative.

While the divergent type of laboratory may be necessary for those industries in which the work is of such various types that a laboratory able to turn out any kind of work is necessary, yet the organization of a new laboratory for a specific industry generally results in one of the convergent type. In order to illustrate the structure of such a convergent laboratory a description may be made of the organization of the research laboratory of the Eastman Kodak Company.

The purpose of this laboratory is the investigation of the scientific foundations of photography and its applications, everything relating to photography in all its branches and applications being of interest. The branches of science which are of chief importance in photographic problems are those of optics in physics, and of the colloidal, physical and organic branches of chemistry. The relations of these sciences to photographic problems are shown in graphic form in Fig. 4.

Optics deals on its geometrical side with the materials used in photography—cameras, lenses, shutters, etc.—and on its physical side with such materials as color

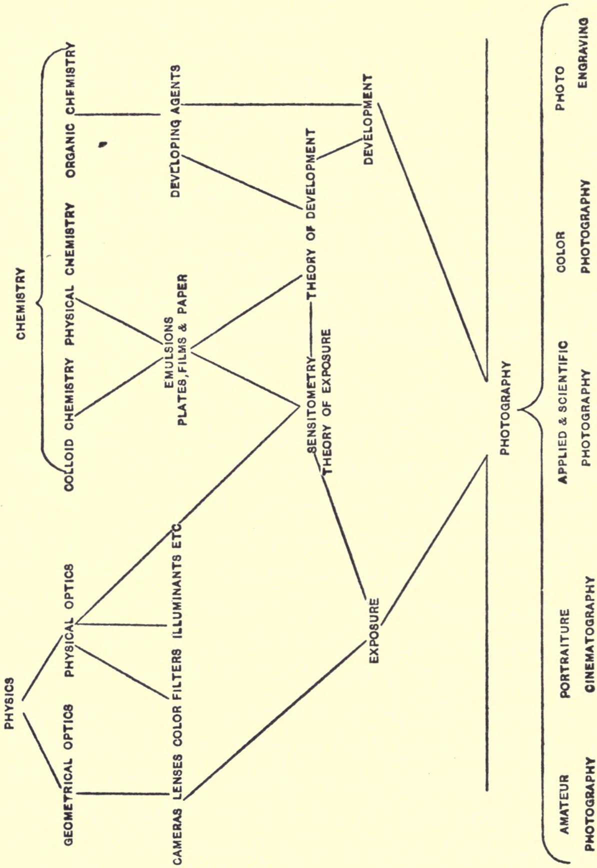

FIG. 4.

filters and illuminants, but especially with the study of the relation of the photographic image to the light by means of which it was produced—a study which is known by the name of "sensitometry." The manufacture of the sensitive material itself, which in the case of modern photographic plates, films and paper is called the "emulsion," is a province of colloid and physical chemistry, colloid chemistry dealing with the precipitation and nature of the sensitive silver salts formed in their gelatine layer, while physical chemistry informs us as to the nature of the reactions which go on, both in the formation of the sensitive substance and in its subsequent development after exposure. The organic chemist prepares the reducing agents required for development and the dyes by which color sensitiveness is given to the photographic materials, and by which the art of color photography can be carried on. While the physicist, therefore, deals with sensitometry and the theory of exposure, the chemist must deal at the same time with the theory of development and with the conditions relating to the development of photographic images.

A laboratory, therefore, for the study of photographic problems must be arranged with a number of sections such as are shown in Fig. 5. In physics we require departments dealing with sensitometry and with illumination, reflection and absorption, colorimetry, spectroscopy and geometrical optics. We need a department of colloid chemistry, one of physical chemistry, one of organic chemistry, one of photochemistry to deal with the action of light upon the plate, and finally a number of photographic departments, dealing with photographic chemistry, with portraiture, color photography, photo-engraving, motion pictures and *X*-ray work. All these departments converge first upon the theory, and then upon the practice of photography.

Each research specialist in the laboratory is given work corresponding to a limited field of science, so that while his special attention is devoted to that one department, his field of activity just overlaps that

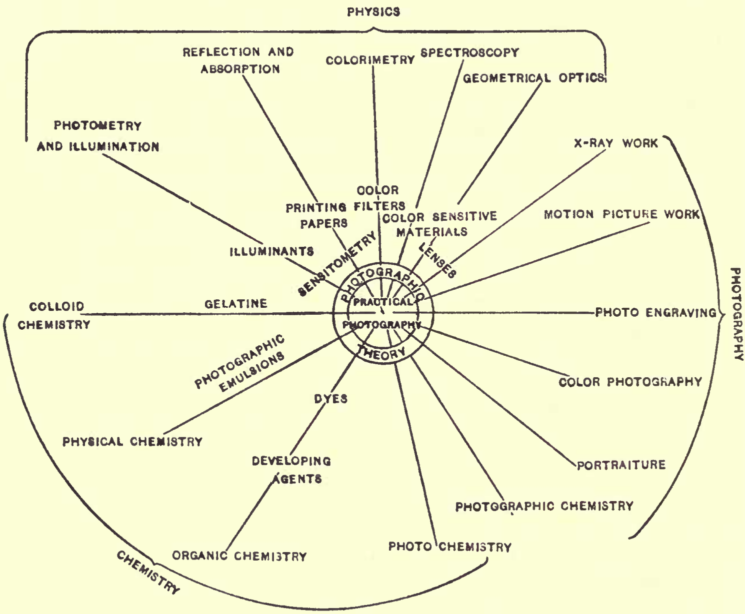

FIG. 5.

of the departments on each side of him, while his general knowledge of the subject should, of course, cover a much wider range. It is important that each man should have his own special field of work and that overlapping should not be complete since this will inevitably produce friction destructive of co-operation and harmony. The way in which such a subdivision is arranged may perhaps be best illustrated by Fig. 6, which shows the range of the specific investigations of those who in the research laboratory of the Eastman Kodak Company cover the range of research work between sensitometry and pure physical chemistry. There are five workers in this range; the first, *A*, being a pure physicist; *B*, a physicist with a considerable experience of chemistry; *C*, a physical chemist who has specialized in photography; *D*, a physical chemist who has specialized in photographic

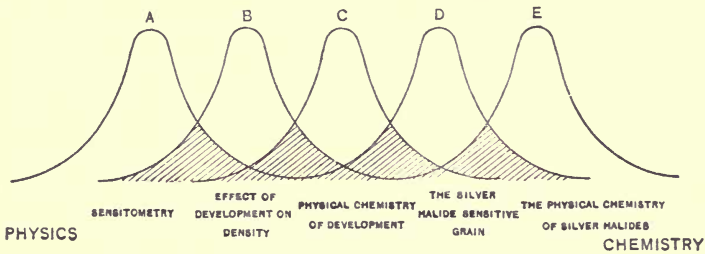

FIG. 6.

theory; and *E*, a pure physical chemist. The interest of each of these workers overlaps the field of the other workers but, nevertheless, each of them has his own specific problem, his own equipment and apparatus. Thus, *A* and *B* use sensitometric apparatus chiefly; *C*, both sensitometric apparatus and the thermostatic and electrical equipment of physical chemistry; *D*, microscopic apparatus and chemical apparatus dealing with the precipitation of silver salts; and *E*, the analytical and solubility apparatus of chemistry. The whole of this range is also connected with colloid chemistry and especially the overlap of the different sections involves colloid problems, so that we can consider colloid chemistry as dealing with the inter-relations of the different sections of photographic chemistry and can represent its province in the diagram by shading the overlapping areas. The colloid division of the laboratory will therefore be interested in the work of each of the specific investigators and will be of assistance to all of them.

These charts, prepared for a photographic laboratory, are equally applicable in form to almost any other convergent laboratory, so that if we have to work out the organization of a research laboratory which is to study any inter-related group of problems, we can do it by the construction of charts similar to these. Thus, considering Fig. 4, we place first at the bottom of the chart the general subject considered and its various branches, and then above these the scientific problems involved, separating out on opposite sides of the chart those problems which should involve different branches of pure science. Thus, we can place on one side biological problems, then physical problems, then chemical problems and so on, constructing a chart similar to Fig. 4 from the bottom up until at the top we have the various branches of pure science involved, subdividing these branches until each subdivision represents the work capable of being handled by one man in the laboratory.

It will now be possible to draw Fig. 5, showing on the circumference the different sections of the laboratory for which accommodation, apparatus and men must be provided and showing the relation of these sections to the problems as a whole. And having worked this out it is easy to find the amount of space and the number of men which will be required or which the funds available will allow for each part of the work.

In the arrangement of a research laboratory it is very desirable to avoid overorganization and red tape. The men working in such laboratories are of a very independent and critical type of mind and are extremely impatient of bureaucratic methods, and it is undoubtedly a great mistake to allow research work to be directed by administrators who have no real sympathy with the results of the work and who attempt continually to standardize and regulate things which in themselves are incapable of standardization and regulation. It is an advantage for the scientific worker to have the administrative burdens of the laboratory arranged for him so that when he wants apparatus or assistance, or when he wants materials prepared, or lantern slides made, he can get them by simple request without spending his own time on them. Order and regularity are also an advantage. Regular hours of work are really better than irregular hours in the long run, and there is no disadvantage in having a proper system of conducting conferences, discussion, etc. But too much administration is as bad as too little, and, especially in institutions controlled by government departments, there is a good deal of danger that the office, which should be the servant of the investigator, may become the master.

CHAPTER VI

THE STAFF OF A RESEARCH LABORATORY

The staff of a research laboratory will consist of a director, who in small laboratories will himself be actively engaged in scientific work, but in larger laboratories will necessarily be occupied to a considerable extent with administrative duties, a senior staff of men of first-rate training and of considerable experience in research, a junior staff of younger men obtaining experience in methods of research under the guidance of the senior men, and a certain number of assistants without special scientific training who carry out routine work under the direction of the scientific staff.

Since a great many of the more important scientific discoveries have been made by men of transcendent genius, there is a general belief that research work must depend upon such men for its execution and that the prosecution of research depends upon the development of men of exceptional caliber. While it is true that men differ very greatly in ability and that their value for research work varies, the fact still remains that much scientific research depends upon the accumulation of facts and measurements, an accumulation requiring many years of patient labor by numbers of investigators, but not demanding any special originality on the part of the individual worker. Providing that an investigator is well trained, is interested in his work, and has a reasonable proportion of new ideas, he can make valuable contributions to scientific research even though he be entirely untouched by anything that might be considered as the fire of genius. And in considering the planning of research laboratories we have no right to assume that we can obtain men who are 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. It is, indeed, a matter of doubt how many of the men commonly considered to be of great genius by virtue of some important discovery they have made really possessed any distinguishing ability compared with their fellows who did not have the fortune to make a similarly important discovery. The imaginative mind will often seize an apparently trivial point which a less able mind might have passed by, and there are many men who have added to our knowledge whose minds appeared to those around them to be so fired that they illuminated everything that they touched, but such men are very rare and the bulk of the work of the world must be done by the average man.

Men who are only average when dealt with singly may become extremely able by the mental contact which follows association with other men working on similar problems. One of the most noteworthy points in the history of science is the way in which an investigator of great ability has surrounded himself with men who afterward showed great distinction in their scientific careers. To some extent this is undoubtedly due to the fact that students of ability are attracted by the renown of an original investigator, but it is also probable that the minds of men are quickened by contact, so that a group of men who taken individually would be only average can be raised to a high level of intellectual activity by association, and especially by the precept and example of one first-rate man. Every laboratory that is to succeed must, in fact, develop a corporate spirit and corporate object, and when such a development has taken place results of the first magnitude may be looked for. The splitting up of such a body of men is no less a loss than their association was a gain, and for the production of the best research it is desirable to facilitate the continued collaboration of men under favorable circumstances for their co-operation in scientific work.

The senior staff of the laboratory should consist of men of the highest scientific attainments available and at the same time of considerable experience in research; in fact, they should be men of such attainments as are compatible with the rank of professor or assistant professor in the university. As far as possible these men should regard their positions in a given research laboratory as permanent, and every effort should be made to induce them to look at those positions in that light, since fluctuations in the senior staff are necessarily very detrimental to the work of the laboratory, and result in the loss of much time and energy by the abandonment or delay of partly finished investigations. As far as possible, gaps arising in the senior staff should be filled from the junior staff, but, of course, it will sometimes be necessary to obtain men from other laboratories.

The continuity of service which should be hoped for from the senior staff cannot be expected from the junior men, since they will desire, as they grow older and acquire experience, to undertake research on their own initiative as well as to obtain positions of greater responsibility and better remuneration, and will therefore go elsewhere; for no laboratory can develop continuously with sufficient rapidity to absorb the growth of its younger men. This will involve the leaving of the younger men to fill higher positions in other laboratories. Every research laboratory, therefore, must expect to assist in the training of the general body of research workers by taking men just graduated from the universities, and after they have had some years of experience in research work seeing them go again to occupy positions for which there cannot be an equivalent opening in the laboratory where they have acquired their training.

The junior men may be taken direct from the university either immediately after graduation, or after one or two years' experience as instructors or as post-graduate research students. It is doubtful if specific training for the work which they are to do is advisable. The most important requirement is that a man should really know the fundamentals of the subject which he is studying. If he is a physicist, he should really understand his physics; if a chemist, he should be well grounded in general chemistry. A man who has taken a scientific degree at a university may also be reasonably expected to have a good acquaintance with the literature of the subject, to be accustomed to reading up on specific points, and to know the journals in which search should be made for publications on different subjects. All scientific research men must be able to read French and German in addition to English; a knowledge of other languages will certainly be an advantage, but in the case of all men who propose to make scientific research their profession a knowledge of the three principal European languages to the extent of reading scientific literature is essential.

There is a considerable advantage in choosing men for a laboratory so that various types of mind are represented. Some men are distinguished for their original ideas, others for their balance in judgment. Some men have a great interest in the study of the literature and are willing to act as bibliographers for their less diligent comrades. A "walking dictionary" is very valuable in any branch of research work. Other men display ability in the design of apparatus and even in its actual construction, though, on the whole, it is a mistake to allow scientifically trained research men to do work which can be done more quickly and to greater advantage by mechanics.

All investigators will find it an advantage to have the ability to express themselves clearly in speech and in writing. It is invariably necessary for an investigator to write up his own work, and a man who has no facility in this direction may consume a great deal of time in doing so. The college training which a young research man may be expected to have in this direction amounts to a training in English composition and as much précis writing as he can get.

The remaining qualifications of a satisfactory research worker are personal and cannot easily be taught. In the selection of men due regard must be paid to their moral qualities. In order to be successful in association with others a man must be unselfish and willing to co-operate. A certain amount of frankness is desirable, since a man who is extremely reticent about his work is likely to produce a corresponding reticence in others.

A characteristic on which Dr. Whitney[1] places great weight is optimistic activity, because, without it, little that is new can be done except by accident. With active optimism, even in the absence of more than average knowledge, useful discoveries are almost sure to be made.

Dr. Nutting[2] considers that the qualities of mind necessary for a research man may be classified under the heading of *imagination* coupled with sound *judgment*, which when combined with *incentive* form the qualities essential for success in research.

Men who have been conspicuously successful in training and inspiring students, such as Nernst, J. J. Thomson, Rowland, Liebig and Ramsey have invariably been men from whom students acquire by association a large measure of scientific imagination, sound judgment and a love of knowledge which acts as an incentive to research.

The director of a research laboratory must necessarily have a considerable amount of experience in organization and also be well acquainted with the subject to which the work of the laboratory is to be applied. In a university laboratory he will naturally be a professor and will consequently be experienced in teaching; in a specialized laboratory he should occupy a position of authority in regard to the general subject on which the laboratory is working. In an

[1] W. R. Whitney, Organization of Industrial Research, J. A. C. S., 1910, p. 71.

[2] Private Communication, but see also "Factors in Achievement," *Scientific Monthly*, Oct., 1918.

industrial laboratory it is most important that he should have had some manufacturing experience in the works processes, but, at the same time, it is absolutely essential that the director of an industrial research laboratory should have a considerable sympathy with purely scientific work and a real interest in the advancement of scientific theory. It would be a fatal mistake to select as the director of a research laboratory a man who was not himself keenly interested in scientific work, however good an administrator he might be or however much knowledge he might have of works processes.

If a man of first-class scientific training who is acquainted with the application of the research work cannot be found, then a man of full scientific training should be chosen and given an opportunity to become fully acquainted with the technical side of the subject. Since in many cases a research laboratory will cover several branches of science it is not possible to find men who are authorities in all the branches covered, but the director should have an interest in all the work that is done, and should be sufficiently acquainted with the different branches of science represented to understand the work which is done and to have a sympathy with the methods and aims of the specialist investigators without pretending to any complete knowledge rivaling that of the specialists. He must, moreover, possess natural ability to analyze problems and draw deductions. Whenever new work is undertaken the director is called upon to analyze the problem into its essentials and direct the work into channels likely to be profitable. The results obtained from completed work must also be estimated and utilized to the greatest advantage, this calling for a considerable exercise of judgment and insight.

However great a reputation as an investigator a man may have, he is not suitable as the director of a laboratory unless he is capable of directing the work of others. He should be a good judge of men and able to manage as well as inspire them, he should be a leader rather than a driver. Moreover, he must be of an independent temperament and willing to allow credit to fall on the men under him, being contented himself with credit for the efficient operation of the laboratory as a whole. Nothing is more disastrous for a laboratory than a director who claims credit which rightfully belongs to his men.

In the end, the character and efficiency of a laboratory will be influenced chiefly by the personality of its director, and the development of laboratories will depend upon the possibility of finding men suitable for their organization and leadership. In criticising a scheme advanced by the author for the establishment of a national research laboratory of great size to undertake researches for the entire industry of a country, W. R. Campbell[1] objects that it would be impossible for one man to supervise adequately so vast an undertaking, that he would inevitably favor those subjects on which he had himself worked, and that a lack of balance would ensue. It is quite possible that at the present time this criticism is valid, but it may be remembered that the same criticism had been made regarding the possibility of operating large armies, and that nevertheless soldiers were found capable of handling the vast groups of armies

[1] National Research, by W. R. Campbell, Pulp and Paper Magazine of Canada.

who fought in the great war. Men of such calibre are, of course, very rare and probably the organization of research has not yet progressed sufficiently to enable them to obtain the necessary experience and training in minor positions.

In the organization of a laboratory it is essential to take into account the peculiarities of the individuals who compose it. Men are of very different types with regard to their ability to work together or their preference for working single-handed. Some men prefer to co-operate with others and to work in groups; others prefer to work almost entirely by themselves and on their own initiative, following up one line of work until they have solved all its problems for themselves. Some men prefer to have a number of assistants under their direction who will carry out instructions literally, so that the work of the whole group of men is based on the ideas and initiative of the senior man, while others again prefer to do the greater part of their work with their own hands and are not interested in directing the activities of younger men, preferring that any assistants should be capable of carrying on work more or less on their own initiative and without any explicit direction.

It is impossible to consider any rigid system of organization where men are of such different types and opinions. A departmental system in which the younger men are all directly responsible to senior men, who in their turn are responsible to the director, may be very satisfactory with some senior men and some junior men but will be unsatisfactory to the senior men who do not wish to direct the activity of others, and to those junior men whose temperaments are such that they feel continually hampered unless they are allowed to develop their own ideas.

On the other hand, a system of organization in which each man carries on a piece of work for himself may be very satisfactory to some men, but others of insufficient initiative may be unable to do any satisfactory work under such a system, although as assistants to other men who could supply the ideas they would prove excellent investigators.[1]

In the organization, therefore, of a laboratory, provision should be made for men of different types, and while on the whole a departmental organization is desirable, and the heads of the departments must necessarily be responsible for the work of their departments, yet it should not be impossible for a young man who displays real originality to branch out into a research on his own account and of his own initiative.

On the other hand many of the younger assistants

[1] For some reason or other it is generally considered that men who wish to work alone and carry out their own ideas are of a higher intellectual type than the organizer who prefers to carry on work which requires a great many hands to develop, but for which his own brain can do the thinking. The first type of man seems to have the public sympathy to the highest degree; he is considered more original and of the more important type. This is probably a complete error; not only does the organizer who can organize more men produce the greater volume of work, but, also, he trains men and establishes a school for the whole product of which he is entitled to some degree of credit. Thus, on the one hand, we have such an investigator as Darwin, who, by reason of his physical limitations, necessarily worked alone, while on the other we have such a master teacher as Liebig, or, in more recent years, Fischer. Great as was Darwin's personal work, who can doubt that if Darwin had been able to carry out his work in connection with many other men not only would far more work have been done, but the school that he would have created would have promoted the progress of biology to an extent which no single man could hope to do?

will want to fly before their wings are grown, and will feel capable of directing their own work long before they really have sufficient knowledge of the methods of research to do so economically, and it is necessary to repress such endeavors without crushing the initiative of the men themselves. A man must realize on entering research work that he must be prepared to work on the ideas of others for a number of years in order that he may obtain the knowledge necessary to arrange the exploitation of his own.

It is very important that each man should have proper credit given him for the work he does. In the publication of research the paper should be under the name of the man who initiated it unless another man did a large part of the experimental work, in which case both names should be put on the paper. Men are very jealous of credit for the work they do, and justly so, and this point must always be borne in mind when considering the question of publication. The publication of the scientific results obtained in a research laboratory is quite essential in order to maintain the interest of the laboratory staff in pure science. When the men come to a laboratory from the university they are generally very interested 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 in touch with the work that 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 publication in the usual scientific journals of the scientific results which they themselves obtain.

In scientific investigation a long time is often required before any results of value can be obtained. An investigator starting in a laboratory will usually take a considerable time before he has acquired sufficient knowledge of the special subject on which he is starting work to carry on his work effectively, unless that work is of a type identical with an investigation on which he has been engaged before entering the laboratory. There are two points which arise from this fact: In the first place, a man who has passed through the initial period and is actually engaged in effective research in the laboratory obviously represents a considerable investment, since he has been paid his salary during the initial period and has probably also spent a considerable amount of money in experimental work without obtaining very much in the way of returns. If men leave a laboratory, therefore, after training, they represent a considerable financial loss to the laboratory. This is the same problem as the turn-over of labor in a business organization, but with the difference that the training of scientific men is usually a far more costly matter than the training of even skilled labor in a factory. The other aspect of the matter is that a man is likely to become very much discouraged during this initial period. He comes to the laboratory full of enthusiasm and anxious to make a success of his work, and at the end of eighteen months he finds himself without anything to show for his pains—often without even the outline of a scientific paper—and he is much tempted either to change and try his luck elsewhere or to turn to some minor piece of work which promises an immediate return instead of carrying out the more difficult fundamental work for which he has been preparing. Some of the most important researches require many years of work before they give any results of value, and it is difficult during this period to prevent both the research workers themselves and those responsible for the management and direction of the work from becoming disheartened and abandoning the work in a half completed condition. Patience and willingness to wait for results are essential both on the part of the investigators and on the part of those in whose hands lies the direction of the laboratory.

Not infrequently, men who are engaged in some definite line of investigation have other interests in scientific work along which they would like to try some experiments, and, provided that it does not interfere too greatly with the general work of the laboratory, it is most advisable that a man should be allowed to follow such a hobby to some extent. It might seem that a man's time should be divided and he should be allowed a certain proportion of it for scientific work of personal interest to himself, but in practice this will generally be found impossible since some men have no interest in any work other than that on which they are engaged for the greater part of the time, while in other cases the regular work may be so pressing that it is not possible to allow any other line of work to be carried on simultaneously. If possible, however, men should always be allowed to follow out their own lines of thought, since in this way many of the most valuable discoveries will be made and the keenness and interest of the men themselves will be stimulated.

In connection with the discussion of the organization of research which has been carried on in the last few years there have not been wanting signs that many research workers are dissatisfied with the conditions attaching to their profession, and while the standing of scientific men is rapidly improving, it certainly cannot as yet be considered to be altogether satisfactory.

Hitherto, a man who has chosen to become a scientific investigator by profession has been expected to be prepared to sacrifice in the interest of his scientific work a certain amount of material prosperity as compared with that which he would probably be able to attain if he entered such other professions as the law, medicine or engineering. The teacher is notoriously underpaid, although he obtains some compensation for this in that he has a larger amount of leisure time than falls to the lot of most other men, but the research worker rarely is able to take much relaxation from his work, and his payment until recently was calculated on the lowest possible scale.

With the increasing number of laboratories the competition for capable workers is producing a considerable increase in their remuneration, and it is not too much to expect that before long scientific research will be a well paid profession which will be attractive even to these who esteem financial rewards above all other considerations. It may be thought that such considerations will not produce first-class investigators, and undoubtedly a man who is attracted to research for money is unlikely to possess the necessary temperament for success, but the great financial prizes offered to first-class surgeons, lawyers, and engineers have not prevented their development even if they have not stimulated it.

To a certain extent the salaries paid for industrial research will be kept down by the competition of the very badly paid scientific men of the universities, but eventually the demand for research men will result in the universities losing at once all those men who are capable of work in applied science unless they meet the competition by raising their standard of payment very greatly.

A point which frequently arises in connection with the remuneration of men engaged in research is the method of remuneration. Should research men receive a straight salary, or should they be entitled to an interest in the profits arising from their work? It is often urged that an investigator has a right to a proportion of the profits obtained from his work and also that when payment is by fixed salary there is a tendency for the work to become perfunctory. On the other hand, the judgment of most men directing large laboratories is definitely against any system of payment by results. In the first place, if a man is to share in the profits resulting from his work he must also share in its risks; that is, he must accept a small salary in the hope of being paid if he succeeds. Such speculation in their own skill is for those who desire it, most scientific men will regard it as the function of the employer to take the risks and to *assure* them a satisfactory livelihood while they are in his employ. In the second place, the effect of payment by results in a large laboratory is most undesirable. Men naturally want to engage in work which will result in direct and visible financial gain, and hesitate to carry on fundamental work for which no commercial application can be seen. Also, men are sufficiently jealous regarding the credit for their work without the added incentive to jealousy which would be supplied if payment were to depend upon the allocation of credit; and jealousy is fatal to co-operation. There is a considerable amount of luck attached to the allocation of research problems. One man may take up a subject and after a comparatively short time may produce results which are directly applicable to manufacture and give an immediate return, whereas an equally good man may spend years on a problem and produce only negative results, although the results may be of great indirect value.

On the whole, the best plan, probably, is to pay men by fixed salary, advancing their salaries in proportion to the quality of their work, whether that work results in direct financial gain or not.

CHAPTER VII

THE BUILDING AND EQUIPMENT OF THE LABORATORY

The laboratory building itself should, if possible, be designed especially for the work which it is intended to undertake, and the form adopted will depend very much upon the work which is to be carried out and upon external circumstances, such as location, surrounding buildings, etc. This can be very well illustrated by a quotation from the report by the Dean of Engineering at Columbia University with regard to the erection of a new laboratory for work on applied science in connection with the school:

"The cost of establishing research laboratories such as we have in mind will of course depend largely upon the site, which should be close to tidewater and to railroad facilities. But a comparison with what we can get on our present site may help us to arrive at approximate figures. The site at the northeast corner of 116th Street and Broadway has been tentatively assigned for the next Applied Science building, when funds for it may become available. A building on this site would have to conform with Hamilton, Kent and Journalism and would cost at least five hundred thousand dollars. With the same amount of money we could, however, buy a site with railroad and water facilities within five minutes walk of the University, erect on it a building twice the size, of a modern factory construction much better suited to our purpose, and have about one hundred and fifty thousand dollars left over for equipment."

As a general rule, a factory type of building is that most suitable for research laboratories, and while the building should be sufficiently pleasant to give an air of distinction, unnecessary architectural ornamentation involves expenditure which might better be devoted to the carrying on of research work. The policy of the Massachusetts Institute of Technology in this respect should be a model to the world. By careful design, they were able to erect their new building at a cost not greatly in excess of factory building costs and of the architectural construction associated with factory buildings, while the external appearance of the building is quite worthy of the important institution which it houses.

It is a mistake for a factory to house a research laboratory in some abandoned building designed for other purposes. The annual cost of research work is very high in comparison with the cost of the building itself. The greater part of that expenditure is on the salaries of the men carrying out the work, and any inconveniences or disadvantages which may be caused by their working conditions and surroundings can easily depress the production to an extent which renders such economies very unprofitable. The cost of the research man, in fact, is so high that it is worth while to provide him with the very best facilities for carrying out his work, since, provided money is not actually wasted on useless ornaments, these facilities will always be inexpensive in comparison with the total expenditure on the work.

Research laboratories are almost always too small, and it is really desirable that, in designing such a laboratory, some system of construction should be chosen in which expansion can be obtained by the duplication of units. This is, of course, a very difficult thing to obtain, especially in the details of the laboratory, but, nevertheless, it should certainly be aimed at by the architect, since whatever the size of the laboratory when it is designed, it is safe to prophesy that within a very few years expansion will be necessary, and if direct expansion is not possible, this will take the form of detached groups of men working in other places, an inconvenient and uneconomical arrangement.

The difficulty of arranging for such expansion may be realized by considering the question of the library. The library is a very important section of the research laboratory. It is constantly required by every scientific man in the laboratory and must consequently be located in a convenient and central position in the main building. But it also grows rapidly, and as it grows it is extremely difficult to provide for its expansion, since it will be surrounded on all sides by other rooms which are fully occupied, and from which any removal means a great loss of time and energy.

The cost of moving in research work is not always realized. Moving into a new building will involve approximately half the total cost of the structure since the men will not be working again at full speed in less than six months, and, as a general rule, the annual expenditure is equal to the cost of the building and equipment. It is important therefore in designing a laboratory to arrange, if possible, that all expansion may take place without any considerable rearrangement. An aid to this is to make the internal divisions of a laboratory movable as far as is possible, and while the building itself should be of fire-proof construction, it will be convenient to make partitions of composition board and wood wherever the fire risk does not prohibit this. In this way rooms can easily be subdivided, combined or rearranged.

It is most advisable that all research work under the same general direction should be conducted under the same roof, since only in this way can good co-operation between the departments be obtained, and the facilities and organization of the whole department be available to all the workers. In technical research, where it is often necessary to install model plants on a small scale, this cannot always be carried out; but, as far as possible, a research laboratory should be a real building and not merely the name for a number of scattered departments at some distance from each other.

Perhaps the best method of providing for the inevitable expansion of a research laboratory is to make the building intended for its use much bigger than is required for the laboratory itself, the space not immediately required for the laboratory being occupied by manufacturing departments of a type which do not need the permanent installation of heavy machinery. Then, as the laboratory expands, the manufacturing departments can be moved and the space vacated occupied by the laboratory. In one or two cases laboratories have been installed in new buildings of eight or twelve stories, built with special consideration for their needs, but of which only two floors were occupied by the laboratory at the beginning, other floors being taken over as the laboratory work increased.

In a modern progressive firm the size of the laboratory will double every five years; this has been the experience of most firms which have started research laboratories, and though, of course, there must be a limit to this expansion, our experience is not yet sufficient to show where this limit should be placed.

The descriptions of a number of modern laboratory buildings have been published.[1] Reference should especially be made to the paper by Mr. A. P. M. Fleming on "Planning a Works Research Organization."[2] In this paper plans are given for research buildings of 6,000, 13,000, and 50,000 sq. ft. floor areas with many valuable suggestions in regard to the design and equipment of laboratories. By the kindness of the Westinghouse Electric and Manufacturing Companies and of Dr. P. G. Nutting, the director of their research laboratory, I am enabled to publish the following account of the building which was erected specially to house that laboratory, which may perhaps be considered typical of a modern laboratory building of the best type.

The building stands on an elevation above the Ardmore Boulevard between the Works of the Company and the city of Pittsburgh. The design of the building is intended to provide maximum efficiency of service and comfort to the workers, with a minimum of expense. Architecturally, the building is plain and simple, but very substantial. It is of reinforced concrete and brick, trimmed with white terra cotta.

It comprises a main building 50 ft. × 150 ft. with three stories and finished basement, together with a detached power plant, 30 ft. × 70 ft. The plans provide

[1] See especially W. A. Tilden, "Chemical Laboratories and the Work Done in Them." London, 1916.

W. A. Hamor, *Jour.*, Ind. Eng. Chem., 1915, p. 333.

A. D. Little and H. E. Howe, Amer. Soc. Mech. Eng., June, 1919.

[2] A. P. M. Fleming, *Jour.* of The Institution of Electrical Engineers, 1919, p. 153.

for further extensions in the shape of two wings, one at each end, these wings to be 45 ft. in width and any necessary length up to 150 ft. or 200 ft.

The standard size of laboratory room is approximately 16 × 20 ft. The partitions, except those necessarily permanent, are of paneled wood. These partitions are readily movable and the floor layout is such that they may be placed at any 8 ft. interval. The design of the building was intended to provide for the ready shifting of these partitions as might be found necessary to accommodate any particular type of research. To date, the rooms 16 × 20 ft. and 16 × 32 ft. have been found to be very satisfactory and no change in the partitions has yet been found desirable.

The lighting of the building is by small distributed units, six units being installed for each 6 × 20 ft. area. The heating is by low pressure steam, furnished from a boiler located in the detached power house. All electric power is obtained from the local lighting company at 13,200 volts, 3-phase, 60 cycles, the transformer being located in a fireproof room which is a part of the detached power house. Here the current is transformed to 440, 220 and 100 volts for motors, lights and direct power service to the laboratories.

In the design of the building special attention was given to the means of running pipe and wire services in such a way as to enable these services to be brought into any laboratory when needed, without disturbing any other part of the building and with minimum length of lines. All of the main pipes and electric power lines are brought to a shaft at approximately the center of the building, through a tunnel from the power house. A small substation, consisting of a number of motor generator sets for securing various kinds of current, is located in the basement of the main building, close to the main tunnel from the power house and these modified services are relayed to the various laboratories through the center shaft along with the various direct services, pipe services, etc.

Connecting with this service shaft are tunnels over the center halls of the building, through which the distribution of the electric and other service is carried. Panels through which wires and pipes may be readily carried from the duct to the various rooms are provided in each laboratory room. Approximately at the middle of each group of rooms on each side of the hall, a floor duct, 6 × 12 in. is installed under the maple flooring and every 8 ft. two 2-in. iron pipes are laid in the floor from this floor duct to the tunnel over the halls. These ducts and the floor duct provide for light, pipe and wire service to the center of any room or to the walls of the room, as may be desired.

The pipe service consists of natural gas, compressed air, house vacuum, and hot and cold water. Distilled water is obtained from a still with a tin-lined storage tank located in a pent house on the roof and is delivered to the various laboratories in bottles.

The power house contains motor generator sets for supplying single phase, two phase and three phase current at 220 volts, and direct current at 250 volts (three-wire circuit). A motor-driven air compressor supplies compressed air at 125 pounds pressure and a large motor-driven vacuum pump supplies the necessary house vacuum. A liquid air machine capable of supplying 1½ to 2 liters of liquid air per hour is also located in the main power house.

The storage battery is located in a separate room in the basement of the power house and consists of a total of 218 cells, so divided that various groupings and combinations may be obtained as desired.

The small substation in the basement includes, together with the necessary service, the following equipment:

One three-machine motor-generator, consisting of one 250-volt compound wound, direct-current motor, and two 60-cycle, 25-kw. generators, one wound for 220 volts and one for 440 volts; one 25-kw. motor-generator for supplying 500 volts direct current; one 12.5-kw. motor-generator for supplying 125 volts direct current; one 10-kva. motor-generator for furnishing any frequency from 50 to 133 cycles; one 4-kva. motor-generator with harmonic booster for controlling the wave form for supplying any frequency from 133 to 800 cycles; and a special motor generator, supplying from 15 to 70 cycles, used for magnetic testing. A control board and a disconnecting switch type of relay board make it possible to connect these machines to any of the circuits through the building. Relay lines lead to the various rooms through the vertical shaft and the horizontal ducts over the corridors. The wiring, all of which is placed in conduit, is generally of 100-ampere capacity. The scheme is, in general, to have a limited number of relays leading to the laboratories, and then switch on to these relay lines any desired electric circuit.

In one end of the basement is located the furnace room with a battery of electric furnaces of various types, together with the necessary control for melting, annealing and various metallurgical processes. Stacks are provided at each end of the building with openings in the basement for experimental furnaces using fuel, usually natural gas. The wood working and metal working shop and store-room are also located in the basement.

On the first and main floor are the main and private offices, the library and the conference room. The remainder of this floor is assigned to physical, electrical and magnetic research. Next to the metallographic room is a dark room. The second floor, which at present is not entirely finished, will be given over to the same general class of work as the first floor. The third floor is devoted to chemical and electro-chemical research, illumination laboratories, and a glass blowing room. On this floor, which is laid out primarily for chemical work, most of the laboratories are provided with hoods with individual flues. These hoods are of alberene stone and are closed with glass doors. The flues, which are lead-lined, have a natural draft which has proved quite sufficient for practically all work. Forced draft can readily be provided for any hood, if found necessary. On the roof is a commodious pent house, in which the major electrolytic researches are carried on; and it is arranged to take care of other work which requires a water-tight floor or plenty of fresh air. A tiled space on the roof provides for outdoor experiments.

The keynote in the design of this building has been to provide for adequate service to any particular laboratory room with the minimum of disturbance to other parts of the building and for ready changes in room size or service as the character of the work changes from time to time. The general type of distribution of services is not new, but it is found to be very effective and satisfactory. The individual rooms contain more or less standard equipment, such as a standard arrangement of electric outlets. Gas, vacuum, conpressed air and heavy current wires are provided for practically all of the laboratories, and special relays are run as demanded.

Everything that has been said as to the necessity for the provision of a satisfactory building applies also to the question of equipment, but with even greater force. It is an economic error to allow expensive men to be short of the apparatus which they require for their work. As a general rule, men will not ask for apparatus which they do not need. There are a very few men who might be considered to be apparatus collectors, and who seem to have a real anxiety to surround themselves with all forms of scientific apparatus, whether they have any use for them or not; but with the exception of these men, who are limited in number, it may be taken for granted that when a research worker asks for apparatus he needs it and must have it in some form or other to continue his work. To force an expensive man to work with substitutes for properly designed instruments, or, worse still, to spend his own time in attempting to build instruments when they could have been purchased, is very poor economy. An illustration of this was afforded when a chemist occupying an important position in a large firm asked for a special piece of apparatus costing about $500. After an amount of consideration which would scarcely have been justified for the erection of a new building, the directors declined his request, and ordered him to purchase a piece of apparatus of the same type for $280, which was unsuited for his work; and he then spent three months in making the second apparatus do what the first would have done as soon as he obtained it.

The total cost of equipment for a physical laboratory represents about two months cost of operation, and, if economies are to be made, it is clear that they should be made by limiting the amount of work undertaken and the consequent cost of operation rather than by depriving the workers of the necessary tools for their work.

The technical equipment of a research laboratory building is of great importance and should be as complete as possible. This is now generally understood, and there is little need to stress the fact that a laboratory requires at all convenient points gas and steam, water and air, electricity at several voltages, and other special supplies according to the work carried on.

A very important matter in most research laboratories dealing with physics, physical chemistry or engineering is the provision of facilities for building instruments. The chief item of expenditure in such laboratories, after the salaries of the investigators, will be the construction of new instruments, which may represent as much as 10 per cent. of the total expenditure on the laboratory, so that a laboratory may spend every year on new instruments half as much as the value of its original equipment. Building instruments is necessarily very expensive work, and no instrument should ever be built if it can be purchased, since building a new instrument involves the whole of the development work which a maker of instruments is able to distribute among all those which he makes of the same model. But even more expensive than the construction of the instrument itself is the delay in work which inevitably results when the need for a new instrument manifests itself and the instrument is not available. When a man has to stop to construct an instrument, which is often a very important part of a physical research, any delays other than those inherent in the nature of the operation must be avoided. It is especially important that when a man has designed the apparatus which he wants, the actual making in the instrument shop should be carried out as quickly as possible. A research laboratory must, therefore, be provided with an adequate machine shop and a staff of mechanics, and it is distinctly advisable that one or more of those mechanics should understand machine design and draftsmanship.

It is generally preferred to have the machine shop directly associated with the research laboratory in the laboratory building itself, and this plan has advantages, but in the case of a large manufacturing company, which necessarily maintains an engineering force of considerable size, it may be better to have the work for the laboratory done under the direction of the mechanical engineers of the company and in the big shops, provided that certain mechanics are acquainted with the work and are closely associated with the investigators in the laboratory. In the case of the research laboratory of the Eastman Kodak Company this scheme was tried at the instance of the chief engineer. At the time, the scientific staff was very doubtful as to its advisability. All the men, having come from different laboratories, had been accustomed to having a tool shop in direct connection with the laboratory, and were doubtful as to whether it would be advantageous to have their work done in the large tool shops of the plant. Five years' experience, however, has shown that the engineer was right, since intruments are certainly built far more rapidly by this plan than is usual in laboratories which have their own shops. The use of the engineering shop for the production of instruments will only be possible when it is equipped for precision work. In the chemical industry, where the construction department is devoted to large machines and precision work is rarely attempted, satisfactory results are more likely to be obtained from a laboratory workshop than from any use of the large shops of the plant.

The question of equipment—both its extent and its type—depends enormously upon the kind of work done in the laboratory. A purely chemical laboratory requires little specialized equipment, and will rarely have to make new instruments. A physical laboratory will require a good deal of equipment, and will constantly be making new apparatus. In fact, a great deal of the work of a physical laboratory consists in the design and construction of instruments, while in one class of science—astronomy—the equipment is by far the largest item of the entire cost, and in such institutions as Mt. Wilson Observatory the construction of new instruments has been an important part of the work of the Observatory since its foundation. These differences between different types of work are well brought out in the following figures for the different laboratories supported by the Carnegie Institution, taken from the Year Book for 1915:

Department	Value of building	Value of equipment shop and laboratory	Annual grant
Botanical Research......	$49,385.10	$12,063.21	$40,615.00
Experimental Evolution..	103,149.20	7,248.25[1]	48,919.00
Geophys. Laboratory.....	120,524.84	90,917.47	89,164.00
Nutrition Laboratory.....	117,200.15	20,827.26	45,064.00
Mt. Wilson Solar Obser...	196,193.06	887,292.37[2]	220,130.00
Terrestrial Magnetism....	131,616.33	184,505.33[3]	141,310.00

[1] Omits Operating appliances and grounds $19,897.95.

[2] Includes Shop equipment, instruments, furniture and operating appliances, and Hooker 100-inch reflector (The amount of shop equipment of these items amounts to $37,129.26, instru. $394,460.17, reflector $371,219.66).

[3] Includes Vessel and survey equipment $129,417.12, and Instruments, laboratory and shop equipment $55,088.21.

It is absolutely essential for a research laboratory to have available a good library covering the various fields of its work. Dr. Whitney has compared a library to a storage battery of great capacity and indeed, a library represents a store of accumulated knowledge which can be made available and which, if properly used, will save a great deal of experimental work. If a laboratory is situated in such a position that good libraries are readily available outside the laboratory itself, then a small library will be all that is necessary in the building, but if such an external library is not available, the library of the laboratory must be fairly complete, and it will be especially necessary to have good sets of back numbers of the chief scientific journals. The extent to which completion of these sets should be attempted is a matter of some doubt and will vary considerably from one laboratory to another.

Theoretically, every published journal should be available to a research man, but the necessity for ready availability depends upon the frequency with which a journal is likely to be required. If a journal is not often wanted, one complete set in a city will suffice, and if it is wanted only very rarely, it may not be worth while to duplicate a journal which can be reached by a railroad journey. Very few scientific libraries, for instance, would think it necessary to have a set of the Philosophical Transactions including the volumes of earlier date than 1800, and would be willing to take the risk of a special journey to obtain the information should a reference to such an early journal become necessary. Moreover, the use of photostat copying cameras for making duplicates of references which can be sent by mail has lessened the necessity for each laboratory containing rare journals.

A library will generally need a special librarian, and, since good librarians are very interested in their books and take a real pride in having them available, it is sometimes necessary to exercise some restraint to prevent a technical librarian becoming a book collector. It is not uncommon to find technical librarians who are very proud of their collection of rare and out of date books, of interest only from a historical point of view, while the latest editions of reference works of very great practical importance are lacking, and it is not unusual to see libraries—especially those of scientific societies—which apparently contain a large number of books, but which on examination are found to have in them very little of value to the practical student unless he is interested in the history of the subject. From the point of view of a research chemist, the last part issued of a dictionary of technology is far more valuable than a rare work published in the seventeenth century, however dear to the heart of the book collector the latter may be.

For the average chemical laboratory, a library of about 5000 volumes should be enough, the important chemical journals which have appeared for a long period of years representing the greater number of the volumes required.

CHAPTER VIII

THE DIRECTION OF THE WORK

Various methods for the direction of the work of a laboratory are in operation. In some cases each investigator is allowed to go his own way, discussing his work as he may wish with those around him, but not formally being required to take the matter up with any one. In university laboratories, and in many industrial research laboratories, all the scientific work is supposed to be directed by the professor in charge or by the director, but in an industrial laboratory of any size this is out of the question, since it is impossible for the director to understand sufficiently the wide field of science covered by his laboratory. If it is attempted, the system simply resolves itself into each senior man directing the work of his own division and possibly competing for men and apparatus with other workers in the laboratory in so far as he can influence the authorities to grant them to him.

It is obviously better for the scientific work of a laboratory to be directed by a conference or series of conferences of all the men having knowledge applicable to the subject, and this will have the further advantage that, while it will relieve the director of the details of the direction of the scientific work, it will keep him constantly informed as to all the work going on in the laboratory.

For the past six years the work at the research laboratory of the Eastman Kodak Company has been directed by such a conference system, and it has proved an unqualified success. To each day of the week there is assigned some group of subjects. On Tuesday, for instance, all questions relating to chemical products may be discussed; on Wednesday, those which relate to the chemical properties of photographic materials; on Thursday, general photographic processes; on Friday, color photography, and so forth. Each group of subjects is discussed at a conference held at the beginning of the morning, and there is present at each conference every scientific worker of the laboratory, whatever his rank, who is directly engaged on the work under consideration, and also representatives from other departments of the laboratory in case their assistance and advice should be required.

The number of those attending a conference should preferably be more than four and less than ten. The director presides at all conferences, and the agenda are drawn from the minutes of the last conference. These minutes are written each week by the director's secretary, who takes shorthand notes at each meeting.

Consider, typically, a conference on color photography. This subject is studied in the photographic division of the laboratory, each section of that division doing work in its own sphere on the subject. At the conference, therefore, there are present the senior men who direct sections of the photographic division and those of their assistants who are working on color photography. These, then, represent the men who are actively engaged in work on the subject under discussion at the conference. There are also present a physicist, who can give advice on the measurement of color and on photographic sensitometry; a colloid chemist, whose advice is often very valuable in relation to the properties of gelatine, collodion, etc; and a dye chemist from the organic research laboratory whose advice is followed in matters related to dyestuffs. At the conference, the senior photographic men report on the work which has gone forward in their departments, in the past week, and, in the case of work which has been carried on more or less independently by their assistants, those assistants report on their own work. Any work having relation to color photography which has been referred to the physical or chemical departments is also reported.

As these reports are made, any difficulties which have arisen are discussed and suggestions made for overcoming them. Frequently, the physics, organic chemistry or colloid chemistry departments are requested, through their representatives, to investigate some detail which is presenting difficulties, and as the reports are made a decision as to how the work shall be carried forward during the next week is reached by the common opinion of the members of the conference. In this way these conferences really direct the work of the laboratory; instead of the work being settled in a personal conference between the director and the worker, it is thrashed out at this weekly discussion with the assistance of all those who are working along allied lines.

The conferences generally last an hour, with the exception of those on general photography, at which many diverse subjects are discussed, and which may last about an hour and a half.

It will be realized that this conference system makes it certain that the work of everybody in the laboratory will be considered once a week, that the difficulties will be explained to, or discussed by, those best fitted to assist in removing them, and that, at the same time, there is a valuable check in the conference minutes against matters which have once been discussed being dropped and forgotten.

Should any matters come up at a conference which seem to require the assistance of those who are not members of it, they are called in for consultation, and those conferences which are of interest to members of the staff outside the laboratory are attended by representatives of the departments interested, thus enabling the laboratory to co-ordinate its work more closely with the practical requirements of the company.

The work of the laboratory for a year can be represented as shown on the chart in Fig. 7. In this chart the departments of the laboratory are shown as circles at the top and bottom, while the conference to which reports are made are shown as rectangles in the middle of the chart, and the work done by each department and reported to a given conference is represented by a line drawn from the circle to the corresponding rectangle, each line in the original chart bearing upon it the title of the piece of work and also an indication as to its completion or otherwise, and as to whether the work was published, reported, or otherwise disposed of. It will be noticed that, while at some conference, almost all the work comes from one department as, for instance, almost the whole of the work on optics and the theory of photography from the physics department, to other sections of the work several departments contribute. Thus, in the central rectangle, representing photographic products,

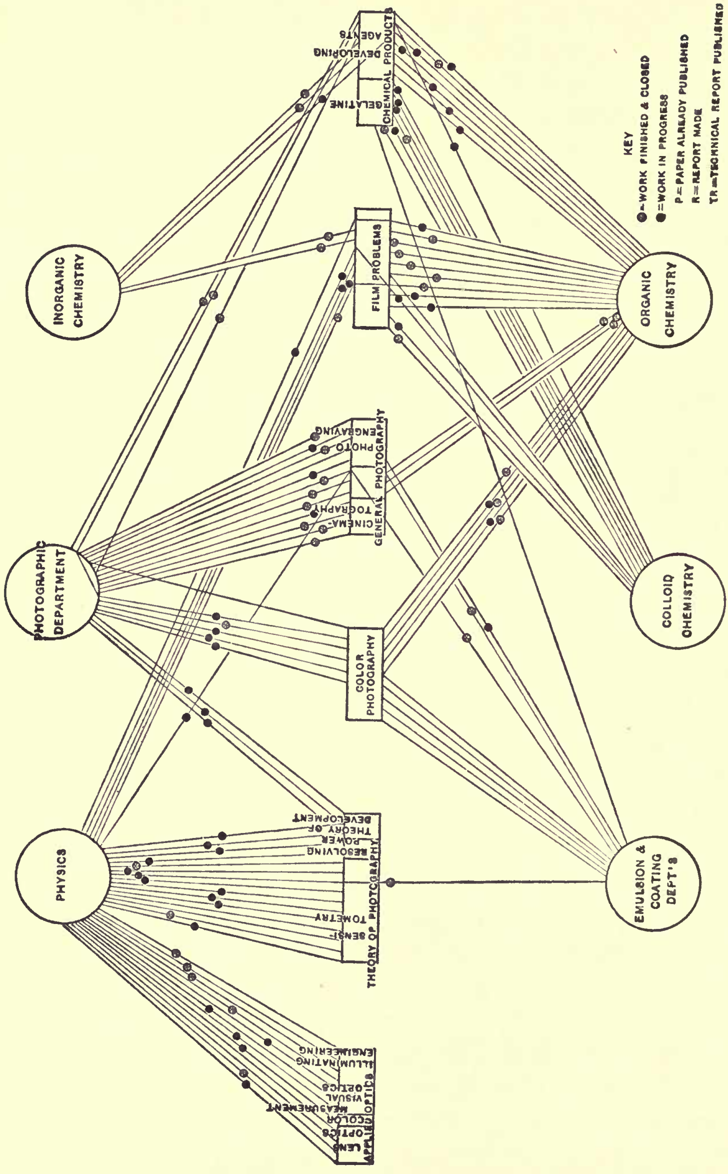
INORGANIC CHEMISTRY
PHOTOGRAPHIC DEPARTMENT
PHYSICS
ORGANIC CHEMISTRY
COLLOID CHEMISTRY
EMULSION & COATING DEPT'S
CHEMICAL PRODUCTS
DEVELOPING AGENTS
GELATINE
FILM PROBLEMS
GENERAL PHOTOGRAPHY
PHOTO ENGRAVING
CINEMA-TOGRAPHY
COLOR PHOTOGRAPHY
THEORY OF PHOTOGRAPHY
THEORY OF DEVELOPMENT
RESOLVING POWER
SENSI-TOMETRY
APPLIED OPTICS
ILLUMINATING ENGINEERING
VISUAL OPTICS
COLOR MEASUREMENT
LENS OPTICS
KEY
=WORK FINISHED & CLOSED
=WORK IN PROGRESS
P=PAPER ALREADY PUBLISHED
R=REPORT MADE
T.R.=TECHNICAL REPORT PUBLISHED

FIG. 7.

every single department has two or more lines representing different pieces of work done in relation to photographic products. Such a chart as this is very convenient for summarizing the work of a laboratory over a considerable period.

In most industrial laboratories it is necessary to consider the financial aspect of the matter when undertaking any new piece of research work. An estimate of the cost of a new investigation is exceedingly difficult to prepare, and can be based only on careful and accurate costs which have been kept previously for work of a similar kind.

A satisfactory cost accounting system is extremely valuable in a laboratory, both for the control of current expenditure and for the preparation of the budget. The cost accounting methods employed for the control of manufacturing processes are not suitable as a rule for experimental work, and it is undoubtedly better to develop an accounting system in the laboratory itself rather than to obtain the costs by the general cost accounting methods used in the Works. A laboratory cost accounting system need not be expensive in operation nor need it involve a hampering amount of red tape, and if properly directed it can relieve those in charge of the laboratory from some of the burden of supervision. It should be in charge of an official whose qualifications are a fair knowledge of scientific work, a liking for detail and accuracy, and a capacity to get on with men.

To each problem which presents itself for study a number should be given and an assignment card made out in triplicate on a form similar to that shown in Fig. 8, one copy being retained in the office, one by the head of the division to which the problem is assigned, and one by the man to whom the work goes. When an answer is required by a specific date, this

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
1 2 3 4 5 6 7 8 9 10 11 12

Problem No.

ASSIGNMENT CARD

Problem

Ref. Referred by Rec'd

Assigned to { Dept.
Individual No.

Promised

Remarks

K P 9192a

FIG. 8.

DAILY REPORT						
DAY ______ MO. ______						
PROBLEM	1	2				
TIME						
NAME						
NO.						
(Kindly fill out this card each day before leaving)						

FIG. 9.

date is noted on the assignment card and followed up by a tickler system. A number is assigned to each man in the laboratory, and he returns a daily report, a form for which is shown in Fig. 9, giving the numbers of the problems on which work has been done during the day and the time spent on each. These time reports are transposed into cost charges in the office, and the work done on each problem as well as all special apparatus and materials purchased specially for its work are charged daily to the account of that problem. For each hour of work an overhead charge is added representing the cost of maintenance of the laboratory as a whole and the charges for administration and superintendence. The amount of overhead will vary very much according to the work done in the laboratory; in an analytical laboratory it may be as low as 100%, in a laboratory engaged in pure research it may reach twice that figure. In each division, the time of certain assistants and of the division chief when he is not engaged on special problems, is charged to the divisional overhead and distributed as a burden on all the problems handled by that division.

From the problem cost reports a periodical statement is prepared showing the progress of each problem and its cost up to date, and the totals of this statement should balance the bookkeeping costs of the laboratory as a whole. In the case of commercial consulting laboratories and of those industrial laboratories which charge their work to the departments making use of it, the costs obtained in this way are made the basis for charges, and in a consulting laboratory making profits the profit or loss resulting from each man's work should be charged to a private account from which his value for the purpose of that laboratory may be gauged.[1]

[1] I owe the arrangement of this account system to Mr. Caswell, Treasurer of Arthur D. Little, Incorporated, of Cambridge, who has worked out a complete accounting system for his own firm and very kindly placed all his material at my disposal. See also *Jour.* Ind. & Eng. Chem., 1920, vol. xii, p. 79.

The problems which are investigated in a research laboratory may arise from many different sources. In an industrial laboratory of the divergent type the problems will be suggested largely from the works and arise out of difficulties occurring in the works processes or from the need for improved materials or methods. In a convergent laboratory the problems usually evolve from each other, so that each completed investigation will suggest a number of problems requiring further investigation, the whole growing as a tree grows, and never attaining to completion.

In divergent laboratories devoted to pure science, such as those of the universities, there is sometimes difficulty in finding problems, but these are the only type of laboratories in which such a difficulty occurs. The difficulty is not really that of finding problems per se but of finding problems which are suitable for the particular circumstances of the laboratory. Thus, problems involving very long continued effort or elaborate apparatus must usually be rejected in a university laboratory, and, if the work is to be done by students, it is necessary to choose problems which present a reasonable certainty of some definite, concrete result which can be published at the close of the time which the student has available for the research; nothing is more discouraging to a beginner than to have assigned to him a research which could not possibly attain to any completion in the period which he can devote to it. Strictly speaking, however, investigation of this type is undertaken not so much for the purpose of enlarging knowledge as for training, and it may generally be assumed that in research laboratories dedicated to the advancement of knowledge no shortage of problems will present itself, and the difficulty will be the choice of the problems which hold the richest promise.

In a convergent laboratory there is always a temptation to stray from the field covered by the laboratory. The men working in such a laboratory will often be intensely interested in the whole of the science with which they are associated, and will have original ideas of considerable value which they will naturally wish to test experimentally but which have no direct relation to the general work of the laboratory. As a rule, it is necessary to resist this tendency, and if a man is very anxious to undertake work which cannot be seen to have any relation to the work of the laboratory, he should be advised to obtain a position in a laboratory where his work will be in keeping with other work done in the place. It is necessary, however, to be very cautious in deciding on this ground that any piece of work should not be done and, especially, problems should not be rejected on the ground that they are too theoretical, provided that the theory is of direct importance in connection with the main lines of work carried on in the laboratory. As a general rule, it is better to err on the side of too much theoretical work than to run the risk of doing superficial work and missing the main points which would have given really valuable results.

It is not often that a research which strikes deep enough in its direction will have to be abandoned because there is no hope of making it successful, and very often a research undertaken to attain a certain practical result may fail to achieve that result and yet be of value, provided that its direction is turned toward the theoretical considerations underlying the work; whereas, if the research had been confined to the practical aspects of the matter, the work done would have been lost when the practical end sought could not be attained.

Only a small proportion of the major investigations undertaken will be finally successful in achieving any end which could be foreseen when they were started. The proportion of researches which are termed successful seems to vary very greatly in different laboratories, but the difference is probably more in the judgment of the director as to what is meant by success and in the object with which the work was started than in any real difference in skill shown in the selection of the work. It may be taken for granted, however, that a considerable proportion of all the work undertaken in any research laboratory will eventually not be considered to be worth the time which has been expended upon it, and it is possible that a gain in efficiency in research could be obtained by a study of the methods of selection of the work carried on. Most investigators at present feel that this is largely a gamble and that no decision of real value can be made. It is certain that many of the most valuable discoveries in both pure and applied science could not have been foreseen as possibilities when the investigations from which they resulted were undertaken. But, nevertheless, it is possible that a further study of this subject would enable a better decision to be reached as to the work which should be undertaken.

When a problem is presented, the first thing to do, of course, is to make a preliminary examination of the question, looking up the literature and studying the matter from various angles in order to decide as to the end to be sought, the apparatus which should be designed and built, and the method of the research. This is very frequently done with insufficient care, and it is not uncommon for a great deal of laboratory work to be done which could have been avoided if a proper study of the literature had been made.

Research men differ very much in their attitude toward published literature. Some rarely make any reference to what has previously been written other than a glance at a text book or dictionary, while other men have a profound knowledge of scientific literature and always study the whole subject carefully before starting work. Men of the latter type are, of course, most valuable, and should not only be encouraged, but should be used for the assistance of their less industrious fellows.

There is sometimes a tendency in laboratories to feel that a man who spends a considerable amount of his time in the library is idling, whereas the reverse is generally the case, and as Dr. Whitney says, "The most useful and fertile investigators use the library the most." It would probably be a good rule in a laboratory to have each man who is preparing to undertake a new piece of work submit a report on his proposals and on what can be found on the subject in the literature before he actually starts experimental work, but men are of such different types that this might discourage some men from trying out ideas which, if they had been able to start directly in experimental work, might give results of value.

Almost as difficult a point as the question of starting a piece of work is that of stopping it. Probably, the tendency is to continue work too long after it should have become clear that it is not likely to prove sufficiently valuable to be worth the time spent upon it, but again the history of science is full of examples of discouraging and unsatisfactory work which, persevered in, finally proved successful. A piece of work which has been commenced and is abandoned without result represents practically a dead loss, and the question is continually arising as to whether it is better to cut the loss and start a new piece of work, or to continue in the hope of retrieving an apparent failure. Each case, of course, must be decided on its merits, but it is important not to let any question of sentiment intervene; that is, the individual worker must not be allowed to feel that it is a reflection on him if a piece of work which he has been doing has to be abandoned; otherwise, he will certainly strive to continue work after it should have been given up. It is rare for a man to be really responsible for a failure; it is more often merely that a bad selection of the problem was made, in which selection the worker himself may have had a very small part. As far as possible, men should be encouraged to look at their problems objectively, and themselves to recommend abandonment of work which they do not believe they can bring to a successful conclusion, without feeling that it is a personal reflection on them to drop a given problem.

When a piece of work is finished, a report should be written including a statement as to whether or not the work has been carried to a successful conclusion so that the information will be available in case the matter comes up again.

The form in which the work on a given problem is reported will depend upon the nature of the problem and the purpose for which it is undertaken. The following classification of the written products of industrial research is due to Dr. Nutting.[1]

1. Full reports on each piece of work undertaken in the nature of digests of notes and data taken during the work.

2. Scientific papers to be read before societies and published in journals.

3. Minor technical reports, usually in the form of letters in response to inquiries or of reports on tests.

4. Technical recommendations as to modifications in works processes, development of new processes or products.

5. Patent suggestions covering new methods, processes or products.

In order that the work of a research laboratory may be utilized in the best manner it must be made accessible to all departments of the industry, and the results obtained must therefore be presented in a form in which they can be understood and used by those for whom they are intended. For this reason instructions governing the drafting of reports should be issued. It must be remembered that a report is to be a permanent record which will be read by those who may not be experienced in the special subject with which the report deals. A report should be capable of being understood not only at the time when it is written and in the factory where it is written but by a reader twenty years hence who has never seen the factory. Terms which have a local application should be avoided, and

[1] Private Communication.

as the work recorded may have to be repeated at some future date, all essential data should be given in sufficient detail to render such repetition possible. The following instructions for drawing up reports are given by the kindness of Mr. William Rintoul, manager of the research section of Nobel's Explosives Company.

1. The report must be impersonal except in the case of reports on visits, which may be written in the first person.

2. The official nomenclature of the laboratory is to be employed in describing materials.

3. No contractions except those which would be recognized by all readers are to be employed. Any other unavoidable contraction is to be explained in a footnote.

4. Each report should as a rule consist of three parts: a description of the experimental work carried out, summary and conclusions. The summary should state concisely the nature, scope and results of the experiments. It should summarize the whole of that part of the report which precedes it and not deal merely with the results obtained. It should be quite understandable by one who has not read any other part of the report, except perhaps the title page. The conclusion should be written as if the author were answering the question implied in the definition of the object of the program. If further work is necessary before anything definite can be stated, the conclusion should contain a suggestion for this further work.

The title of the report should be carefully selected to give the reader as much information about the report in as few words as possible. A title such as "Report on Program B. D. No. 6" is not permissible; neither is such a title as "Report on Lenses submitted by Mr. Smith." If a general title is given, the report must be a general report. A title such as "On the Determination of Nitrogen" would not be suitable for anything less than a monograph. If the subject were an examination of the suitability of the Kjeldahl method for a particular purpose, the title should read "Report on the Use of the Kjeldahl method for the Determination of Nitrogen in . . . ."

Headings should be used in order to facilitate reference. They must not be inserted haphazardly but be co-ordinate and logical. It must not be assumed that the reader reads all the headings, and the headings must therefore be repeated in the text.

When tables are given they should be, as far as possible, self-explanatory. Enough information should be given in the headings to make the table understandable without too close an examination of the text. Chemical formulæ should not be used in the text of the report in the place of names of materials; they may be employed in tables.

These instructions may seem to be too detailed, but such detailed instructions have a very beneficial effect upon the type of the reports; since after two or three reports have been submitted by a worker and departures from the regulations have been pointed out to him, the improvement in manuscript submitted is very marked. In every laboratory there should be somebody whose business it is to deal with literary matter, and in a large laboratory one or more qualified persons may be appointed as editors, their whole time being occupied with the form of reports and of matter for publication.

It is by no means easy to prevent work which has a real bearing on practical questions being ignored by the practical man to whom it should be of value. The mere filing of a report is not always sufficient, and some method of following up the application of the work is desirable.

In some firms all the reports from the laboratory go to the management, which notes on them directions for applying the results and returns the annotated report to the laboratory. The director reports as to the steps taken to carry out the directions, and finally returns the report to the management for filing with a statement as to what has been done.

It is sometimes thought that men engaged in technical industry are anxious to make use of the facilities for obtaining information which are available and that a library will therefore be fully utilized if it is available. This is quite incorrect; as a rule technical men are very much occupied with their own work and find it difficult for lack of time to follow technical literature or even to look into the possibility of obtaining information on subjects in which they are interested, It is, consequently, very desirable for the laboratory to make a practice of abstracting the technical literature of interest to all departments of the company, and circulating these abstracts so that those likely to concern the technical men will be brought to their attention.

There is some doubt as to how such work should be done. It is often suggested that the abstracts should be made by one man connected with the library, but it seems to be very doubtful whether a man can generally be found with sufficient knowledge of what is required by all the different workers to prepare satisfactory abstracts. It is probably better to arrange for the men working in the laboratory to prepare abstracts dealing with their own special section of science. This really does not involve any hardship, since each man should certainly read the journals with which he is specially concerned, and any papers which are of sufficient value to be worth abstracting are worth the time which he will have to spend to make the abstract.

Abstracts of patents are perhaps best made by the patent department, if there is such an institution in connection with the company, but some means should be taken of making certain that every one who is really interested in patents has them definitely called to his attention. In addition to its use for the techincal men of the organization outside the laboratory, a proper indexing system will make such abstracts of great value to the laboratory itself.

In this connection, an experiment has been made for the last five years at the laboratory of the Eastman Kodak Company which has proved successful, and which seems to be worth trying on a larger scale. The laboratory publishes each month, for the use of the employees of the company, an abstract bulletin of the photographic journals, including also such abstracts from other scientific journals as have any relation to photographic problems or manufacture, the abstracts being made by the laboratory staff, and each abstract being given a reference number. These numbers refer to a numerical classification of photography based somewhat on a decimal system, but adapted to the special needs of the subject. Each month as the bulletin is issued the abstracts are clipped out, pasted on cards, and filed under the numbers printed on them in numerical order, so that each recipient of the bulletin can prepare for himself a file, either of all photographic literature, or of any portion of it with which he may be specially concerned. For example, in the classification, abstracts dealing with photographic apparatus commence with the number "2," and if a particular worker is interested only in apparatus—not in materials, photographic processes, or in applications of photography—he need file only the cards starting with 2, while, if his interests are even more limited—if, for instance, they are confined to photographic shutters—he can file the cards starting with "262," thus obtaining only a very limited file which is, however, complete for that particular subject in which his interest lies.

If the scientific abstract journals would use a similar system, adopting as their basis either the numerical classifications of the International Catalogue of Scientific Literature which have proved themselves satisfactory or some different classification adopted after due consideration, then each recipient of the abstract journals could prepare for himself card index files of the scientific literature in which he is interested.

To prepare a card index of all science or even a complete index of one large branch of science in this way, would, however, be too formidable an undertaking either for an individual or even for a small library, but it should certainly be possible for large libraries, such as those of the scientific societies or of large cities, to keep such numerically indexed files to which reference could be made by correspondence from any research worker.[1] Thus, adopting the classification of the International Catalogue, a worker who became interested in questions, *e.g.*, of catalysis, could apply for a copy of the reference cards on this subject, which would include all those indexed under 7065, and could be supplied with a complete file or with a partial file covering any period of time; the copies could easily be made by photographing the cards with such a camera as the "Photostat."

All scientific work, including that which arises in the course of an investigation undertaken to obtain a practical result, should be published in the form of technical or scientific papers. 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 in the direction of withholding entirely harmless information. It is much more satisfactory, if possible, for one responsible executive to pass on all matter submitted for publication, and this will inevitably

[1] On the subject v. K. C. Walker and A. D. Flinn, Development of Existing Agencies for Co-operation in Industrial Research, *Proc.* Amer. Soc. Test. Mat., v. xviii, Part II, 1918, p. 1. Also, A. M. Patterson, *Jour.* Ind. & Eng. Chem., 1919, p. 487.

result in a much more liberal policy than where the responsibility is delegated to a number of representatives of different departments of the company.

The importance of free publication of scientific work for the maintenance of morale in the staff has already been referred to,[1] but such publication also has a value for the laboratory as a whole; it gives a corporate spirit and a sense of individuality which can be obtained in no other way.

It is most unfortunate that the regulations for the organization of research associations in Great Britain lay much stress on secrecy. Secrecy is very antagonistic to the scientific spirit and is fatal to co-operation; in a laboratory where secrecy is strongly emphasized there is an atmosphere of restraint and suspicion which is very undesirable. While some industrial secrets must necessarily be kept very strictly inside the organization, it is generally best to confine the knowledge of such secret methods and processes to very few people and to allow the rest of the laboratory to work frankly and with the minimum restrictions as to discussion and intercourse.

The practice of different laboratories in the method of publication of their results varies considerably. A number of laboratories publish their own bulletins, either as separate papers or as periodical volumes. Others publish in the scientific and technical press, either in one or two journals or in a number of different journals, according to the subjects dealt with.

Naturally, the best method of publication will depend to some extent on the nature of the work published and the character of the laboratory. In the case of a purely technical laboratory publishing a

[1] v. Chapter VI, p. 100.

large number of papers on one special technical subject, the method of publishing separate bulletins, mailed directly to a selected list of those interested, may be quite satisfactory, but if the publications of a laboratory cover a large range of subjects it would seem to be preferable to publish each paper in the journal which deals with the department of science most akin to that of the subject. If this is not done, there is grave danger that the paper may be missed by the abstract journals and be overlooked altogether, while in any case the publication of single bulletins increases the burden of any investigator engaged in compiling a bibliography of a subject.

In the laboratory of the Eastman Kodak Company it has been the custom to confine the publication of scientific comunications to the recognized technical and scientific journals, and the first fifty communications were published in no less than seventeen different journals, twenty-nine being published in journals relating to some branch of physics, five in chemical journals, and seventeen in photographic publications. Since all the papers issued from one laboratory have a common interest, and it is therefore an advantage to have them available in some collected form, this laboratory periodically publishes bulletins containing abridgments of all its scientific papers.

In addition to the publication of papers, the workers in a research laboratory should certainly be encouraged to summarize in the form of books the work that they have done over considerable periods of time. The most valuable books are those written by actual workers, and, although it is difficult to persuade a man engaged in practical research work to write a book on his work, it is nevertheless well worth the time spent on the task if a good account of the whole of the work can be obtained written by the man most concerned in it, and the director of a research laboratory should certainly encourage the preparation of books dealing with the subjects on which research is going forward in the laboratory.

If a sufficient amount of material is available, publication can be greatly encouraged by the employment of a special member of the staff to whom is assigned the sole duty of preparing papers and monographs for publication. Such an editor can do bibliographical research, obtain and check references, write historical and introductory sections, and generally lighten very greatly for the scientific men the labor of writing. Under such conditions men, who would otherwise never be willing to face the task, can often be encouraged to write papers and books.

In addition to scientific papers, special technical reports for the information of the staff of the company itself should be circulated by the laboratory, and when a laboratory publishes an abstract bulletin, these technical reports can be conveniently incorporated in the bulletin. It is often advisable also to prepare special bulletins dealing with the application of published scientific investigations to the special needs and interests of the company. The director of the laboratory will use these reports and also the minutes of the conferences in making up his periodical reports to the authorities to whom he is responsible. In the case of an industrial laboratory it is convenient to make these summarized reports every month, and from the monthly reports, the published papers, and the report files an annual report dealing with the work of the laboratory during the year can be prepared.

CHAPTER IX

THE DESIGN OF A RESEARCH LABORATORY FOR A SPECIFIC INDUSTRY

The principles dealing with the various aspects of scientific research which have been discussed in this book may be applied directly to the design of a research laboratory for a specific purpose, and it is proposed in this chapter to attempt to outline some typical laboratories as a guide to the directorate of any firm contemplating the establishment of a research department.

Since the financial aspect of the matter will naturally govern the scale on which a laboratory is established, it is necessary first to consider the cost of laboratories in order to ascertain how large a laboratory a given sum will support.

From various sources, but chiefly from the convenient list of American laboratories given by Mr. Fleming, there can be obtained the cost of a research laboratory per scientific worker employed. It might seem that there would be very great variations in this, but, provided that the laboratories are all of the physical and chemical type, there is a surprising agreement between the figures, which show that the cost of building and equipment for a laboratory in 1916 was between $3,000 and $4,000 per man. In the whole list, the only one which is appreciably below this is a laboratory which is used almost entirely for testing and apparently largely for chemical testing, and in such a laboratory the cost of apparatus is naturally low, since routine analyses do not involve very much apparatus. It may be taken, therefore, that the first cost of a laboratory will be approximately $3,500 per scientific worker employed. From the same sources the annual cost of maintenance of such a research laboratory appears to be slightly lower than the first cost. Probably $3,300 per man would be a fair estimate of the cost of maintenance, and of this we may take 60 per cent. as representing salaries and wages and the remainder all other expenses.

In his recent paper on "Planning A Works Research Organization"[1] Fleming gives a careful analysis of costs for buildings and equipment with an estimate of running costs. These are prewar figures for Great Britain and are lower than the estimates given above.

According to Bacon,[2] $1500 per year is the amount necessary to obtain first-class graduates, $1800 per year for men with experience in research. An industrial laboratory will take a number of its men without research experience, starting them as low as $1200 per year, while on the other hand the chiefs of departments will require about $3000 per year at the start.

Owing to the rapid increase in the cost of living the above figures are certainly too low and probably should be increased by 50 per cent. at the present time (1919).

In Great Britain salaries are somewhat lower than

[1] *Jour.* Inst. Elect. Engineers, 1919, p. 153.

[2] Some principles in the Administration of Industrial Research Laboratories, by RAYMOND F. BACON, J. S. C. I., 1916, Vol. xxxv.

in the United States, and in order to convert figures given in this chapter, therefore, $1000 in the United States may be regarded as equivalent to about £150 in Great Britain when considering the cost of research work.

The laboratories which we are contemplating must be prepared to act in all the capacities which we have discussed in previous chapters, they must be equipped with libraries and with accommodation for small-scale industrial work, and their scientific equipment must be entirely adequate to the work undertaken.

That work may be classified in three divisions:

A. Work undertaken on the initiative of manufacturing divisions for the improvement of operations, for the lowering of cost, or in order to locate manufacturing difficulties.

B. Work undertaken with a view to the development of new materials or of entirely new processes. This may be initiated by the management, by manufacturing sections, by sales divisions who see the need for such materials or processes, or by the staff of the laboratory.

C. Work which deals with the fundamental theory of the subject the results of which, if successful, will lay a foundation for the expansion of the industry as a whole, along lines which usually cannot be foreseen when the research work is commenced.

In a study of the work of a special research laboratory all the work done during the year was analyzed from a classification of the work of each part of the laboratory, and the proportionate expense which should be charged to each class of the work found. This analysis showed that Division A, that is work done for the manufacturing departments, corresponded to about 20 per cent. of the work of the laboratory; Division B, work on new materials, 47 per cent.; Division C, or fundamental work, absorbed 27½ per cent. of which 22½ per cent. was devoted to the scientific work and 5 per cent. to the accompanying educational work; while work for the assistance and information of the office force was estimated at 5½ per cent.

At the commencement of a laboratory, work belonging to Division A will probably absorb the greater part of its energies, but however the work is started some apportionment of the time of the laboratory among the three divisions will eventually be made, in which each of them will take its own place.

Let us first consider a laboratory suitable for an industrial undertaking whose business consists in the dyeing of textiles. Let us suppose that the industry is making a turn-over of $1,000,000 a year, of which 10 per cent. or $100,000, is net profit, and that the directors have decided that in order to improve their product and extend their business, possibly to diminish costs, they will at the outset undertake an expenditure of $20,000 a year on scientific research. Now, let us consider what they can do for this.

In view of the increased cost of building due to the war, the building for an expenditure of $20,000 a year will probably cost $20,000 and the scientific equipment $5000, while the small experimental plant can be equipped partly from material already available in the works and may cost an additional $3000. So allowing $2000 for library and office and other sundry expenditures we have a capital expenditure of $30,000.

Taking the basis of $4.00 per square foot for building as a rough approximation, we shall have 5000 square feet of floor space, or, dividing this into three floors, a building about 40 feet square. In order to allow for expansion it would be better to erect a building with a floor area of 5000 square feet, say

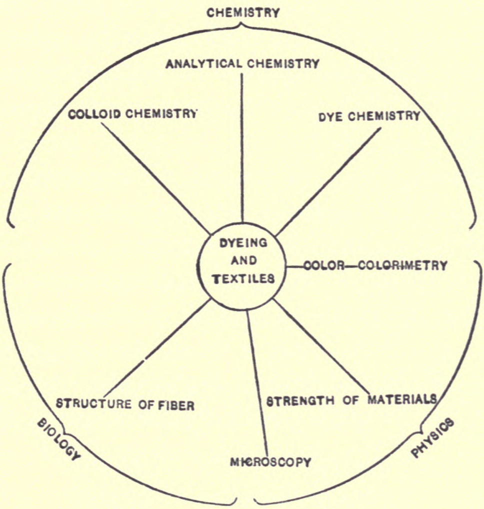

Fig. 10.

50 × 100, using the upper floors for manufacturing until they are required by the laboratory, but naturally a decision on this matter would depend upon financial considerations.

The work of the laboratory may be analyzed according to the chart shown in Fig. 10. Dividing it into the three main divisions of chemistry, physics, and biology, we shall get the following sections for the work. In chemistry we shall require an analyst and dye chemist who must understand organic chemistry, and a colloid chemist who will study the relation between the fiber and the dyes. In physics, we shall have work to do on the testing of the strength of materials, and especially on colorimetry and the measurement of absorption. In biology, we shall require a man who understands vegetable and animal fibers, their structure and their bio-chemical properties. We shall also require an expert microscopist who will understand the staining of fibers and photomicrography. This will give us the chart shown in Fig. 10.

We cannot hope, of course, to represent all these departments by separate men, since the number of men will be limited by the appropriation available for the laboratory. With an appropriation of $20,000 per annum a basis of $4000 per man should give us five men, but with a small laboratory the cost per man will be somewhat higher and it will be safe to divide the $14,000 available for salaries, thus:

Director	$5000
Colloid Chemist	$3500
Organic Chemist	$3000
Physicist	$2500

The director will be a chemist who has had works experience in dyeing, or who must be given this works experience before the laboratory is commenced if a fully trained scientific research man is not available from the works. It is of no use to take a man from the works who is not fully trained in research methods and in sympathy with scientific work. If such a man is not already available with a knowledge of dyeing, then the best available man must be obtained from a university or elsewhere and given the works experience to learn dyeing before the construction of the laboratory is attempted. The colloid chemist will be a bio-chemist and may be expected to understand the chemistry and biology of textile fibres and to undertake microscopical work. We may expect our organic chemist to look after analytical chemistry as well; that is, we must get a man having experience in organic chemistry and with some knowledge of dyes, who can specialize in the study of dyestuffs and on their analysis, but who also can do what routine analytical chemistry it becomes essential for the laboratory to carry out. We may expect our physicist to understand colorimetry, and at the same time to know enough general physics to be able to look after questions involving the strength of materials.

We can now consider the structure of the laboratory itself. If we have three floors, each of them containing about 1600 square feet, one will be required for the library, office and the dye room, which will be a small edition of a works containing small model machines in which all the works processes of dyeing, washing and drying can be carried out. This may occupy about half the ground floor, the other half being taken up by the library, staircase and the laboratory office, which in such a small laboratory may be united with the library. The next floor will be devoted to chemistry and may be divided into two or three rooms, while the top floor will be used for physics and will contain rooms for ordinary physical work as well as for colorimetry and probably for microscopy, since it is inadvisable to have microscopes and similar instruments exposed to the fumes of a chemical laboratory.

A design similar to this can be made out for any other industry, the factor of size being determined by the expenditure which it is proposed to make, and the work being distributed in accordance with the demands of the particular industry in question.

A study of a laboratory suitable for research on zinc has been made by Dr. John Johnston. The fundamental work of this laboratory would deal with the physical and mechanical properties of zinc, such as the study of its crystalline transformations, the temperature of inversion and the effect of impurities upon these changes. This work would then be extended into a systematic study of the zinc alloys, first the simpler ones, later the more complicated, through a wide range of conditions, ascertaining their mechanical properties and correlating them with their constitution.

As a result of this work new uses or extensions of existing uses for zinc might be found, that which appears most promising at present being the development of zinc alloys with properties more suitable for die casting, or the production of zinc wire of high tensile strength.

The laboratory work proposed is estimated by Dr. Johnston to require personnel and equipment somewhat as follows.

(*A*) A first-class physical chemist, familiar with the technique of high-temperature experimental work and with the methods of alloy investigation, with two assistants.

The equipment needed would include small electric furnaces of various kinds with appropriate devices for measuring temperatures; colorimetric apparatus; an apparatus for determining density (including volume change at an inversion or on melting) and vapor pressure at any temperature, in addition to that ordinarily found in a physico-chemical laboratory. It would probably also be advisable to arrange for determination of physical properties such as electrical conductivity, thermo-electric power, etc.

(*B*) A first-class metallographer, provided with the best kind of metallographic outfit, with an assistant.

(*C*) A man familiar with the methods of testing metals for tensile strength, hardness, resistance to fatigue, compressibility and other mechanical properties, with an asssistant.

In addition to the various testing machines it would be advisable to install equipment to enable tests to be made on the properties of the metal or alloy when extruded, on its suitability for die-casting, etc. It might also be well to have a small experimental rolling mill with the necessary furnaces and equipment.

(*D*) A first-class analytical chemist who would control the chemical composition and purity of all materials used and products investigated, and would standardize methods of analysis of zinc products, with an assistant or probably two.

The equipment would be that of a first-class analytical laboratory, including apparatus for electroanalysis and other such methods.

(*E*) A first-class mechanic, with a small well-fitted shop, capable of making and repairing apparatus in the experimental work, with a helper, part of whose duties would be to look after things generally.

On the basis outlined above, the initial annual salary budget would be about as follows:

Director	$10,000
4 men (*A*, *B*, *C*, *D*)	15,000
6 assistants	12,000
Mechanics	2,000
Clerical, janitor, etc	4,000
Total	$43,000

The necessary equipment to begin with would cost $25,000, but a further sum of $25,000 would need to be set aside for additions to the equipment within the first few years. Including the necessary overhead and operation costs, this laboratory would thus cost about $80,000 per annum and a suitable building would cost about $100,000.

This zinc research laboratory may be taken as typical of laboratories for the metal-producing trades, as the one outlined for the dyeing of textiles is typical for the industries of a technical manufacturing type dealing with engineering processes, handling chemicals, and also involving certain biological considerations, such as arise throughout the textile and leather industries.

A scheme for the organization of research and analytical control in chemical manufacturing has been published by Ferguson.[1] The organization of the analytical department in this scheme is particularly interesting, being worked out for a corporation having a number of laboratories requiring co-ordination.

As laboratories are organized and experience gained in the type of laboratory suitable for different indus-

[1] W. C. Ferguson, *Jour. Ind. Eng. Chem.*, 1912, p. 905.

tries, it will doubtless become possible to lay out a definite scheme of organization for a laboratory suitable to the requirements of any industrial undertaking. At the present time it is possible to do this only in the most general way, and it is very desirable that those who have experience in the operation of research laboratories should publish their conclusions in order to make them available to those whose duty it is to organize new undertakings.

There is no doubt that the organization of scientific research will advance very rapidly during the next few years, and the efficiency of its advance will depend very much upon the frank collaboration of those who are engaged in direction of the work.

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