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RESEARCH IN INDUSTRY

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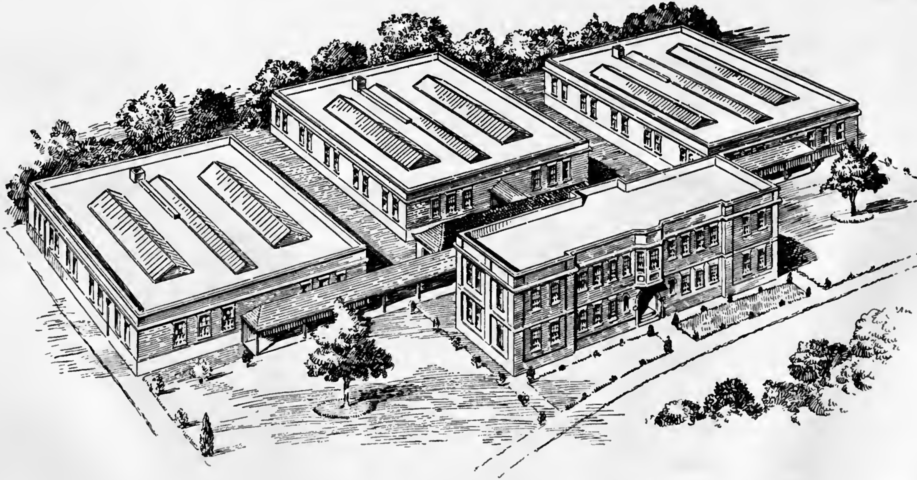

Research Buildings, Projected and Partly Constructed (Metropolitan-Vickers Electrical Co., Ltd., Manchester)

[Frontispiece

PITMAN'S
INDUSTRIAL ADMINISTRATION SERIES
Edited by A. P. M. Fleming, C.B.E., M.Sc., M.I.E.E.

RESEARCH IN INDUSTRY

THE BASIS OF ECONOMIC PROGRESS

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PREFACE

THE state of industry during 1921, reviewed in the light of the unprecedented conditions of the past seven years, has served only to throw into sharper relief the vital economic principle on which healthy industry is based; that of providing commodities and services at a minimum, and preferably diminishing, cost. The reduction of production costs in the past has always been obtained through improvements in manufacture resulting in greater yields for a given expenditure of labour, but the progress achieved thereby has been largely fortuitous and unregulated. In order to maintain current standards of living and culture in the face of burdens left by the war, it is imperative that industrial development in future be definitely assured. Since manufacturing advances are won by the introduction into industry of new knowledge, it follows that new knowledge must be systematically sought, and that a portion of the product of industry must be set aside for pursuing the means of further progress. In existing manufactures, new knowledge will result in the introduction of the most efficient and socially most beneficial productive methods; to the possibilities of the future it implies organized and intensive effort towards the cultivation of new industries and new products.

On the material side, the cause of progress demands close study of commercial resources, whether actually or potentially valuable, and of their application and disposition in manufactured products; it demands, that is to say, scientific research. On the personal side, it calls no less for the proper technical and social education of all grades of workers, together with the fullest utilization of their powers in modern administrative systems affording the most effective co-ordination of personnel.

The organization necessary to meet the two requirements thus broadly distinguished as research and education will be an integral part of the newer type of industrial administration, and the exercise of these functions will provide solutions to many pressing industrial problems. Research and education will prove powerful economic weapons in the conservation and development of those markets on which our industrial prosperity depends, and instruments for the quickened, ordered progress of society.

An attempt has been made in this book to consider the nature of research and its application to the progressive development of industry, and to indicate the manner in which existing research resources may be placed at the disposal of industry, thereby affording guidance to industrial managers in determining the most effective manner of dealing with their manufacturing and other problems. Recent tendencies towards co-operative action for the conduct of research, notably instanced by the formation of Research Associations in Great Britain, are examined, together with the conditions under which a works research organization may be established. The internal organization, design, staffing, equipment, cost, and direction of research laboratories for industry, and their relations to national, university, and private laboratories are outlined. The progress made in the world-wide movement towards the foundation of research institutions is briefly considered.

Some of the illustrations employed have been reproduced from a Paper entitled "Planning a Works Research Organization," delivered by one of the authors to the Institution of Electrical Engineers during the session 1918–1919, and the courtesy of the Institution in permitting reproduction is hereby acknowledged. The authors are also indebted to the following firms for permission to make use of photographs and drawings of their research laboratories—

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RESEARCH IN INDUSTRY

THE BASIS OF ECONOMIC PROGRESS

CHAPTER I

THE BASIS OF SOCIAL PROGRESS

PRIOR to 1914, many of those who had had occasion to consider the condition of British industries were conscious of the ill-effects of the lack of contact between, on the one hand, industrial and commercial life, and, on the other, academic and professional life. The tendency of the public school and university systems to prepare young men for the so-called learned professions rather than for business life was by no means the most harmful consequence. Far more harmful was the general failure of those not directly engaged in productive work to realize the extent to which the well-being of the whole community depended upon industry. One of the minor compensations of the war, however, was that this dependence was brought home to all, partly through shortage of labour and supplies, partly through increased prices of such materials as were available, partly through the adaptation necessary to secure an enormously increased output from a much smaller number and from very unusual types of workers.

At the present time it is generally recognized that the common standard of living and leisure is virtually dependent upon the efficiency of productive industrial processes.

Sociologists are agreed that ethical and moral progress is closely related to material progress; so much so that the latter is the inevitable precursor of the former. In other words, social progress, as understood among Western peoples, is dependent upon the steadily increasing productivity and efficiency of manufacture.

INFLUENCE OF INDUSTRIAL PROGRESS ON SOCIAL DEVELOPMENT

Since the war the means of production, which had been considerably modified or hastily improvised to meet the demand for war products, have been only slowly re-adapted to supply normal requirements, and the pre-war rate of production has not yet been reached, although the demand has been great, and will probably continue so, except for periodic fluctuations or abnormal depressions due to financial disorders. The burdens imposed by increased prices and taxation alone would have been difficult to bear under pre-war conditions, but the quickened social consciousness which has resulted not unnaturally from the war, the higher ideal of social development and progress, demands enormously increased expenditures, not unproductive in the truest sense, but yet requiring the provision of funds not yielding an immediate monetary return. Thus, apart from payment for war services or injuries, money is urgently required for all branches of educational work, for the provision of relief work for the unemployed, the provision of old-age pensions on a more generous scale, and for other social projects. Nor does it appear that the relief which was anticipated in some departments of national expenditure will be realized, at any rate for some time to come. Industrial workers demand hours of labour, remuneration, and working conditions which industry in a rudimentary state of development is unable to bear. Wages tend no longer to depend upon and to fluctuate with the general prosperity of industry. The tendency is to determine a level from social and personal considerations, often without adequate thought for economic possibilities, and to leave it to the industrial administrator to endeavour to arrange that the return from industrial processes shall be such as to permit of it.

If, therefore, this is all to be accomplished without impairing the effectiveness of British industries in competing for foreign markets, new sources of wealth must be created and exploited, and more effective methods of wealth production established. It must be borne in mind that while there is every need for individual and national economy in all expenditure, true economy directs that wise expenditure on the means for cheaper production should be encouraged. Only in this way can the material well-being ancillary to social progress be secured.

THE PROGRESS OF INDUSTRY AND ITS MODERN TREND

Industry is, in its simplest conception, merely the transforming process whereby natural resources are modified, through a series of operations, often extending over a period of years, into commodities required to satisfy the needs of the community. Originally, each man provided himself, through his own exertions, with shelter, food, clothing, and weapons, but with the growth of small communities he was compelled to recognize the economic value of specialization, which permits advantage to be taken of natural tastes and aptitudes, and facilitates the development, through long practice, of special skill. This process of specialization has continued at a quickened pace, and, by reason of the resulting saving of time, has rendered possible that leisure from which intellectual progress has sprung.

The transforming process involves the employment of men and women of every kind, unskilled, semi-skilled, and skilled workers, foremen, managers, engineers, chemists, accountants, salesmen, financiers. Also directly engaged as a consequence of industry are those employed in the various transport systems. Less directly engaged, but concerned as intimately in the industrial equilibrium, are teachers, preachers, barristers, solicitors, medical men, and other professional workers. Institutions such as schools, universities, hospitals, churches, libraries, museums, prisons, are all maintained out of the product of industry, and their financial stability depends on the general prosperity of industrial countries. Even those who find comfort in the thought that they are remote from the business world and its activity are very vitally concerned, if only as consumers of industrial products. Particularly in a country so dependent as Great Britain on its manufactures, each person, whatever his or her occupation, is affected by the general industrial position, and should be interested in those circumstances which enhance or retard trade, which assist or diminish the rate of production, which influence raw material supplies and their economical use, and which determine the efficiency of methods of production; that is, in the factors that influence or determine industrial progress.

Progress in Industry

Industrial progress depends essentially upon the acquisition, development, and application of new knowledge. In the rudimentary stages of growth, new knowledge is abundantly derived from the everyday experience of the workers themselves, all of them adding, consciously or unconsciously, to the body of technique comprised in the sum total of the industrial processes. Occasionally impetus is given through the inspiration of a genius, not necessarily engaged in the industry, who accelerates progress by some remarkable invention or discovery.

A time ultimately arrives, however, when the more obvious developments are exhausted, and the continued expansion of the industry makes the likelihood of startling innovations by workers, or even by gifted amateurs, progressively smaller. Unless the industry is left to stagnate, or to wither through competition, the material for growth must come from other sources, and what was the province of manual skill must pass to design, direction, and management.

Trend of Modern Industry

Everyday experience and observation, garnered in the first place by manual workers, ultimately become organized, sifted and tested by trial, to form a body of knowledge or science which can be developed further by observation and experiment, and applied to assist the progress of industry.

The further experience gained in the expanding industry suggests fresh subject matter for scientific enquiry, and so science and industry act and re-act on each other continuously, the horizons of both being widened indefinitely. Any one branch of science may influence innumerable industries, some of which may be of recent growth, but science had its origin in the primitive practical arts and domestic crafts, such as the preparation of food, treatment of skins, agriculture, brewing, the preparation of textiles and dyeing. The art of navigation was practised prior to, and provided the initial impetus for, the study of astronomy and geography. Botany sprang from the lore of herbalists, shepherds, and tillers of the soil, while ordinary contact with things sufficed to rouse the spirit of inquiry which has resulted in the sciences of physics and chemistry.

Improvements in industry, and the bases on which new industries are founded, are provided in the main by invention and discovery. The former is principally contributed by those engaged in the technical direction of industries, which, by virtue of their complexity, demand extensive technological training. The latter is mainly contributed by scientific workers in research laboratories.

While the potentialities of science as an aid to industrial progress have long been realized, the pursuit of improvements has not been systematic. It will be shown later that scientific discoveries cannot in general be predicted, and that scientific endeavour must largely proceed without a clear vision of the end to be achieved. Consequently, discovery cannot be systematized, although it can be more effectively co-ordinated, and the probability of new discoveries being made can be increased by the proper endowment of research and the provision of opportunities for suitable men to undertake such work as a vocation.

There is no doubt, however, that applications of discoveries can be systematically made. Hitherto there has frequently been a considerable time lag between a discovery and its application, largely owing to lack of experimental facilities through which rigorous large-scale tests may be conducted.[1] Advances in different fields of science have been unequal, although it is known that advances in one field profoundly influence those in others. A striking case was afforded by the construction of the Panama Canal, the most spectacular achievement of engineering science, rendered possible by research in medicine.

In the past industrial progress has been largely fortuitous and due to the stimulus which the desire for personal achievement and reward gives to individuals. While the progress thereby secured has been remarkable, it now appears necessary to make a deliberate and conscious attempt to aid industry by all the devices of which human ingenuity is capable in the directions of selecting and training men, of setting them aside specially for research, of providing the necessary funds, liberally administered so as not to impose constraint or restrictions, of endeavouring to apply discoveries, not only in one but in all branches of industry in which they can be of service, and of educating all grades of workers to appreciate the benefits of research so that they may accept and welcome progressive development and the changes which it necessitates. How this deliberate and conscious evolution can be secured through proper organization will be discussed later.

[1] *See* Mr. A. E. Seaton's paper in the *Trans. Inst. Naval Architects*, 1918, for some illuminating examples in marine practice. In such an industry as marine engineering, unless full scale demonstrations can be made, conservatism is essential.

THE APPLICATION OF SCIENCE TO INDUSTRY

From the above considerations, it is clear that a narrow view of the particular sciences which require to be studied will not provide for the fullest progress of industry. Not only must those sciences be included which enlarge our immediate knowledge of industrial materials and processes, such as chemistry, metallurgy, physics, but also those the application of which is less obvious, as, for example, biology, medicine, psychology, anthropology. The problems of industry are primarily human problems and only secondarily material problems.

Furthermore, the term "industry" must be equally broadly interpreted. For the present purpose it may be held to include not only ordinary manufacturing processes of all kinds. large or small, hand or machine, but also agriculture, mining, and methods of transport. The applications of science will not merely refer to industrial materials, processes, and products. They may be utilized at every point in industry where there is need for the determination of standards, for ascertaining facts, or for accurate measurements. In such important fields as vocational selection, education, industrial administration, and management, scientific investigation may be requisitioned. It is not unreasonable to hope that it may provide the solution to many acute industrial problems in which the goodwill of conflicting parties is not lacking but in which facts are in dispute. Its academic impartiality and thoroughness cannot be questioned.

FRUITS OF RESEARCH IN INDUSTRY

It has been emphasized above that social progress is very intimately bound up with the increase of material wealth which industry renders possible, and that scientific research provides an important means of adding to our methods of wealth production. The value of research, which is its justification, is therefore both material and moral, and of consequence to all classes of the community. The more striking value is perhaps economic and tangible; the less obvious, though perhaps more important, is social and educational.

Economic

It is virtually impossible to assess financially the achievements of scientific discovery; only a few bald and isolated illustrations can be given. No one requires, however, to be convinced of the value to humanity of the work of such men as Kelvin, Faraday, Watt, Bessemer, Darwin, Lister, to mention only a few distinguished British names. As a consequence of research one is enabled to travel farther, whether by road or rail or water, or even under the sea and in the air; to communicate farther, whether by telephone or telegraph, with or without wires; to produce more food, to make more goods, and to save more time and labour. It has given us more knowledge of the human organism, has provided anaesthetics, antiseptic surgery, drugs and dyes. It has devised the electric drive, prime movers, and a whole range of materials and products for our convenience and use. Research, through the amenities which it has provided, has added to the spaciousness and the grace of human life, which it has lengthened both literally and figuratively.

The economic benefits of research are shared by the whole community. The manual worker is especially concerned with the lowering of prices consequent on cheapened production, and with the greater possibilities of employment arising from the establishment of new industries. The opportunities open to the technical worker are increased. The investor and financier find in research a means for the provision of new fields in which capital may be profitably employed, and for the analysis of projects of a technical character involving the expenditure of capital.

Some illustrations of the money value of research may be indicated. The electrical engineering industry has been built up since Faraday, son of a blacksmith and apprentice to a bookbinder, first ascertained the phenomena of electromagnetic induction. The capital employed in electrical manufacture now runs into hundreds of millions sterling. In 1900, the value of American manufacturing industries developed from patented scientific inventions was about eighty millions sterling per annum. German pre-war exports of coal-tar dyes, all discovered through research, amounted to five millions sterling per annum. Dr. W. R. Whitney states that the improvements in electric lamp manufacture from 1901–1911 have saved consumers about fifty millions sterling per annum, and the most remarkable advances in lamp production have taken place since this date. The value of research to industrial firms may be indicated by the experience of the Du Pont de Nemours Co., U.S.A. This firm spent annually in research amounts increasing from £10,000 to £400,000. During the period 1912–1915, it is estimated that the total expenditure was £240,000, while the direct and indirect savings resulting were about twelve times this amount. The application of scientific method to agriculture, one of the most ancient occupations, has revolutionized our ideas of the yield of crops from a given acre of soil.

A most important economic aspect of research lies in the conservation of resources. Evidence is not lacking that some natural products now essential to civilized life—for instance, oil, coal, metallic ores, wood-pulp—are within measurable distance of exhaustion. Through scientific research, combined with surveys of natural resources, it will be possible to conserve these products, develop substitutes, synthetic products or alternative supplies, or obtain them from new raw materials. The recovery of waste products and by-products needs investigation as a necessary supplement to the work of conservation.

Social and Educational

The social possibilities of research follow from the economic possibilities. The more intensive production of the means of subsistence will enable industries to work for shorter hours and will afford the means for a higher standard of living and culture. The educational value of research is of less general concern, but educators agree that one of the best ways of developing power and independence of mind in a mature student is to permit him to undertake an investigation in some branch of science, involving some degree of personal responsibility. Indeed, research work arising from this educational function has produced an appreciable fraction of new scientific knowledge, although the rate of production of the latter renders increasingly difficult contributions of great value by immature workers.

Political

Since the war it has been freely recognized that scientific research is one of the principal ways in which one nation may seek to establish an ascendency over another, and that it is a legitimate and necessary sphere of activity for all the great industrial countries. Merely from the point of view of national safety it cannot be neglected. In the case of a nation bearing such vast overseas responsibilities as Great Britain, and having access to such remarkable natural resources in comparatively undeveloped countries, a vigorous and broad-minded research policy is doubly necessary.

CHAPTER II

CHARACTER OF RESEARCH

RESEARCH implies the purposeful seeking of new knowledge. The term is applied to any branch of enquiry, though it is in connection with the natural sciences, such as biology, chemistry, or physics, that it has come to have a special significance. Through research, scientific workers endeavour to establish by selection of and comparisons between facts, either previously known or disclosed by experiment, those definite consistencies in natural phenomena termed laws, which, modified as science expands, ultimately attain a universal validity. The procedure followed is that imposed by the use of scientific method, in which experiments under rigorous control are performed, observations are made and logical conclusions are drawn within the limits of the observations. A keen, well-trained mind with a wide knowledge of science may be able to achieve by a process of analysis and synthesis a generalization or hypothesis without the aid of experiment, although the truth of the conclusion has to be tested practically. Such procedure is frequently followed in mathematical, astronomical, and physical science, and by preliminary theoretical work a scientific worker is sometimes able to predict a truth. The prophecy of Clerk-Maxwell respecting the existence of electric waves, detected later by Hertz, and the independent prediction of the existence of Neptune by Adams and Leverrier, are well-known examples. In the chemical, biological and physical sciences, the chief method of attack is experimental. The conclusions drawn are frequently limited in scope, but suffice for many purposes. Between the simplest experimental work on the one hand, and the daring and transcendental imagination of genius on the other, there is every grade of difficulty and complexity in scientific work. While few men can hope to rival the achievements of the most famous investigators, a conscientious application of scientific method, directed by a trained mind, will enable much necessary work to be accomplished. There are also innumerable improvements continually being made in industry by technologists, whose primary concern is not research in the ordinary sense, and who lack time and opportunity to apply scientific method fully. Such improvements may be assisted by rough qualitative experiments, sometimes on a large scale, and intelligent anticipation and surmise are freely used, the results being of the nature of first approximations only. Industrial conditions necessitate rapid decisions, and circumstances may prevent exhaustive examination, even to a research specialist proper, but such work may for the present purpose be considered as research, since it does reveal something, previously unknown, of value, even if the knowledge is incomplete.

Research may therefore be considered to mean the application of scientific method—observation, experiment, deduction, verification—to the disclosure and utilization of hitherto unknown or unrealized facts, and the establishment of relations between them, however slight their general significance or local their application. It is essentially creative.

ACADEMIC AND APPLIED RESEARCH

Modern research may obviously be classified into two main divisions, the first of which has been termed "pure science," or "academic," or "pioneer," or "abstract" research; the second being "applied" or "technical" research. Where the latter has been concerned with the advancement of manufacturing industries it has become known as "industrial" research.

Academic research is generally directed towards the exploration of uncharted areas of science; collecting, collating and interpreting facts, by experiment or otherwise; formulating theories based on selected facts found to be inter-related; and determining the general validity of such theories by experiment. Applied research endeavours to utilize existing knowledge for the solution of some scientific problem or for accomplishing some utilitarian end, such as the prevention of or cure for a disease in medicine or surgery; the development of some new field of human activity in industry, or the more efficient and economical conduct of existing industries; or, indeed, with any preliminary or experimental work involved in the "direction of natural forces for the use and convenience of man." The boundaries of such a problem are set by some human need and not by a philosophic desire to add indefinitely to the existing structure of scientific knowledge. Academic research results in ascertaining new facts, while applied research uses these to serve some practical end. The distinction that is often drawn between academic and applied research is expedient, and will doubtless be perpetuated. Considerable harm, however, results from the assumption often made as a consequence of this distinction, that academic research is confined to research institutions and university laboratories, and that applied research is confined to industrial laboratories. The mischief is increased by the further assumption that the aim of academic research is essentially good and altruistic—the increase of the sum of human knowledge—and that the aim of applied research is essentially base and mercenary—being shaped by commercial and economic considerations. The extreme view was perhaps expressed by the professor whose chief pride in a certain discovery lay in the fact that no one would ever be able to make use of it.

Experience indicates that it is difficult if not impossible to define sharply between the two branches. Between the most empirical—if exhaustive—factory experiment at the one extreme and the elaborate and remote scientific investigation at the other there is a complete range of gradation.

It is erroneous to suppose that any one type of research is conducted in any particular kind of institution. In many universities applied research is done on a considerable scale, and in the case of the National Physical Laboratory it would probably be no exaggeration to say that this institution in its early days purchased its right to carry on pure science research in a fugitive fashion through considerable standardization, routine work, and industrial research. The proportion of research conducted at these institutions that is inspired by industrial needs is much larger than is commonly supposed, but this is no matter for regret, since many industrial problems can only be solved after additions have been made to knowledge which contribute to the sum total of pure science. On the other hand, industrial laboratories are not necessarily restricted to applied research. They may undertake pure research with just as little certainty of ultimate utility as other laboratories, and always a certain amount of pure science work will be inevitable before sufficient data is available for many applications of knowledge. Some industrial laboratories, in fact, have produced work in pure science which confers on them a reputation rivalling that of many academic institutions. It is, therefore, a great error to identify one branch of research with a particular type of laboratory.

Particularly unfortunate is the superior attitude displayed by some pure science workers towards those engaged in its practical application, an attitude which is responsible for much of the lack of co-operation between science and industry. Science confers many boons on humanity, but its potentialities are lost if the application is not made. To-day the application of a discovery may necessitate considerable expenditure, together with many years of effort on the part of highly trained technologists, who now form a new profession. The sole difference between the two branches is one of aim, academic research working for the increase of human knowledge, applied research for the satisfaction of some human need. The motive of the latter, that of service to the community, may be no less honourable and disinterested, and is probably more human than that of the pure research worker. The research worker in industry frequently chooses not to undertake pure research exclusively, for the reason that the more austere ideal of academic research does not appeal to his sense of need for practical results, and it is doubtful whether many academic workers would continue if they were convinced that their labour would never be of use other than as an addition to abstract knowledge or as an educational stimulus to themselves. Many, indeed, derive their chief interest in the thought of possible application, even in their most remote investigations. To attribute a mercenary view is unjust to a large and increasing class of workers in industry and elsewhere which normal specialization of function has brought about. In the process of application, the work of those engaged in pure and applied research forms, as it were, two links in the chain, in which the manufacturer, technologist, and manual worker may perhaps join, before a discovery materializes into a convenience to the ordinary citizen.

It will be shown later that workers for both branches require similar types of academic training, although other personal qualifications may, in the case of industrial work, determine the choice between two men of similar capacity and experience. The equipment and buildings required are essentially similar, except in scale. Men now move freely from one type of laboratory to the other, without regard to the nature of the work to be performed, and any other procedure would harm both pure and applied science.

For the purpose of this book, therefore, the terms differentiating the one type of research from the other will be freely used, but without any implication as to the laboratory in which they are performed. Industrial research will imply research conducted in industry, including both academic and applied research, academic research not necessarily meaning the research work of universities, nor applied research that of industrial laboratories.

RELATION OF ACADEMIC TO APPLIED RESEARCH

The main difference between academic and applied research in practice lies in the fact that the pure science worker does not know precisely what end he will achieve, since he has to explore tentatively in any direction he can, while the applied science worker does know definitely what he is required to accomplish. The opinion has been expressed[1] that industrial research is more exacting and difficult than academic research, and more varied and interesting. The pioneer worker explores the unknown field, while the applied worker surveys the territory in detail and makes it habitable. Clearly, without pure science research, nothing can be applied. Academic research is fundamental, applied research is consequential. The one is the foundation, the other the superstructure. The one reveals the forces of Nature, the other controls them. The result of pure science work is the raw material of those engaged in application.

The worker in the field of industrial research requires a deep and intimate knowledge of the technology of the materials and processes of the industry concerned, of its needs, of the limiting factors which govern and determine the weight, strength, or quality of its products. He can thus foresee applications of knowledge of which the originator is ignorant. Any one scientific discovery may be applied in innumerable industries, the character of the application being different in each. The research worker in

[1] *See* remarks by Dr. W. H. Eccles and Prof. F. Bacon in the discussion on "Planning a Works Research Organization," *Journal, I.E.E.*, 57,181 and 57,183, and Swinburne, "Technical Research," *Electrician* (1916), 77, 836.

industry is, therefore, essential to the adequate application of contemporary advances in science.

"All science is one. Pure science is often immensely practical, applied science is often very pure science, and between the two there is no dividing line. They are like two members of a long and intergrading series, very distinct in their isolated and extreme expression, but completely connected."[1]

RESEARCH AND INVENTION

A discussion of the relationship between scientific research and invention may be conveniently postponed until consideration arises of the type of worker required for research. Many people, however, confuse applied research and invention. There is a broad distinction which may be noted, although the difficulty of differentiating between them arises from the fact that many discoverers are to some extent successful inventors, and nearly all research workers at some time or other are compelled to devise and develop apparatus and appliances which are virtually inventions. The emphasis in research is on training, and in invention on experience.

In research the means govern, or tend to govern, the end; in invention the end governs the means. Pure invention is empirical, but the field of science is so little charted that purely empirical efforts may and often do produce astonishing results. It has been said, for example, that the telephone could not have been invented by an electrical engineer, so distinct from ordinary electrical practice is the principle it embodies. Nevertheless the optophone was invented by a physicist, and physicists have been responsible for all the remarkable developments in wireless telegraphy and telephony since Edison made that original and purely empirical experiment now known as the Edison effect. There is, therefore, much to be said for the mere observation and recording of superficially

[1] J. M. Coulter, *Science*, 18th April, 1919, 49, 365.

inexplicable phenomena of this character, as any one, made by a man who is not under the tyranny of preconceived or established theories, may be the starting point of a mass of scientific work.

Research, moreover, is a vocation, in which a worker may be continuously engaged, pursued in the light of fixed scientific principles. It results in new knowledge, which may be applied in an invention. On the other hand, few people invent continuously for the purpose of making a living. Invention, which results in a practical working device or contrivance is largely a matter of circumstance and environment, as no one is likely to formulate a device unless compelled to recognize a need. It is generally of two kinds. An enormous amount of invention, ranging from insignificant improvements to revolutionary devices, is made in the ordinary way of professional services by industrial technologists, and simply records the progress of the art in which they are interested. Such workers are frequently highly technically trained, and if they do not formally conduct industrial research it is because their major interests lie in other directions. Another type of invention is made by men who have what is termed the "inventive type of mind," and who are able to visualize mechanical motions to an exceptional degree. Such men are not interested primarily in research. The end is to them all-important. They would, for instance, during work on an invention, ignore phenomena not relating to the main issue that would at once rouse the curiosity of a research worker. A characteristic of research work, on the other hand, is the manner in which important side issues are noted for future investigation. Inventors of the latter type often have very slight technical education, and it is possible that, being less subject to conventional ideas, they are able to exercise a freshness of view which results in fertile suggestions. Many industries, such as textile manufacture and printing, daily use remarkable inventions, though they have been comparatively little influenced by scientific research. Invention is closely related to empirical work of a " cut and dry " character, although it is frequently less systematic. But what it lacks in system is often compensated for by the pertinacity and doggedness with which an inventor pursues his idea. In much invention the end is achieved with but a dim understanding of the principles involved, the consequent uncertainty being minimized by the number of trials. In this way invention often antedates scientific research and thus provides applications the principles of which are not fully understood. Some men, such as Lord Kelvin, combine in an extraordinary degree high scientific genius with great inventive skill, but such cases are rare.

There is a tendency to consider that research results in the establishment of new industries, and that advance in existing industries is mainly due to invention, but this is not the case. Research in existing industries will result in improvements which will fill in the large gaps left by individual invention or inspiration. Some of the most ancient industries, spinning and weaving, agriculture, tanning, have hitherto been little influenced by scientific research.

Invention is therefore not necessarily applied research, though it may be. Research may be conducted without resulting in an invention and yet be well worth while to industry through the light it throws upon other phenomena. The places of the inventor and research worker—pure or applied—in industry are complementary, but not interchangeable. Much invention is not patented and much patented matter is the result of research. Research will be fruitful, automatically and inevitably. Without research invention tends to be localized.

RESEARCH AND KNOWLEDGE

A scientific research worker will, in general, be acquainted with the existing knowledge in his particular subject, but this is not necessarily the case. Conversely, a man so acquainted will not be necessarily a research worker. Some research workers have wide knowledge. They make frequent and great use of the library and are intimately in touch with all phases of the work in which they are interested. Others are not experts, and never trouble to determine other workers' achievements, except incidentally. They work from first principles. It has been said that Hertz, for instance, was not acquainted with the electric transformer.

The difference between the research worker and the expert is analogous to the difference between the creative artist and the critic of literature, art, or music. The former in each case may have almost universal knowledge of the particular fields involved, but cannot be adjudged deficient if this is lacking, while in the latter it is essential. Occasionally the creative artist is a critic, but not often. More frequently he is the worst possible judge of his own or his contemporaries' work.

ILLUSTRATIONS OF RESEARCH

It is evident from the above that one and the same piece of work may be under some circumstances pure research, and under others applied research. The same investigator may, during the progress of an investigation, be swayed first by the one motive and then by the other. An industrial research engineer, designing a light alloy of specified properties, may experiment with aluminium containing varied proportions of added metals, discarding unsuitable alloys after preliminary tests and making the tests increasingly exhaustive as he approaches the one most nearly satisfying his requirement. A pure research worker, totally ignorant of applications of aluminium may investigate the equilibria of a whole group of binary or tertiary alloys containing aluminium and tabulate their properties merely to add to existing knowledge. An industrial research organization or a research institution may decide to conduct a similar investigation for the deliberate purpose of selecting all alloys which show promise for industrial purposes, covering the whole field thoroughly. The work conducted on behalf of the Alloys Research Committee of the Institution of Mechanical Engineers was done by pure science workers for industrial purposes solely, while the gain to science was considerable.

The work of the Burroughs Wellcome research laboratories contains records of many freely published researches by highly qualified men, financed by a company, as does the work of the research laboratory of the General Electric Co., U.S.A , which has produced the drawn-wire lamp, the half-watt lamp, the Coolidge X-ray tube, and many other products of considerable industrial importance.

The theoretical investigations of Clerk-Maxwell laid the foundations of a development, which through the efforts of Hertz, Lodge, and other pioneers, together with the work of Marconi in developing the industrial side, has led to wireless telegraphy and telephony.

Kelvin and Joule laid the foundation of the method used for liquefying air which Hampson and, finally, Linde utilized in a liquid air machine. The work of Claude led to the enormous industrial developments in the use of oxygen in welding and cutting, and in nitrogen fixation. On the problem of nitrogen fixation a large number of men have worked at all points, and several methods are now commercially available.

Taylor, in America, studied the art of cutting metals for a period of over twenty years, and was largely instrumental in discovering high-speed steel, a piece of industrial research of fundamental and far-reaching importance.

Röntgen, who discovered the properties of X-rays, rendered possible, first to the medical profession and now to metallurgists, a method of diagnosis of great value.

Recent work on the physiology and psychology of fatigue has already had considerable influence in industry.

These instances could be multiplied indefinitely. The course is always the same. The pure science development takes place frequently without any appreciation on the part of the discoverer of its possibilities, and the application follows. No part of the development is necessarily confined to one particular type of institution.

CHAPTER III

AGENCIES FOR RESEARCH

AGENCIES and institutions for the prosecution of research may be broadly classified according to the sources from which their financial support is derived. This classification, as might be expected, affords little indication of the work carried on, but, on the other hand, it shows the lines on which provision for research has developed and the reasons which gave rise to it, since few research institutions and laboratories other than those of a private character have been founded merely for the purpose of conducting research. They have been developed in the main to meet some requirement involving research, the survey of economic resources, the establishment of national standards, the development of agriculture, industry, or medicine, either generally or in specific directions. This peculiarly applies in Great Britain, where the strong practical sense of the people does not favour the conception of the endowment of purely abstract study without any justification other than its contributions to knowledge. Even in the universities research is subsidiary to the educational function. A distinguished exception, however, is the Royal Institution, with the scientific work of which is associated the names of Davy, Faraday, Rayleigh, Huxley, Tyndall, and Dewar. The research institutions developed in response to some definite need possess, to some extent, characteristics and spheres of activity peculiar to themselves, and comprise the following principal types—

National institutions, supported partly or wholly by the State.

Privately endowed institutions, founded by donors, but frequently becoming national or quasi-national in character.

University laboratories, attached to universities and technical colleges of university rank.

Co-operative laboratories, maintained by mutual co-operation of interested parties.

Industrial laboratories, attached to manufacturing concerns.

Consulting laboratories, provided by consultants for general use.

Laboratories for limited liability research, for the development and exploitation of new products.

Industrial fellowship laboratories.

The features of each type may be briefly considered.

NATIONAL AND QUASI-NATIONAL INSTITUTIONS

There are many matters of fundamental importance to the whole community that involve scientific research necessitating considerable equipment and the services of a large number of specialists working over long periods. As examples, there may be quoted the conservation of fuel and other natural resources, the smoke problem, the determination, conservation and extension of national and international standards of measurement—fundamental to all scientific work,—the transport problem, public health, the development of agricultural industries and fisheries. These problems are so vast, and their influence on society is so pervasive, that they can be effectively dealt with only on a national scale, and hence the tendency on the part of all countries to establish national institutions in which they may be studied. With such institutions may be grouped those laboratories endowed by private benefactions, by one or more persons, which, by virtue of the manner in which they are controlled or of the assistance and recognition they receive from public bodies, have become national in character.

Numerous illustrations of national and quasi-national institutions may be cited—in Great Britain, the National Physical Laboratory, the Royal Institution, the Rothamsted Experimental Station, the Laboratory of the Fuel Research Board; in the United States, the Bureau of Standards, Bureau of Mines, Department of Agriculture, Smithsonian Institution, Carnegie Institution, Rockefeller Institute; in Germany, the Physikalische-Technische Reichsanstalt; in Japan, the newly established National Laboratory at Tokio.[1]

Scope and Function

The precise scope of national research institutions differs considerably in different countries, and, indeed, may vary considerably in the history of any one institution, according to the view of its functions taken by its director or governing body. The work of all, however, answers to the broad test of utility to the country as a whole. Sectional interests are not served, but work which finds use by a particular industry only is undertaken if it has a national importance or refers to or influences other important industries. The use of public funds is, therefore, the factor determining the research carried out at a national institution. Some institutions undertake private routine testing for payment, but tend to abandon this as they become well established financially.

The advantage of national institutions and private foundations lies in the broad and fundamental character of the research carried out. On the whole, however, there is comparatively slight contact with industry, and consequently their staffs, mainly drawn direct from universities, lack experience in undertaking technical problems on a large scale. Both pure and applied research are freely undertaken, and the results are usually promptly published, but further work is required as a rule before the application can be made effective to specific industries.

[1] Further reference to these institutions is made in Chap. X.

Administration

National institutions cover so wide a field that they sometimes grow to a considerable size, employing hundreds of workers. The organization tends to resemble that of the Civil Service, having a large number of grades, each grade having definite responsibilities and range of salary, although the director is generally chosen for his personal experience in research work, and is, presumably, not sympathetically disposed towards a rigid type of organization.

It is often a characteristic of privately endowed institutions that a competent research director, selected for his eminence in research, is burdened with purely administrative duties.

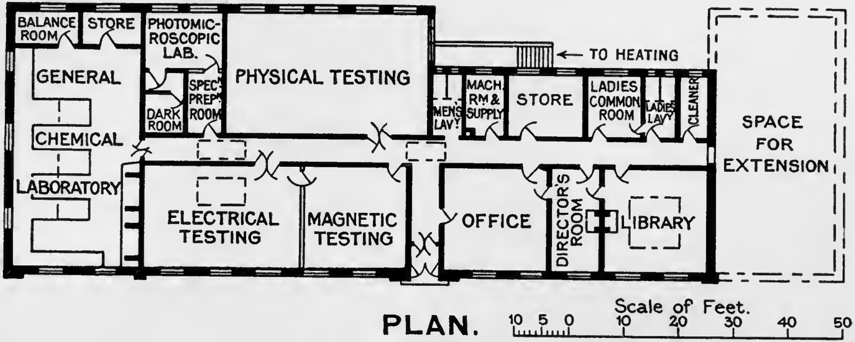
Buildings and Equipment

Since the major part of the work is academic, the buildings are generally of the multi-storey type, but the use of large scale apparatus sometimes necessitates buildings of one floor only. The equipment is frequently unique in some respects, particularly in apparatus for the accurate determination of standards of measurement and for precision work.

UNIVERSITY LABORATORIES

Since their foundation, it has been the peculiar function and privilege of the universities to preserve, transmit, and increase the existing stock of human knowledge. Advanced teaching has always flourished best in an atmosphere of the development of science, in spite of the fact that men of great research genius are seldom competent teachers. If the latter frequently fail, however, to understand the condition of relative ignorance of their students and to sympathize with their difficulties, they inspire their disciples with their own keen enthusiasm, often with most splendid results.

FRONT ELEVATION.



PLAN.

The primary function of the universities is to train men, and it has been found by experience that nothing develops in an advanced student such a sense of responsibility, independence, and power, as the endeavour to accomplish a piece of research and reach a successful conclusion as a result of careful experimental work and logical deduction of cause from effect. In this way the student frees himself from the scholastic domination of the professoriate and begins to think for himself. The research function of the university, therefore, arises from and is subject to its educational function. The criterion of success of the university is not its output of scientific research, but its production of men competent to enter the professions and business life, research men among them. Its primary object is not research, but the men without whom research would be impossible. Research cannot be neglected, but it cannot safely be emphasized at the expense of the training of students.

Two features characterize university research. It is essentially individual work, and taken altogether it may be universal in scope. The professor is subject to no restrictions as to what work he may undertake, except those determined by the funds and equipment at his disposal. The association of many workers in one institution, each working in his own field, provides exceptional opportunities for the interchange of experience. Mathematical research, for instance, is situated with peculiar advantage in a university. Those engaged in the experimental sciences can freely consult the mathematical staff, to the great benefit of both, for the aloofness of the latter from practical conditions becomes less pronounced. It follows from these considerations that much university research is fugitive and fragmentary. There is no formal administration in the ordinary sense—little or no careful planning, sub-division of labour, or co-operative working on any but the most limited scale. Occasionally, a great research worker, holding a professorial chair, recognizes the progress which is possible by organization, and, having the power to attract a large number of students, arranges their work so that it systematically covers a particular field, founding thereby a school of research; but, in general, the limited time spent at research by the average graduate, the short time many lecturers and professors spend at one institution, and their lecturing duties—particularly onerous since the war —all tend to prevent continuity.

Academic versus Applied Research at the Universities

Considerable discussion has recently taken place regarding the particular type of research which universities should undertake, and the present demand for the application of science to industry presents a great temptation to them to conduct research which is conceived to be of value to manufacture.

The university tradition is undoubtedly on the side of academic research, and since this forms the principal source of advancement in pure science, it is particularly undesirable that the amount of pioneer work should be diminished in favour of applied research. University staffs, as a rule, are more fitted for the former, as they have seldom had sufficient industrial experience to be intimately acquainted with industrial needs, and without this familiarity they would probably be led to engage in psuedo-research of little value. Further, the limited funds available prevent the erection of apparatus on a large scale, or of ample expenditure on one investigation. The discontinuous and individual character of university research is not suited for applied research, in which co-operative working is an essential feature. Finally, a prominent motive in much university research is the very proper desire for the credit which is gained as a consequence of publication, and in applied research this is not always possible, not at any rate until some considerable time after the conclusion of the work.

All these considerations suggest that the type of work which the universities should undertake, and which it is in the highest degree desirable should be undertaken, is fundamental pioneer research. There is nothing to prevent universities undertaking applied research ; it has been done in some cases and may be done in future with conspicuous success, but tradition, the experience and predilections of the staff, the desirability of free publication, the limited funds and equipment available, and, except under rare conditions, the lack of continuity and the individual character of university research, all combine to form an overwhelming and unanswerable argument in favour of research which does not primarily aim at utility, whether in industry or any other branch of human activity. The work done is then universal in character, and is better suited to the training of research men. Conditions, in short, are actively unfavourable for the conduct of applied research, and actively favourable for the conduct of pioneer research.

The necessary qualifications of this general view require attention. Some universities and other institutions of university rank are, through their methods of government or the experience of their staffs, so closely associated with the industries of the area in which they are situated that they are in an unusual position to undertake applied research. There is a constant interchange of men between the industry and the staffs of these institutions, and the majority of the students trained are immediately absorbed in the industries. Such institutions are able by this association to carry out a considerable amount of work on the borderland between pure and applied research, where the vague and shadowy line of demarcation makes definition difficult.

A tendency is steadily growing for students to take up research work in industry immediately after graduation, while still associated with the university, and to present the work done—not necessarily applied research—as a thesis for a higher degree.

Irrespective of the particular type of research most appropriately carried out by university and industrial laboratories, great benefit will result from closer connection between them through interchange of lectures, visits, and even through the exchange of apparatus and equipment. In some cases, university staffs are allowed to supplement frequently inadequate salaries by private consulting, which encourages close contact with industry, though if this becomes excessive, an undesirable condition arises in which the choice of research becomes unconsciously limited.

If fellowship laboratories at, or in connection with, universities, in which researches are subsidized by manufacturers and conducted under university conditions by graduate students, are founded in Great Britain similar to those in America, care will be required to ensure that touch with academic research is maintained. In the laboratories of the Metropolitan-Vickers Electrical Co., Ltd., graduate students pursue investigations in industrial problems, in conjunction with the universities, for the master's degree.

CO-OPERATIVE AND INDUSTRIAL LABORATORIES

Research in industry is conducted largely by manufacturing corporations either on a co-operative basis, with or without State assistance, or in laboratories built on works premises, to serve the interests of a particular firm or group of firms. Their organization will subsequently be considered fully in Chapters V—VII.

CONSULTING LABORATORIES

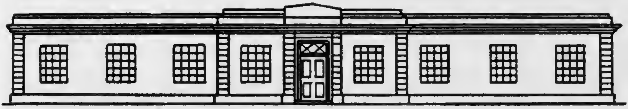
There are many industrial concerns which, either on account of size, of their highly specialized character, or nature of output or of organization, do not find it possible to maintain a research organization or even a member of the staff devoting his whole time to research work. Even large firms with their own research organizations occasionally have problems which cannot conveniently be dealt with by their existing staff. In such cases, as it is often naturally felt desirable to maintain secrecy, an impossible—or, at any rate, an undesirable—condition in a university, independent specialists are consulted, some of whom do not undertake to advise more than one client in one particular problem. Financiers desiring to set up manufacturing concerns or to exploit some development, frequently ask a consultant to investigate the validity of proposals suggested to them. Sometimes consultants are retained to undertake all the work of a manufacturing concern.

It is therefore not surprising that many consultants maintain laboratories and small staffs in which investigations may be made incidental to the work required by clients. Generally, this work is of a subsidiary character but in recent years a more ambitious type of laboratory has been developed in which the investigation is the main feature, and the staffs and equipment assume a much greater importance. An excellent instance of this kind is the laboratory of A. D. Little, Inc., Boston, U.S.A., which is furnished with the most modern resources in equipment, utilized by high-grade workers under competent direction, and which undertakes investigations for any client.

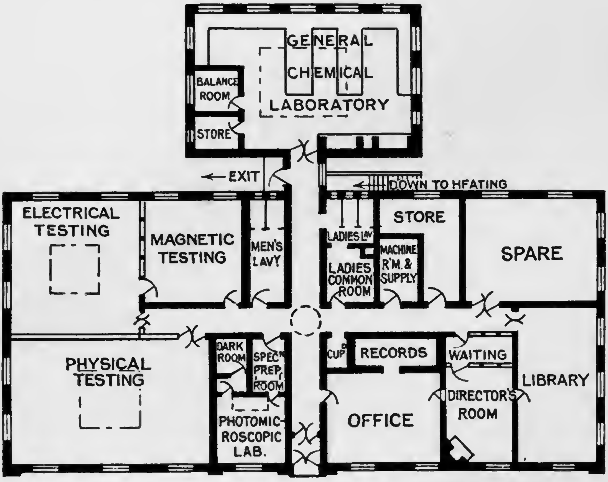
The field of work of such laboratories is naturally very wide, but, except for this, they closely resemble in administration and organization the research laboratories attached to large industrial concerns.

LABORATORIES FOR LIMITED LIABILITY RESEARCH

A type of research laboratory, now only in the preliminary stages of development, is that in which research in any



FRONT ELEVATION.



PLAN. Scale of Feet 10 5 0 10 20 30

Fig. 2. Single Storey Research Building
6,000 sq. ft. Gross Floor Area
(*See page* 116)

matter likely to yield commercial results is investigated as a speculative investment. Such laboratories maintain close touch with market conditions in order that advantage may be taken of local shortages of raw materials which may be synthesized, or for which more suitable or cheaper alternatives or substitutes may be found. The establishment of new industrial processes is also undertaken, together with the manufacture and sale of new products. Each result, when worked out completely, may be handed over to a separate company—floated for the purpose—for manufacture, the promotors either maintaining an interest in it or selling out to others.

The scope of such laboratories depends very much upon those responsible for their direction. It may be as wide as, or wider than, the consulting laboratory referred to above, or may be quite narrow. The administration, however, would be in any case very similar.

Such laboratories are chiefly valuable to those manufacturers who may be interested in founding them. To others, the value is only indirect, through the products rendered available on the market.

There is, of course, nothing to prevent a group of manufacturers, allied or in different industries, subsidizing a research laboratory as a separate company, the cost of the work done being allocated on a basis of time taken, in order to simplify the administration. Such laboratories have, in fact, been established for the routine testing incidental to the control of materials and processes of manufacture.

INDUSTRIAL FELLOWSHIP LABORATORIES

The industrial fellowship laboratory, closely allied to both the university laboratory on the one hand, and the industrial laboratory on the other, and in many respects forming a bridge between them, deserves separate consideration. This type of institution was developed in the

United States through the efforts of the late Prof. R. K. Duncan, first at the University of Kansas, later at the University of Pittsburgh, in connection with which was founded the Mellon Institute of Industrial Research and School of Specific Industries, built and endowed by the brothers Mellon.

The scheme elaborated by Duncan arose partly from the lack of contact between the university and industrial life, partly from the cost of establishing a research laboratory for a small industry. The Institute is specially arranged for research involved in the solution of industrial problems, and manufacturers requiring its services endow a fellowship for one or more years to cover the salary of a research worker and expenses for materials, the director finding a suitable university graduate for the work, and placing the resources of the Institute at his disposal. Publication of results is deferred for a period of years. Obviously, research of this character is partially subsidized, and the success of the Institute is striking testimony to the character and range of problems to be met in industry demanding solution.

The growth of research of this type would appear to depend largely on the subsidy provided by laboratory facilities and supplies, together with expert supervision. If no endowment is possible, manufacturers will probably prefer consultants who will undertake to maintain the confidential character of the work or to erect their own laboratories.

Since it is unlikely that private endowment will furnish an appropriate number of industrial fellowship laboratories, the only source from which endowment could reasonably be expected in Great Britain is the Government, which is already committed to subsidizing Research Associations of manufacturers and which would not in any case encourage researches for private individuals at the expense of other subscribers. Consequently, the prospects before this form of laboratory in this country are meagre, although there is probably ample room for one or more of them in assisting smaller industries.

Fellowships held by university graduates in industrial laboratories are referred to later. A form of industrial fellowship research which has arisen in this country from war developments, and which has been due largely to the shortage of research workers and laboratories, is the establishment at a university laboratory of a group or colony of research workers who are members of the staff of an industrial concern, or who are retained by it, in which research work is pursued under the guidance of one member of the group as director. Whether this will continue permanently after the deficiencies referred to have been made good remains to be seen.

The disadvantage of research work of the type pursued at the Mellon Institute—several methods of overcoming which are now being tried—is its dissociation from pure science work, the preoccupation with the industrial aspect being strongly emphasized.

CHAPTER IV

INFLUENCE OF CHARACTER AND CONDITIONS OF INDUSTRY UPON RESEARCH

It will be evident that research, in the broad manner in which the term has been interpreted, really underlies all industrial progress from earliest times. The modern interpretation of the word "research," however, implies systematic and deliberate effort, through a specific organization, towards improvement, rather than the enquiries which are pursued promiscuously, tentatively, subject to competitive and many other conditions, and which no longer suffice to ensure the successful development of industry.

FACTORS INFLUENCING RESEARCH IN INDUSTRY

The character of the research required for any industry, the policy to be adopted, and the amount of work to be done, will depend on a number of circumstances which differ in different industries, and even in the same industry at different stages of growth. These circumstances may be briefly examined.

Rapidity of Development

The research carried out in an industry which is passing through a particularly rapid state of development is necessarily much greater, relative to the size and output of the industry, than at later stages, since entirely new problems crowd upon each other. As experience is gained changes are less and less radical, and improvement becomes more a matter of detail and refinement, an investigation, as it were, of side paths rather than the pioneering involved in laying a new road. Many industries passed through this stage in an incredibly short period during the war, notably certain key industries that had become monopolized by enemy countries.

Position of Foreign Manufacture

In industries in which a competitive nation has secured an advanced position, particular attention to research is necessary to overcome the deficiency in manufacturing experience and development. The illustrations provided by Germany in fine chemicals, synthetic drugs and dyes, and optical glass, are well-known illustrations. The same is true of agriculture and electrical engineering. A measure of the neglect from the point of view of the State is indicated by the financial assistance necessary to the optical glass, dye, and other industries for the research required for their establishment on a competitive basis. The extraordinary richness of the British Empire in natural resources leaves no reason for any key material falling entirely into foreign hands, and co-operation with the Dominions in research on the exploitation of these resources is urgently required.

Character of Production

It is well known that the nature of industrial production influences the work of a research organization associated with it. Large scale manufacture and mass production introduce problems not met with in outputs smaller in number and size of units produced. The use of low grades of labour and the automatic character of operations call for scientific supervision and for larger margins in manufacture. This cheapening of production and its more intensive character are rendered necessary on account of increased wages and material costs, which would otherwise force selling prices to a point at which there would be no market.

Maintenance of Monopoly

Some firms endeavour, by delivery of high-class goods at low prices, by courteous and ready service, and by proper publicity, to create such a general demand for their goods as to build up a virtual monopoly. In other cases the monopoly is secured by patents. Naturally such monopolies are generally more lucrative than most competitive trading, and are, therefore, much more subject to competition. The lead can only be maintained by research directed to this end. From this point of view research is an insurance in which a suitable proportion of immediate returns is spent to secure the continuance of the returns in future. Many instances exist of firms having, by successful organization or by patents—frequently founded in the first place on research work—established a strong position which has subsequently been made almost unassailable by judicious expenditure on the means of maintaining their prestige.

If circumstances are such that there is no likelihood of competition on equal terms, this does not absolve an undertaking from conducting research, if only for ethical reasons. This is particularly the case with companies and municipal or government departments operating monopolies such as the provision of gas, water, or electricity services, railways, canals, telegraphs, and telephones. Owing to the natural tendency, in the absence of healthy and stimulating competition, of such public utilities to become complacent and self-satisfied, they are under a special obligation to provide the public with a continuously improving and cheapened service. Only thus can the criticism they easily and frequently arouse be silenced. The example of the Detroit Edison Co. in providing new ways for the utilization of electric current in houses, garages, and elsewhere for the convenience of users, is an admirable case in point. The intrinsic value of research in such cases is enhanced by its publicity value.

Nature of Industry

Many industries of ancient origin, such as metal casting, spinning, tanning, and agriculture, require to be re-studied from their foundations. The principal industries which stand in great and immediate need of research are agriculture, mining, transport, and manufacture. Agriculture is of vital importance to the country, and research is particularly called for in improving the supply of home-grown food, and in correcting the distribution and improving the stamina of the population. It is an occupation so widely scattered that research is best provided for nationally, as in the United States through the Department of Agriculture, and in the United Kingdom through the Board of Agriculture, although much work would still be done through other channels. The problem of education is of particular importance in connection with agricultural research.

The transport industries offer unequalled opportunities for investigations. Shortage of rolling-stock, increased operating costs, and general congestion are such that any improved methods of handling either *en route* or at termini would be an incalculable boon to the whole community. From another point of view, an example of the work possible to an enterprising railway company is afforded by the Canadian Pacific Railway, which authorized an investigation into the natural resources of the territories which it served.

For the extractive industries, mining and quarrying of all kinds, there are various research laboratories in the United Kingdom. Thus, the Rhonddha Laboratories are connected with the economical utilization of coal, and the Laboratories of the Fuel Research Board will deal with the matter on a national scale. In addition to inquiry into conservation, use of colliery waste, recovery of by-products, much work has to be done in investigating improved methods of winning coal, the use of electricity

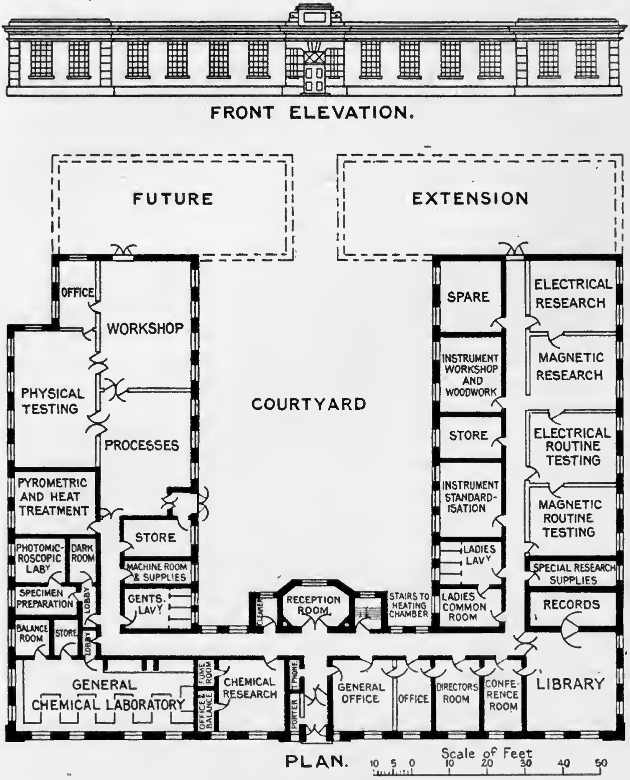


Fig. 3. Single Storey Research Building
13,400 sq. ft. Gross Floor Area
(*See page* 116)

in mines, occupational diseases, and the relation of hours of work to output.

The manufacturing industries form several main groups. Engineering, both heavy and light, the most important of the group, and equal to about one-fourth of the whole, includes the manufacture of iron, steel, and structural materials, machinery of all kinds, rolling stock, ships, electrical apparatus, and instruments. The materials and processes employed are more varied and the type of works organization more complex than in any other industry, and the need for research is therefore most keenly felt.

The building and associated industries employ a limited range of primitive materials, but rapid developments are taking place in the use of reinforced concrete. There is also great scope for organization and planning of operations to expedite work.

The chemical and allied industries cover a wide range, and for the present purpose may be held to include the manufacture of pottery, glass, cement, oils, soap, explosives, alkali, leather, paper, and food. The need for research is as pronounced as in the engineering group, but the problem of any particular works is generally simpler.

The textile group includes the preparation and manufacture into fabrics of all textile fibres, silk, wool, cotton, hemp, flax, jute. The research problem is large and complex, necessitating much work of a botanical, biological, chemical, and physical character.

CLASSIFICATION OF INDUSTRIES

Manufacturing industries are so involved that it is impossible to provide a rigid classification of the operations which are conducted in them. For the present purpose, however, of approximately determining research requirements they may be considered to fall into three principal classes, which may be termed analytical, simple process, and synthetic respectively.

Analytical Manufacture

This type predominantly produces a single material in bulk, from naturally occurring raw materials, a process involving several operations, and sells sometimes in the open and sometimes in a closed market. The chemical and metallurgical industries afford many illustrations. Although production is on a large scale, the idea of mass production in the conventional sense scarcely enters, as only single comparatively simple processes are employed, sometimes carried on continuously. The labour employed is frequently unskilled and of low standard. Increase in output is obtained through additions and extensions to existing plant. The tendency towards increased plant units for this purpose is present, but output is influenced less by the size of the plant than by technical considerations affecting the materials or processes used. The main problem of such a plant is technical rather than human, and the research provision is comparatively easily determined. It centres round the material manufactured, the laboratory being, to use a phrase applied by Dr. Mees, of the "convergent" type. The constitution, structure, physical properties of the material, the process of manufacture, the manner in which it may be cheapened, and new applications, form the basis of the work required. Thus, in a cement works, research may profitably be directed towards chemical composition, the functions of each constituent and their influence on the mixture, the equilibria involved, manufacture of cement, special cements for new purposes, water-proof and oil-proof cements, and so on. The laboratory may comprise chemical laboratory, mechanical testing and physical laboratory, and microscope room.

Simple Manufacturing Process

This type generally employs and is characterized by one main process in a series of operations, the material worked at any one factory varying according to market requirements. Spinning, weaving, bleaching, wire-drawing, casting, rolling, form examples. In each case the process is employed to work materials to a new form. The one-process factory represents a comparatively high degree of specialization. The labour employed is frequently skilled, the success of the process often depending upon the craft-skill displayed. Consequently, the human factor assumes more importance than in the analytical type of manufacture, in the sense that the workers have more control over the quality of the product, and research provision required is more complex, owing to the different materials employed.

In a rolling-mill, for instance, the research organization would comprise chemical laboratory, mechanical testing laboratory, and experimental heat treatment laboratory, and would be concerned with the manufacturing conditions of pressure and temperature which would give best results for each material handled, and the influence of rolling and rate of reduction on the characteristics of the materials.

Synthetic Manufacture

In this type the purified and worked-up raw materials resulting from the two previous types of manufacture are modified in various ways, combined and assembled to form products such as are manufactured in the engineering industries. The research problem is more complex than in either of the previous cases, owing to the variety of materials used and the manifold processes through which they are passed, and the necessity for knowledge of the physical laws governing the performance of machines. The problem of the human factor again is also more pronounced than in the two above-mentioned classes, as many grades of workers are employed on a wide range of occupations. Problems of organization and management are most acute.

The research organization requires laboratories for the study of the constitution, structure, behaviour under various conditions and treatments, and physical properties of the various materials employed, and the processes through which these are applied, for the study of the proper disposition of material in designs, and for investigations into industrial fatigue, selection for employment, and other questions of a physiological and psychological character.

Clearly, consideration of the research requirements of a complex industry such as the engineering industry will include in some measure those of other industries and will form the most convenient general illustration.

CHAPTER V

CO-OPERATIVE INDUSTRIAL RESEARCH

THE provision of research for industry may be made by manufacturing concerns either individually or co-operatively, and the respective merits of both methods may be compared.

Research may be considered as co-operative from two points of view, the one relating to the methods by which it is financed, the other to the manner in which it is conducted. Those who are interested in the prosecution of a particular investigation, for example, a body of trustees, a group of manufacturers, the community acting through a Government department, or the members of a profession acting through their professional institution, may consider that the objects of an enquiry are of sufficiently general value to themselves or to the public to justify co-operative action, the necessary funds being provided and some laboratory charged with the task. This type of research, provided for by the action of a representative body, existing or formed for the purpose, has by common consent been considered *co-operative* research. It will be evident that all research endowed or aided by public bodies or the Government falls into this category, although those who ultimately provide the funds may not have direct control over the expenditure involved.

From another point of view, the term "co-operative research" may be considered to imply that research work which, however provided for, is conducted in common by a number of research workers. In this sense all research is co-operative, for all who make scientific advances cannot fail to be largely influenced by and indebted to those with whom they discuss their ideas. The university professor inspires and instructs his students, and receives benefit in turn from their association with him. The professional research worker talks freely with his colleagues. Indeed, to all men, except possibly to the genius, this interchange of knowledge and experience with their contemporaries or their predecessors is of the greatest value, and has an important bearing, which will be referred to later in connection with the centralization of research and the distribution of scientific intelligence.

The question arises as to whether any particular research is best done co-operatively or individually. With exceptional workers engaged in the more abstruse regions of scientific work, it is decidedly advantageous to have work done individually, even if this involves considerable overlapping, for different men work according to their particular aptitudes and experience. Research work in pure science cannot be systematized. Each worker should be allowed to proceed according to his vision, be liberally provided with apparatus and equipment in a suitably fitted building, and not be required to spend undue time in teaching or administrative work. For men of average type, association in groups leads to advantageous results in the case of applied research or, in the case of that work of pure science involved in the determination of constants and the like where the magnitude and complexity of the task render subdivision desirable. Since each worker will have had different training and experience, each is able to make a contribution to the programme or policy adopted, and several specialists in different fields can co-operate to bring a problem to a rapid conclusion. Such association for the prosecution of applied research has a most important bearing on the type most suitable for selection as research worker, upon such questions as the allocation of credit for work done and published, remuneration, patents, and upon the problems of administration.

In general, research by highly talented men in pure science, whether conducted in the works or in the university, is best carried out by individual workers. Other pure research and all applied research may be most advantageously performed by workers associated in groups for the purpose. In particular, two men on one problem working together will tend towards unbroken continuity and each will react on the other in stimulating ideas, especially if the men are carefully chosen. It is a good plan to arrange a certain amount of work to be done to act as a relief to the research work, and this may even be routine work. The performance of a set task at specified intervals well within a worker's capacity will restore self-esteem, which is apt to dwindle if a long period of non-success or failure of inspiration occurs in performing a major research. The depressing effect of failure has to be recognized and provided for.

Co-operative research proper, financed by groups, may be either academic or applied, and may be done in any laboratory. The most interesting recent developments refer to groups of manufacturers associating for the purpose of providing funds from current income for research which may be serviceable in their particular industry.

Advantages of Co-operative Research

Several reasons account for the rapid development of co-operative research. Research is undoubtedly costly, and considerable capital expenditure is required, which only begins to produce a return after several years' work. The shortcomings which the war rendered apparent in British industries resulted in a demand for research workers greatly in excess of the supply available from the universities, with the consequence that there is a dearth of good research workers. There is always a dearth of men of first-class ability. Compared with America or Germany, there is a much smaller proportion of students of university standard in England. The United States has, in proportion to population, more than twice as many, Germany has nearly three times, and Scotland more than three times as many as England.[1]

The results of co-operative research do not enable one manufacturer to secure any advantage over another if both are subscribers ; but the whole industry is raised to a higher level, and is thereby more favourably placed for meeting foreign competition.

Association in the conduct of research therefore minimizes the cost and renders more generally available the services of existing workers. The creation of groups of research workers tends towards greater effectiveness than when working singly owing to interchange of ideas.

PROVISION FOR CO-OPERATIVE RESEARCH

Co-operative industrial research may be provided for principally in three ways, each of which may cover the association of a few subscribers for a particular purpose, or of a whole trade or industry with quite general aims.

1. Co-operation of those interested in an industry primarily as users of the product (i.e. as consumers).
2. Co-operation of those interested in an industry primarily as manufacturers of the product (i.e. as producers).
3. Co-operation of both producers and consumers in dual associations.

Many delicate questions are involved in determining to which body the responsibility for conducting research of a specified character should belong. As a consequence of an invention or development, proposals for improved materials or products often come from an inventor or supplier who may or may not have been stimulated by

[1] The Report of the Education Committee of the British Science Guild (*Journal*, April, 1919) gives striking comparisons between the numbers of students at universities and technical institutions in Great Britain, Germany, and the United States.

the needs of the user. In general, however, the pressure for modification or improvement arises through the user, who is most closely in touch with practical requirements. He is thereby tempted to undertake work which the producer is in a better position to perform. For instance, in technical industries such as the manufacture of high-class instruments and apparatus for physical work, fresh demands are continually arising for improved steel, non-ferrous alloys, papers, textile fabrics, and the like, forming initially a small, special, and non-remunerative market which suppliers are not easily persuaded to meet. Sooner or later, under ordinary competitive conditions, some producer may receive sufficient stimulus to meet the demand and ultimately the industry grows and becomes a special branch in itself. Immediately after the Armistice this stimulus was lacking owing to the large general demand for all kinds of products, and it was, therefore, particularly noteworthy that manufacturers combined to form Research Associations. The tendency to manufacture exclusively for a general market without reference to specialized needs enables foreign nations to establish an ascendancy in what may prove to be key industries.

Associations of Users

In considering the industries in which an association of users or consumers is likely to be successful, the various types must be kept in mind. Combination for research is not to be expected on the part of non-technical consumers, the general public, unless action is taken on their behalf by some public body or Government department, acting in a representative capacity. Questions of national importance only are likely to be treated in this way, as illustrated by the work of the Fuel Research Board.

Associations of users mainly comprise manufacturers employing the product concerned, and having, consequently, a direct interest in its improvement. In order to prevent research becoming diffused over a wide area, they will preferably be localized and concentrated in a few main industries.

These associations have not yet been developed in Great Britain, but for the purposes of illustration mention may be made of the association of users of metallic alloys recently proposed in the United States. In this particular case of metallic alloys it is suggested that any problem of special interest to a subscriber could be undertaken in the association laboratory by a worker supported by an industrial fellowship. Unfortunately, the proposal has not met with sufficient support to warrant the scheme being pursued.

The principal claim made on behalf of the associated consumers is that of a common interest, greater than that existing between associated producers. For instance, all users of a material or method are keenly interested in lowering its cost or in replacing it by a superior material or method. On analysis, however, the claim of a common interest largely breaks down owing to the numerous applications of the same material by different consumers. While a most important interest is that relating to the lowering of cost, it may be suggested that the efforts of users would be better directed towards consideration of the ways and means of lowering the cost of their product, of which they have some experience, rather than in endeavouring to do the same for suppliers of raw materials of whose processes they may be relatively ignorant. The producers have the experience and knowledge which enable them to undertake the investigations involved with a minimum of unnecessary expenditure, for these frequently require plant and equipment on a scale only found in their works.

The difficulties of such an association are obvious, and lie in the disinclination of producers to change a process when it is prejudicial to their immediate interests. Assuming that a research is satisfactorily completed by users, either they must manufacture for themselves through a secret or protected process—in which case they become producers—or they must invite manufacturers to produce on their behalf, allowing the ordinary operation of competition, which brings more progressive manufacturers into a promising market, to overcome their reluctance.

The magnitude of the problems suggested in the United States for associations of users—alloys and metal cutting—is such as to warrant national action, for scarcely any maker or user in the heavy industries—engineering, metallurgical, shipbuilding railway transport—remains unaffected. Both of these problems have been investigated in the United Kingdom on behalf of technical institutions, the work on alloys at the National Physical Laboratory for the Institution of Mechanical Engineers, and on metal cutting at the Manchester College of Technology for the Manchester Association of Engineers.

The grave limitations under which an association of users has to work must be borne in mind when considering their possibilities, but the structure of industry is so complex and the field of work is so wide that it would be unwise to predict that such associations have no place which they may fill successfully.

Associations of Producers

Until the necessity for providing unlimited supplies of war munitions—often involving the use of novel processes and plant—convinced manufacturers of the value of free discussion and interchange of opinion with competitors, it was the common practice to take every means of preventing leakage of details concerning manufacturing processes. To-day this situation is considerably modified. In many industries it is recognized that a non-existent demand can be created by publicity, and a small demand increased by organizing in such a way as to permit a lowering of prices due to standardization and production in bulk. Manufacturers during the last few years have thus become accustomed to acting in concert. In any case, it is evident that few industries could remain secret under scientific analysis, manufacturing supremacy being achieved by developing a sound organization and a goodwill. Employers have learned by experience that interchange of information with their competitors results in an ultimate gain.

The industrial success of Germany in penetrating new markets, and particularly the financial results from industries founded by and nourished in an atmosphere of scientific research, taught British manufacturers the value of collective action. Extensive industrial amalgamations and the formation of trade associations have indicated a widespread tendency in this direction on the financial side. Such amalgamations confer strength and provide resources obtainable in no other way, which are essential to the building up of enterprises the return on which may be deferred for many years. One amalgamation is generally formed from a number of firms in different industries associated only in so far as the finished product of one is the raw material of another, such a sequence as, for instance, a colliery, iron and steel works, rolling stock and locomotive manufacture, shipbuilding yards, engine building, and electrical works. This chain formation of a series of related industries, as opposed to aggregation of interests in one industry, together with the existing fiscal system, safeguards the community against those abuses generally associated with trusts.

In view of the advantages of co-operation in research already outlined, it is not surprising that a movement in this direction should have taken place among producers. Their formation, however, is not without its difficulties. A permanent association, particularly if aided by Government funds, should, to be ideal, comprise all the manufacturers in an industry. Otherwise, public funds are devoted to the promotion of sectional interests. It is, however, obviously impossible to ensure a membership including all firms in an industry, however attractive may be the inducements offered to those outside. Some have an inherent objection to co-operation. Others prefer to rely on the work of their own laboratories, from which they obtain considerable publicity value in addition to facilities for training staffs. Others again consider it difficult to maintain the confidential character of work done in a co-operative laboratory, while some firms may be operating under such keenly competitive conditions as to find it difficult to finance even that form of insurance we call research. Finally, the argument is occasionally advanced that some producers are more interested in maintaining the *status quo* than in making improvements.

The unbiased manufacturer considers the work of a co-operative laboratory not as replacing but as supplementing the work of his own laboratory, the one in investigating problems common to the industry as a whole, the other applying the knowledge gained to the processes in his factory. The co-operative principle is valuable because it is economical, as it prevents overlapping and duplication just where they are most undesirable. Finally, any manufacturer who fails to make improvements is ultimately driven off the market, as modern business is characterized by a continuous decrease of the cost of manufactured products as the business extends.

The simplest illustration of an association of producers is that of the National Canners' Association of America, which organized a research laboratory in 1913. The industry would find it extremely wasteful to have a laboratory at each canning works, as their problems present many similarities. A central laboratory is able to solve problems, with a minimum of time and effort, such as those relating to defective machining and packing, deterioration of canned goods, and so on. The results obtained from this institution are communicated to all packers, whether members of the association or not, on the excellent general principle that defective packing on the part of one canner prejudices the industry as a whole. Many other trade associations have their research work undertaken for them at various laboratories.

British Research Associations

In Great Britain, co-operative research has been developed through the Research Associations, which are primarily associations of producers. In one or two cases it has been possible to include both users and producers in one association.

Their history dates from July, 1915, when the Government appointed a Committee of the Privy Council to advise the Lord President of the Council—a Minister without administrative responsibilities, and in close touch with all parts of the Empire—on the expenditure of a sum of money to be voted annually by Parliament for the encouragement and organization of scientific research. An Order in Council was issued referring all proposals for such expenditure to a committee of scientific experts, members of the Royal Society, called the Advisory Council for Scientific and Industrial Research. This Council is permanent in character although, of course, the personnel changes, and the Department of Scientific and Industrial Research was initiated to administer its decisions and to provide a permanent staff. By this arrangement it may be noted that for the first time scientific men were provided with an opportunity of directing a broad research policy. The responsible Minister and the Privy Council merely form necessary parts of the machinery for accomplishing this under the constitution as it stands, and they accept the recommendations of the Advisory Council. The Council were given three terms of reference in the Order in Council of 28th July, 1915: to institute specific researches, to establish special institutions for research in industrial problems, and to establish and award research studentships and fellowships. As a consequence, a number of urgent researches were aided at once, and steps were taken to encourage research workers and to increase their numbers, to organize industrial research, and to set up Research Boards for the purpose of studying those problems of national importance which cannot be delegated to any other body. These latter include the Fuel Research Board, the Food Investigation Board, the Industrial Fatigue Research Board, together with the executive committee of the National Physical Laboratory, which was taken over as a Research Board in order that the Advisory Council might assume financial responsibility for the Laboratory without interfering with its scientific direction.

Subsequently, on the recommendations of the Advisory Council, a fund of one million sterling was voted by Parliament, the money and other property being held by the Imperial Trust for the Encouragement of Scientific and Industrial Research, a body comprising seven Cabinet Ministers acting by Royal Charter.

With regard to the second term of reference, the Advisory Council found that the most promising advance would be secured if industries themselves undertook the research necessary to their continued existence. It was therefore decided to encourage co-operative action on the part of those who know most about the conditions of an industry, viz., the manufacturers, and this took the form of assisting financially those representative groups of manufacturers, whether already existing or formed for the purpose, undertaking research for the benefit of the industry. Such a group is termed a Research Association, which is a limited liability company working without profit, having a nominal guarantee from members in place of shares. Members subscribe annually to the funds of the Association, usually an amount proportionate to the size of their business, and the Research Department contributes to the funds of the Association, in most cases an amount equivalent to the sum received from the subscribers, the maximum generally being £5,000 per annum, though in certain special cases this has been largely increased.

The members of the Association govern it through a

Council elected from among their number, frequently comprising the members of the Provisional Committee which is formed in the preliminary stages largely through the efforts of the enthusiastic firms. The Association has full control of its income, and has the power to appoint and dismiss its officers. The Research Department may prohibit the sale or communication of results to the Press or to foreigners if considered desirable in the national interest. The results of research are communicated to subscribers.

The Advisory Council recognizes the important educational function of Research Associations. The growth of Research Associations will be found recorded in the Annual Reports of the Research Department. It is estimated that about forty Associations could be formed in British industries of which over one-half have been already established.

The Department of Scientific and Industrial Research has been criticized in some directions, largely by scientific men, on account of the danger of placing the development of such an important and unorganizable matter as scientific research at the mercy of a bureaucracy, since the permanent officers of the Department are Civil Servants, or on account of the impossibility of co-ordinating scientific research. The Research Association scheme has not been subject to criticism beyond the allegation that business men may get too much control over research, although it is the one feature of the whole of this development which has not been widely imitated by the Dominions and some of our Allies.

Research Associations and Existing Research Institutions

The work of the Research Associations will be intermediate in character between that of the university laboratory on the one hand, and the industrial laboratory on the other ; these Associations will undertake pure science work and applied research of a character useful to a whole industry, but requiring further research at the works laboratories before complete application can be made on a commercial scale. It follows that membership of a Research Association is consistent with the maintenance of an industrial laboratory; indeed, many of the keenest believers in the co-operative principle, members frequently of several Research Associations, are among those who have very complete research organizations at their works.

The Council of a Research Association will comprise scientific men by co-option as well as industrialists; the staff will include men of all kinds of academic and industrial experience. Some Associations have already commenced work in temporary laboratories provided on university premises. There is a general tendency—the Woollen Association is an exception—not to interfere with the existing work of private consultants.

The Work of Co-operative Associations

One of the difficult questions which will arise in many Associations will be the choice of work to be undertaken. The Council, which ultimately controls the research programme, forms a series of research committees, of which the director of research is an ex-officio member. The difficulty will lie in deciding where to draw the line beyond which an investigation shall not be carried. If work is made too general, so as to cover the whole industry, there will be a danger of criticism through lack of immediate utility to any member, while if applied too specifically it may benefit some members more than others. A very useful field of activity to most Associations, immediately open to them, is the standardization of the common materials of the industries and the investigation of widely used processes. This will in most cases involve considerable research, for in spite of the obvious community of interest resulting from association in one industry, the field covered in some cases is very wide. Thus, the Non-Ferrous Metals Association includes in its scope the precious metals, in addition to all the base metals and their alloys, the diversity of industrial interest in which is exemplified by the number of trade associations in this field. It is possible that some solution to the difficulty may be found in the endowment by a subscribing member of a fellowship at a Research Association laboratory for the study of a problem peculiar to his works, but this clearly involves partially subsidizing a few at the expense of the many and is not equitable if the space or equipment is required for other purposes. At the same time, where choice of work is difficult some form of basic subscription in addition to extra charges depending on services rendered would decide order of preference by a purely economic reference.

Dual Associations

A dual association may be considered to comprise both consumers and producers. In some respects it forms an ideal combination ; the relative lack of experience of the consumer is balanced by the intimate knowledge of the producer, while the ever-growing requirements of the former can be placed before the latter, who is not so well able to appreciate how his product behaves in practice.

The researches frequently undertaken by the great technical institutions virtually form examples of work conducted by both makers and users, both of whom may be fully represented in the institution. The work of the British Engineering Standards Association testifies to the value of such co-operation.

Unfortunately, the conditions under which dual associations for co-operative industrial research may operate successfully are restricted. In some cases the manufacturers do not feel disposed to place users in a position to know the details of their business. In other cases, users do not feel called upon to contribute to the cost of researches which are the proper burden of the manufacturers, and which will result, presumably, in placing improved products on sale in the open market on equal terms for non-subscribing and subscribing users alike. Furthermore, users are frequently a much more widespread and less homogeneous class than manufacturers and are without any associations centred around any common interest.

In some cases an apparent union has been formed, as in the various textile Research Associations, in which all branches of the industry have combined, but in this connection it has to be borne in mind that the entire textile industry is so highly organized that price fluctuations are outside the control of the ordinary manufacturer, who is in most cases engaged on a very limited range of operations, and is the user of the material provided by the manufacturer immediately before him in the productive chain. In times of prosperity all makers share in it, while in times of depression all feel it equally acutely. In trades where standards of quality are well established, and individual business judgment exercises little influence on price, the user and maker combine without difficulty. Where, however, business judgment begins to enter, as with dealings in woven cloth, combination is more difficult. Merchants are not admitted to the Textile Associations.

Some Associations—the Non-Ferrous Metals Association is an example—invite the membership of users, but while this has been done, the makers remain in the large majority.

CHAPTER VI

THE WORKS RESEARCH ORGANIZATION

AFTER considering the influence of the general conditions which determine the value and extent of the provision required for research in an industry, the manufacturer who contemplates such an organization on his own premises needs to pay particular attention to those factors bearing upon research relating to his work. Since industrial concerns differ so much from each other in magnitude, internal organization, external connections, and manufacturing policy, each one forms a particular case which has to be treated on its merits.

FACTORS INFLUENCING WORKS RESEARCH

The influence of these conditions can only be generally indicated.

Magnitude of the Works

As the size of a works increases, its organization usually becomes more complex. The functions of various members of the staff become increasingly specialized and provision for research is more readily made, because requirements are sufficient to justify the exclusive attention of a responsible member of the staff to this work. Similarly, the larger the works the greater will be the advantages of the research organization, as a greater degree of specialization is possible in a larger staff.

Up to the point at which internal provision for research becomes desirable, the concern may rely wholly upon consultants, national or university laboratories, or Research

Associations, in which case it should be the whole or part-time duty of some officer to assist the staff to co-ordinate the work thus carried out with industrial requirements.

Internal Organization of the Works

In modern works, the principal executive officers of the company are directly responsible to the managing director, and are in charge of the chief functions which the nature of the business demands. Thus, even in the smallest works, responsible men are invariably found in charge of manufacturing, selling, and accounting. Where the products are non-standardized with respect to type and size, there may be a technical department, comprising engineers, chemists, or physicists exercising technical control. In works of larger size, the purchasing department may become separate from accounting. The nature of the product in some works is such that virtually no sales department is required, while in others it may be of great importance, and may include a publicity department. In general, the principal executives of a company work in parallel, the ultimate control being exercised by the managing director, conferences regularly taking place to determine policy.

The position occupied by a research department relative to other departments depends very considerably on its origin and function. If originated by an executive already engaged in the business, it will probably be associated with his department as an integral part of it. Thus, a commercial department may conceivably create a research and statistical bureau for the purpose of investigating economic conditions in various countries with a view to anticipating the trend of various markets. In such a case, the bureau would appropriately be controlled by the sales manager. A department exclusively investigating works troubles arising in productive departments may be controlled by the works manager, as is frequently the case with routine testing laboratories which examine such

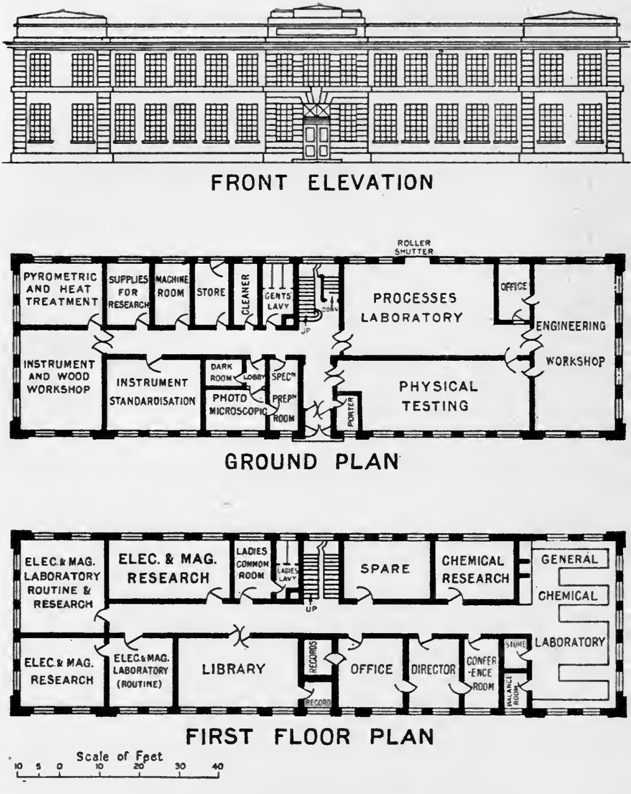


FIG. 4. TWO STOREY RESEARCH BUILDING
12,400 sq. ft. Gross Floor Area
(*See page* 116)

difficulties. A department engaged in experimenting on new machines for the market, as, for instance, the experimental departments of automobile works, may be made responsible to the chief engineer. Where, however, a research department is established as a separate department for the purpose of centralizing and co-ordinating all these and other functions, and actively assisting in the development of the company's products, the research director should be solely responsible to the managing director, working in parallel with the other principal officers and consulted with them on all important questions affecting the policy of the company. The place of the Research Department depends to some extent on the length of time it has existed.

In general, the process of growth has been the same in America, Germany, and Great Britain. The research department in the early stages has been associated with an existing technical department, being subsequently constituted a separate department charged with all the experimental and investigational work of the company, and ultimately in the largest firms becoming a department concentrating exclusively on research in pure science and on the application of the discoveries made.

External Connections

The policy of amalgamation pursued by many industrial concerns in recent years has been directed by the necessity for building up large capital resources necessary in opening new markets and for establishing self-contained enterprises, permitting a considerable degree of centralization in certain business functions. It is not surprising, therefore, that the question of centralizing research should arise. The fact that the majority of such associations take place between firms of different, even if related, kinds renders co-ordination difficult. Industrial combines are generally the result of very careful planning, and the industries concerned tend to form a closed chain, the finished product of one industry forming the raw material of the next industry. There is, therefore, a unity underlying the apparent complexity, and the most involved case arises in a group of highly technical industries, such as the sequence already instanced above.

So far as fundamental research is concerned, the problems presented by such combines and by new industries which spring from them are ultimately problems in one or more of the sciences of chemistry, physics, metallurgy, etc., and, consequently, a trained force of research workers having experience in these industries can apply themselves to any problem with equal facility, for the first function of the research worker is to recognize similarities of principle underlying widely different practical applications. For the investigation of manufacturing problems different treatment is necessary. Some of these problems are so pervasive that they could be conveniently dealt with centrally, such as those relating to furnace construction for industrial heating, the heat treatment of steels, alloys, feeds and speeds, electric welding, and so on. In other cases the problems are peculiar to one works, and demand not only special equipment but also locally specialized experience and knowledge. These require facilities at the particular works concerned.

In the case of a complex chain group, centralized facilities would tend to concentrate at the largest and most complex works in the group, because its own research needs are largest, more particularly so if this works were also the end works of the productive chain, utilizing in a wide range of assembled products the materials produced by the remaining works.

The advantages of thus centralizing and co-ordinating research at one works are as follows—

1. Reference of research work to a central department avoids overlapping and duplication between the various works, while the maintenance of proper

records in the Research Department prevents internal duplication.

2. The best men and equipment available can be concentrated at the central laboratory. This arrangement is not only economical, but, in view of the acute shortage of technically trained men and the difficulty of procuring high-class equipment, it is in some respects the only one possible.

3. The efficiency and output of a Research Department increases much more rapidly than its size, owing to the increased specialization on the part of the staff and to the interchange of experience permitted by their concentration.

4. The services of highly-qualified independent experts can be most effectively retained and utilized through a central authority.

5. The experience and knowledge of any member of any works in a combine can be readily made available, through a co-ordinated scheme, in solving technical problems.

6. A considerable degree of uniformity of practice in the employment of common materials and processes can be secured, this leading to economies in purchasing.

7. A central research organization may act as referee in cases of difficulty arising between one works in a combination and another regarding the quality of supplies of material. As a combination becomes more and more self-contained and self-sufficing, this is of increasing importance.

Manufacturing Policy

In a company manufacturing one line of specialized products, the sphere of activity of a research department is correspondingly limited. When a firm has established one branch of manufacture successfully, however, it frequently seeks to diminish its overhead expenses by undertaking other lines of manufacture which can be developed and carried on without a proportional increase in the staff and non-productive expense. In this case, the services of a research department are invaluable. New applications and uses for existing products can be sought, and new products can be considered and tried fully. In the largest firms the manufacturing policy is so broad that the research laboratory has unfettered freedom to investigate anything which promises to be of commercial value, even if the application of results should take a considerable time. In some instances the laboratory undertakes the manufacture of the new product until the scale is sufficient to justify a separate manufacturing department or a separate company.

RESEARCH AND OTHER MODERN INDUSTRIAL TENDENCIES

In determining the relation of the research organization to the remaining divisions of the works, it is necessary to consider how research work stands with regard to other tendencies in industry, particularly the greater recognition of the human element, notably through education, welfare, and representative government, and that tendency towards cheapened and increased production through scientific management, standardization, and mass production.

Research and Scientific Management

Industrial management is an art which, like all other arts, has a scientific basis capable of being extended and amplified, re-acting thereby on the technique of the art itself. The conscious recognition of the assistance which can be given by scientific method, observation, experiment, deduction, verification, to industrial administration marks a new epoch in industry characterized by endeavours to increase manufacturing efficiency and to diminish avoidable waste. The importance of having in any works adopting modern management methods an organization through which the scientific work required can be conducted can scarcely be over-estimated.

Many problems in modern management turn ultimately on accurate measurement or the impartial assessing of evidence. The ventilation, heating, and lighting of workshops, the determination of fatigue and rest periods, the measurement of intelligence, the conduct of trade surveys, and the prediction of the general tendencies of industrial demand, all provide material for a research department.

A pronounced feature of modern management is the standardization of parts throughout an industry (such as commonly used machine parts), and of types and sizes of machines throughout a works. Larger outputs for a lesser expenditure are thereby rendered possible. Standardization through the properties of materials and engineering design is based on research which determines the most suitable form for the purpose intended. The most successful examples of mass production have been based on research, and manufacturing concerns adopting this working principle are generally permeated with scientific spirit and method in every department. Where mass production is not based on careful planning designed to reduce costs, but rather secured by aggregating machines and workers, failure is likely to result, as the increased demand can only be created by reduction in prices following on more intensive production. Research is an indispensable function of progressive management. It provides the proper equipment, staff and accommodation for experimental work, and removes this from productive departments.

Research and the Human Factor in Industry

Progress in industry depends not merely on the development of improved methods, but also on the willingness of workers to take the fullest advantage of them in the works. Research is useless if the co-operation on the part of workers, which alone can make it effective, is lacking.

This co-operation can be secured only by a lengthy process of education which will ensure sympathetic understanding, in the light of which broad industrial questions can be considered without bias or prejudice. Research is vitally concerned with the establishment of industrial peace.

Research and Education

Apart from its value in inculcating self-discipline, education in industry can be utilized as a means of conferring that knowledge and skill which all workers must possess, in differing degrees, according to the nature of the work they are called upon to perform. It may apply to both juveniles and adults. The present proposals of the Education Act, 1918, will enable all young persons between the ages of 14 and 18 to obtain continued education for eight hours weekly, either in a works school or in a municipal school. Adults may be provided for out of works hours.

Thus may provision be made for the dual function of education, to develop intelligence and craft skill, so that workers may be enabled to undertake operations in new industries called into existence by research, to understand the structure of the industrial system, and to realize that the prospects of an improved standard of living are bound up with the increased productivity of industry.

Education is also required throughout the whole community, to reveal the principles on which industry operates, the variability of demand, and the factors on which depends the return any worker may expect from industry without injustice to others, together with the influence of research on industrial progress. In other words, in parallel with research work a systematic publicity and educational campaign should be conducted in order that the fullest results of research may be achieved.

The research department should also play its part in training apprentices of all grades who will ultimately work in other parts of the factory, and so help to permeate industry with scientifically trained men.

FUNCTIONS OF WORKS RESEARCH ORGANIZATION

The variations in kind and range of manufacture in different concerns renders a universally applicable statement of functions impossible. As an inclusive case, however, it is proposed to examine those of a large works engaged in a wide range of complex products in the engineering industry, electrical and mechanical, large and small, in which the research department is charged with the responsibility not only for academic research but also for the detailed investigational work on which improvement in current practice is based. The functions of a department more circumscribed may be selected to meet the particular circumstances of any given case.

The functions relate either to the improvement of existing or to the development of new manufactures, and in both cases necessitate investigation into—

1. Materials and Processes.
2. Finished Products.
3. Methods of Testing and Standards.
4. The Human Element.
5. Academic Research.

Materials and Processes

The materials employed by an industrial concern and the processes which they undergo in the transformation termed manufacture, whether they actually form part of the finished product or are incidental to it, are so closely connected that the two things cannot be considered separately. The characteristic properties of materials demand processes peculiar to each kind of material, the one changing with the other. An industrial process implies a modification of material, in size, form, character, or constitution.

A manufacturing concern with a reputation to conserve aims at purchasing for its products only the highest class of raw materials of the kind most appropriate to them. This aim conflicts with the desire to manufacture economically by purchasing supplies on the open market at prices ruling at the time of purchase. Sources of supply thus vary as some materials become scarce, as improved materials become available, or as advancing prices in some commodities make it cheaper to use equally satisfactory substitutes. One of the most important functions of a works research organization is the establishment of a suitable technical basis for purchasing material, specifying the minimum demands with which the material must comply in order to satisfy the technical requirements involved. This specification is prepared formally for the use of the purchasing department, which then endeavours to secure the material from any suitable source. The work of sampling and testing incoming materials naturally follows, in order to ensure that the specification is met. This work may be delegated to an inspection department, but the research department should have final authority with regard to acceptance or rejection.

Purchasing Specifications

The plan of purchasing to a specification is satisfactory in many ways. The existence of a definite standard—which, it should be noted, is constantly susceptible to improvement—precludes disputes between buyer and seller. Where a specification does not exist, purchases should be made to sample, which should be examined and reported on prior to ordering. It is highly desirable that for the more commonly used materials the standard specifications prepared by the British Engineering Standards Association, or, in less general cases, by recognized trade associations or technical institutions, should be utilized. In some cases, official specifications used by Government departments may also form a basis for specification for industrial use. The material purchased by most firms falls into two easily definable categories, that obtained for stock, which may be drawn upon for current use by any department in the factory, or that purchased specially for a particular order or purpose, and held for the use of particular departments only. In either case, the material may actually form part of the completed product or may be employed in and disappear during the process of manufacture.

The use of specifications should receive careful consideration. There is a tendency to restrict the supplier by specifying unnecessary requirements which frequently impose such attention or treatment during manufacture that the price is raised. A manufacturer should be given the fullest discretion in producing material provided it actually satisfies the tests to which it is submitted, which should be a measure of service conditions. If a material supply is found to be irregular and a specification is desired simply to eliminate irregularities, the specification may be used in the works for a period before the manufacturer is invited to comply with it. As the permissible limits of variation in properties may be much greater in some applications of the material than in others, the manufacturer may have to do not more than select that part of his output which is needed by one particular user.

In a large works, purchasing specifications ensure a very desirable uniformity of practice throughout all departments. If each department orders materials without reference to the rest of the works, there is not only an actual loss on purchasing small quantities from several suppliers as compared with one supplier, but loss due to increased clerical costs in purchasing, and increased stocks and store space. In this connection, standardization of sizes is of as much importance as standardization of properties.

This work of supervising materials forms a natural basis on which to investigate the improvement of materials, or to find equally satisfactory and cheaper substitutes.

Increasingly severe demands arise through service conditions, such as higher speeds and larger sizes of material in prime movers and machines, bringing into prominence requirements entirely novel, and frequently it is the quality of material available that is the limiting factor in design. The nature of these requirements can frequently be discerned from a study of failures and defective materials, which should also be undertaken by the research department. The cause of failure having been ascertained, steps may effectively be taken to avoid recurrence.

Material supervision involves the whole range of work of the Research Department from the inspection and evaluation of routine tests and the experimental work directed towards establishing properties and ascertaining behaviour under specified conditions to meet definite industrial requirements to pure science work of a high order involved in the study of phenomena such as magnetism, etc.

Process Specifications

Similar procedure may be adopted with regard to works processes. Even in cases in which the materials employed are constant, results of processes frequently vary if conducted by a foreman or workman without written instructions. The issue of a specification covering the steps to be taken in the process has the double effect of locating responsibility if the instructions are not followed, and of facilitating improvement where a defective result is obtained in a process conducted to specification. Some processes involving temperature and pressure control, rates of flow, and so on, are such that slight variations in the conditions produce proportionally greater changes in the product. Where this is not the case, care should be taken to give the widest permissible range of conditions.

Process specifications should be prepared by the research department, which should obtain information from all possible sources, including the traditional knowledge of those workers engaged in the process. A tentative specification should be prepared for extended trial, the changes which experience suggests being made before it is finally issued. All subsequent changes in the process should be recorded in a new issue of the specification. As with materials, existing processes should be carefully studied with a view to their simplification, defects being examined and eliminated. In many cases it will be found that processes based on inadequate experimental work are unnecessarily clumsy, or the conditions unnecessarily rigid.

The development of a new process, say of electric welding, rust proofing, heat treatment, may involve experimental plant on a semi-manufacturing scale, for which laboratory space is required.

A legitimate field for the research department is in connection with general factory economics, as, for instance, establishing effective methods whereby usable material may be recovered from factory waste and scrap, and in exercising necessary technical control over such work. The preparation of some materials required in works processes, such as special alloys or compounds peculiar to the works not purchasable from ordinary suppliers, is closely allied to work of this character. The savings effected are often considerable.

Process work also covers the whole field of research. The results of routine supervision and check tests and comparison of records provide suggestions for improvement. The study of particular processes and the influence of varying conditions indicates the method of securing highest yields or best results and ways in which conditions may be maintained constant. The establishment of some processes demands research in pure science.

Finished Products

The research department can be of great assistance in finding new applications for a firm's products. New products similar in type to, but different in size from, existing products can also be tried, and duration tests under service conditions, destruction tests, and others which cannot readily be undertaken by the commercial testing departments, will frequently give data of great value to designers regarding performance.

The construction of engineering apparatus involves not only the judicious selection of properly treated material, but also its adequate disposition in the machine, in both quantity and location. The disposition, for instance, is determined by the laws underlying the electrical and mechanical sciences, such as govern the transmission of heat or electrical energy, the loss of energy in magnetic material, the behaviour of fluids subjected to temperature and pressure, or the phenomena accompanying surface-tension, capillarity, osmosis, occlusion of gases, etc. Many of the causes of these phenomena are imperfectly known or are known only qualitatively. In other cases the laws derived from theoretical assumptions are vitiated by the use of imperfect and non-homogeneous materials, the precise influence of which can only be determined experimentally.

The research department may, therefore, become acquainted with the current state of knowledge of such laws, and conduct investigations either generally or in respect of particular pieces of apparatus, to collect data for rendering possible more accurate design.

Methods of Testing

The study of new materials and their behaviour, and of new apparatus, necessitates new methods of testing, devised to determine whether particular properties or performances can be assured. The research department should be prepared to develop testing apparatus required under these conditions, and even to manufacture it in its workshops. More accurate and speedy methods of routine testing also repay consideration. Closely associated with this work is that of maintenance of local standards of all kinds.

Physiological & Psychological Research

Scientific work promises a means of reconciling differences between employers and employed which are due to erroneous conceptions or interpretations of facts, means for the measurement of which may be lacking. Thus, the difficulty regarding cutting piece-rates has often been due to rates being set in an arbitrary and unscientific manner, without reference to the amount of work that could be done under the existing circumstances. If workers and employers co-operated to secure impartial and accurate measurement, satisfactory rates could be set which would not necessitate subsequent alteration.

Psycholcgical methods of determining intelligence and selecting candidates for employment also demand trained workers who can concentrate on careful analysis of the measurements of intelligence by methods which experience indicates may be accepted as trustworthy.

Academic Research

A research organization commencing with the above-mentioned responsibilities places itself in direct contact with the works with which it is associated. Sooner or later the organization grows to the point of undertaking investigations not necessarily dictated by a pressing industrial need, but which may serve more remote ends. Thus it commences academic research. Some works at this point separate the research department into two divisions, one of which, the research department proper, is responsible for academic research. Other works commence by forming a research department without any responsibilities other than the performance of pioneer research. In the early stages it is decidedly advantageous to maintain a close association between the research department and the manufacturing organization, and this is best obtained if the research department originates from the manufacturing side. Division or other suitable change in organization may be made later, if desirable.

The investigations undertaken serve no direct industrial end, but are chosen because of their obvious bearing on wide industrial problems. Continuous investigation is bound to reveal something of value, sooner or later, in such fields as heat transmission, the rare earths, alloys, electric wave transmission, crystal structure, etc.

ROUTINE TESTING

The work referred to above respecting control of materials and processes necessitates a considerable volume of purely routine testing, required in connection with productive work not connected with the regular testing of finished products, but involving chemical, electrical, mechanical, and microscopic apparatus. The relation which should exist between this work and research proper must be determined at the outset, as it has an important influence in organization, buildings, and equipment.

No hard and fast rule can be laid down as to what relationship is desirable, as so much depends on local circumstances. Some works associate the two, and some segregate them from the beginning. In other cases, separation ensues after a lapse of time, when the research department is fully developed and occupied with fundamental research. The opinion of scientific workers is divided, but those who lack an intimate knowledge of industry are generally to be found opposing the association. In some cases a capable worker in charge of a routine chemical or physical laboratory can, often without special staff or equipment, accomplish good work which is not strictly of a routine character.

The disadvantages of associating the research and routine work may be stated thus—

1. The routine testing laboratories are part of the productive system, and are best associated with the

works manager or chief engineer. The research organization is superimposed on the productive system, and should have an independent director free from other responsibilities.

2. The research staff does not obtain adequate opportunity to concentrate on research proper if it is liable to be called upon to meet immediately pressing and temporary demands of manufacturing departments.

3. The staffs and equipment required for each are different.

4. The expenses incurred in routine testing are direct charges on production, while research charges are not.

Against these it may be urged—

1. That research work develops slowly, and the first duty of a research department is to place on a sound basis existing materials and processes, and to make them and the resulting products as efficient as possible. Defects in materials and difficulties in manufacture are best revealed through day to day routine tests.

2. That a research department should maintain the closest possible relations with manufacturing departments, and this is best assured by giving it responsibility for appropriate productive work. Many improvements can be made merely by evaluating and comparing the results of routine tests. If the research department is responsible for supervision of materials and processes, it must control routine testing.

3. That a research staff can be very considerably relieved of much work capable of being performed by other grades of workers if a proper routine testing department co-operating with or under control of the research department is available. Highly specialized men, therefore, remain on the most appropriate work. The proper division of work between routine and research sides is a matter of organization, and the

latter need never be neglected for the former. The association of works of different types and grades of training is beneficial.

4. That distinctions between research and routine work as arising in a factory are difficult to make and are frequently arbitrary in practice. Hence, there is grave danger of overlapping and friction between the two organizations.

5. That the combined department makes it possible to work with a minimum of floor space and equipment. The question of allocation of costs for each kind of work is easily arranged.

RELATIONS WITH OUTSIDE INSTITUTIONS

It is desirable that a works research organization should establish a definite liaison with the various bodies and institutions engaged in pursuing research and closely related matters, such as national and consulting laboratories, the British Engineering Standards Association, Research Associations, universities and scientific and technical institutions. A generous policy should be adopted in dealing with requests from outside bodies for information and in co-operating to form committees for the study of special problems or the standardization of materials. The research department may with advantage keep in touch with the outside activities of the staff of the works as a whole and so ascertain what the works is contributing to common effort.

DIVISIONS OF THE RESEARCH DEPARTMENT

In an organization undertaking work for a large electrical and mechanical engineering works, including responsibility for the routine scientific tests and for materials and process control, the department will comprise a number of sections, so arranged as to ensure continuity and appropriate division of work, and each comprising a section leader, assisted by a complement of senior and junior assistants. In cases where one or more research workers are engaged in one branch of science, even though they work independently for administrative purposes, costing and records, etc., they may be considered to form a small section.

For a works engaged in mechanical and electrical engineering the sections may be as follows, each having suitable accommodation—

Administrative

The director of the organization and his personal assistants and secretarial staff constitute the administration engaged in facilitating the work of the department and relieving technical workers as far as possible from administrative duties.

Intelligence

The systematic collection, indexing, and distribution of scientific intelligence should be the function of a separate section, which should be equipped and staffed to prepare bibliographies, undertake translations, and to maintain a library and records of work done. On the knowledge obtained by this section from inside and outside the works a consistent research policy can be founded.

Chemical (Organic and Inorganic)

This section should undertake analyses of ferrous and non-ferrous and organic materials intended for works use or passing through process of manufacture and should investigate chemical problems arising in the works.

Mechanical Testing

Investigations in strength of materials and structures, and the performance of various mechanical tests on metals, textile fabrics, papers, fibre and other insulators, cements, are appropriately conducted by a mechanical testing section.

Metallurgical—Ferrous and Non-Ferrous

Foundry processes, including ferrous and non-ferrous castings, cupola, and furnace control, require to be supervised by a small section concentrating on this important and neglected branch. The heat treatment of steels employed in machining, punching, or as integral parts of finished products should be supervised by this section.

Electrical and Magnetic

This section should be responsible for tests on conductors, resistances, electrical steels, permanent magnets, for tests on finished machines, where required, and for oscillograph investigations and other experimental electrical work.

Insulation

Insulating materials and processes are of great and increasing importance, and form a specialized branch of modern electrical engineering. The range of materials used is wide, and in its practical and theoretical aspects forms a suitable field for a separate section.

Materials and Processes

Work on materials and processes, especially when it is required to prepare specifications, may be co-ordinated by a special section, able to call in the assistance of specialists in other sections as and when required.

Physics

This section may undertake investigations of a purely physical character, such as are concerned in heat transmission, standards of measurement, acoustics etc. In a works undertaking lamp manufacture, this section is of great importance, and an illumination section may also be required.

METROLOGY

Fundamental standards for works use and precision apparatus for measurement may be located in a separate section.

A psychological and physiological section would be formed by workers investigating fatigue and allied subjects. For all the sections, a well-equipped workshop should be available in which equipment for experimental work may be rapidly devised and made.

ADMINISTRATION

From the above outline it will be evident that the responsibility exercised by the research department with respect to materials and processes involves division into a number of sections, according to the nature of the tests and investigations which may be required. The superintendent or responsible leader of any section would report to the director and be charged with the duty of maintaining the equipment and apparatus required for the section, and of being responsible for the staff and discipline. The superintendent should plan all the investigations undertaken in the section. Some workers will be engaged on special investigations, directly reporting to the director of the department but having no executive responsibilities, so that they can, as specialists, concentrate without interruption on the work in hand.

The administration of a research department usually takes one of three forms. In the case of a department engaged on pioneer research, the director may be assisted by a number of specialists working independently, any co-ordination required being undertaken personally by the director. Such a system gives fullest opportunity to scientific individualism, but there is considerable danger either of overlapping or of insufficient correlation of purpose, and in some cases the time of the highly-salaried

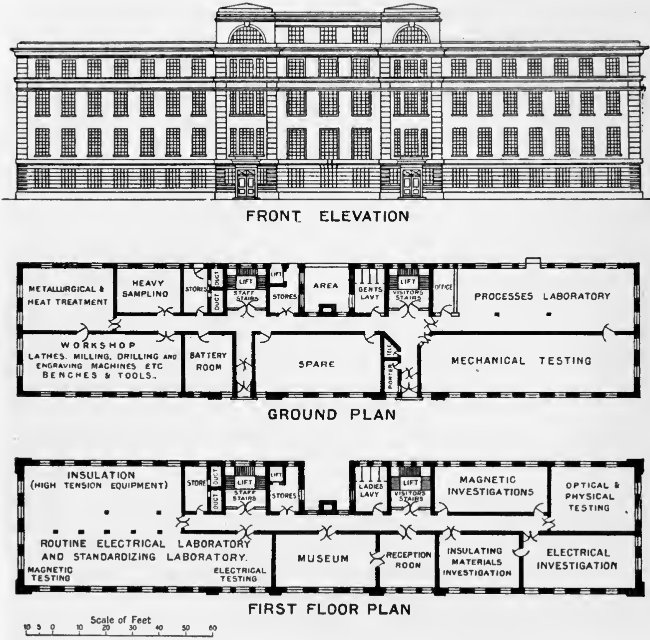


FIG. 5. FOUR STOREY RESEARCH BUILDING

52,600 sq. ft. Gross Floor Area. Elevation, Ground and First Floors

(*See page* 116)

staff may be unduly occupied in the performance of work auxiliary to an investigation which can well be carried out by others.

A department exclusively engaged in the solution of day-to-day difficulties may, on the other hand, be organized in a series of sections, the recognized leader of each of which reports to the director. In this way it is possible to arrange for all the work to be performed by workers of appropriate capacity. All the advantages of co-operative working and continuity are ensured.

In the third place, a department combining the two functions of pioneer research and the investigation of manufacturing difficulties will embody a mixed organization, including both sections for the conduct of work of the latter type, and its incidental tests, and research workers specializing independently on work of the former type. The association of the two types of workers is beneficial to both. The tendency towards acute specialization on the part of the pioneer worker is corrected, and he is also relieved of routine tests incidental to his investigations. The routine workers and technologists learn more of the research method in its theoretical and experimental aspects.

The work of a research department is greatly facilitated by the conference method of working, if judiciously employed. The total experience of the staff can be utilized if regular meetings are arranged to discuss work in hand and the difficulties experienced. Further, when occasion arises for an investigation to be conducted, it is an advantage to arrange for a discussion between those who are directly interested, including commercial men, engineers, and other members of the staff. A programme can then be drawn up which has the merit of stating specifically before work is commenced what it is hoped to achieve and the methods which it is proposed to adopt. Those parts of the investigation which fall into different sections—electrical, metallurgical, chemical, etc.—will be carried out by the sections concerned, and the results incorporated into a final report. Such co-operative working is possible in most industrial investigation, and is a speedy and satisfactory means of obtaining results, provided care is taken that all the workers interested in an investigation fully appreciate the contribution they themselves make to the whole. In other words, there should be complete understanding of the aim and method by all; the saving in time arises through the division of the actual experimental work itself.

At interdepartmental conferences it is desirable to have a member of the intelligence staff present, in order that the fullest information relating to data on the subject under discussion from any available sources can be provided. When results are being discussed prior to the issue of a report, a technical assistant having some knowledge of patent law should be present. Care should be taken to credit suggestions to those making them, and a shorthand writer should record the details of the discussion.

To take an example, suppose it is desired to improve the manufacture of a composite insulating material with respect to its behaviour under heat, tendency to support combustion, hygroscopic properties, or its dielectric strength. The problem would be discussed in conference with the insulation engineers from the insulation section, a physicist, a process engineer accustomed to handle material on a manufacturing scale, an electrical engineer, a chemist, and an intelligence officer, together with representatives from the manufacturing and engineering departments, if necessary. The programme of work is drawn up and one worker appointed to take general charge of the investigation. The work may be divided among the sections, the leaders of which would report to the co-ordinating engineer, who issues a final report. This is discussed and approved, and the necessary action is taken. Changes necessary in material purchased or in processes are made in existing specifications, and the results of the investigation come automatically into operation. This procedure prevents an investigator working on wrong lines through imperfect understanding of the requirements and maintains the interest of workers from other departments in investigations in progress.

The advantage of division of work can only be secured where a department works as a team without friction, and the ability to co-operate, not always characteristic of scientific workers on account of the highly individual character of much research work, is, consequently, of considerable importance. With regard to working hours and discipline, the staff of a works research department should conform with the practice of the works itself. Considerable latitude, however, should be afforded the director in dealing with his staff on account of the difficulty of making research work conform to a predetermined routine, and of the fact that most research workers spend a considerable proportion of their leisure in developing ideas relating to their work and in attending meetings of societies.

Costing

There are many reasons for desiring accurate costs of tests and investigations in works research, but the returns from successful research are so out of proportion to the initial expenditure that careful accounting appears unnecessary, and to some scientific workers itemized accounts imply a stringency in financial matters foreign to the true spirit of inquiry, which does not stop to count the cost. From the practical point of view, the character of the output is so intangible that a research department cannot be treated as an ordinary works department. At the same time it is necessary to know, even if only approximately, the costs of investigations, as they afford a basis for guidance in estimating future expenditure. If the research department is granted an appropriation for a year or a period of years by the directors, a knowledge of costs incurred from month to month is indispensable. If the management of the company provides funds for particular investigations from time to time as required, it may be necessary to estimate the cost very closely in advance. If working expenses are met by charging works departments or subsidiary companies for work done, a fairly accurate knowledge of costs is again desirable to avoid difficulties. In short, wherever the research department is recouped for its expenditure on a basis of cost of each investigation, the individual costs are necessary. Machinery for ascertaining the elements of these costs is a certain check on extravagance without necessarily preventing expenditure which may be speculative, but justifiably so.

In a research organization of the type described above, there would be three sets of costs to ascertain, viz.

For routine work incurred in materials and processes control.

For investigations which may or may not include some routine tests.

For advisory work.

Routine tests under the first head are generally performed on behalf of some productive department or some department (as purchasing) acting for a productive department. The cost incurred is part of the cost of production. If done on a client's order it can be charged to the order, otherwise, to the general expenses of the department for whom the work is done. The department requiring the test should make in duplicate a requisition, one copy of which is sent to the research department as a formal request for the work to be done.

An investigation may involve considerable expenditure. If it is solely for the benefit of a particular works department, that department may be fairly charged with the cost ; otherwise the expense may be shared. In some cases the application is so general that the cost may be distributed over the works as a whole ; or again, work may be done for a non-productive department, serving the works as a whole, which passes on the charge on some existing basis.

Costs of investigations can most readily be determined by giving each investigation an identification number. All materials purchased or drawn from works stocks, and all services required from the works in connection with any one investigation, should be made on requisitions bearing the number. Each section leader should advise the cost accountant regularly of the number of hours per week spent on investigations in hand. In any one section the cost per worker-hour can readily be ascertained by dividing the total salaries of active workers per hour by the number of workers. The cost per hour of overhead charges, which cannot be allocated directly to one investigation such as for supervision, general clerical assistance, and that proportion of factory expense, rent, rates, taxes, power, etc., allocated to the research department, may similarly be ascertained, and the sum of these, being the cost per hour per active worker, forms a permanent basis on which the expenditure on any one investigation can be calculated if the number of hours spent on it is recorded. When the cost of materials and services also incurred is ascertained and added, the total charge is obtained.

The cost of a routine test, such as a chemical analysis, can be similarly determined, but it can with sufficient accuracy be predetermined if an average time occupied, found by experience, is taken. Thus, standard prices can be fixed for all regularly performed tests and the costing is considerably simplified.

Work of an advisory character and the supervision of technical processes can most appropriately be dealt with by charging all work of this type to an order number distinguishing the department for which the work is done. If it is desired to ascertain which section of the research department does this work, an appropriate numerical combination can readily be devised to indicate both the section performing the service and the department requiring the work. This system does not attempt to differentiate between all the different services rendered to one department, as this is not necessary except in special cases. It is therefore best for work of a routine character. Any deficit remaining after routine and investigation costs, supervision, and advisory work have been costed will be due to work undertaken by the research department on its own initiative or to charges which cannot be disposed of in the ordinary way. These should be divided over the factory as a whole, and the division may be made on any suitable basis dependent on service rendered to each department, or on the size of the department—its wage bill is a rough index of its ability to pay—or a compromise based on both of these factors. Equipment should not, of course, be charged to current expenditure but to a special account coming out of capital or profit and loss account.

The result of the above system is that all costs incurred for individual tests and investigations are known, and, consequently, estimates for expenditure can be prepared in the light of known figures for similar cases. Of course, standard charges for routine tests require reconsideration periodically, as materials increase in price or as more rapid methods are introduced, and changes in the staff of a section may necessitate modification of the average hourly rate. Such adjustments are readily made.

The above system represents a compromise between the desire of those who would impose a rigid system of accounting on a laboratory and of those who would have no system at all, the only knowledge of expenditure being the monthly or annual total. To the former, it should be obvious that a rigid system cannot apply to a "non-productive" department in which workers are not paid by the hour, as in a works department, and in which payment is made during holidays, illness, or absence. Approximation is therefore inevitable, especially since any worker may be conducting several investigations in parallel. Further, a detailed statement of time spent by a research worker would be onerous to prepare and would probably be inaccurate. The conventional character of much works costing does not render advisable elaborate attempts to ascertain costs in a department not engaged in producing commodities for which a definite market price has to be fixed. All that the research worker is called upon to do in connection with this costing system is to keep an account of the distribution of his own time, and to take care that materials or works services (*i.e.* use of machines, works maintenance department, and so on) required for research are charged to the appropriate number on requisitions.

If the above system is carried out fully, and all costs for investigations and routine tests are charged, the remaining cost of the department will be comparatively small.

It sometimes happens that products are being developed for a new manufacturing department, or expensive investigations are carried on for a department not able to bear all the cost in any one year. The expenditure should then be provided for from a suspense account and liquidated by a royalty charged as part of the cost of the finished article and placed to the credit of the research department, which would, in fact, be treated as an outside inventor would be treated, the royalty lapsing when the cost incurred is paid for, or accumulating to form a credit balance to be drawn on for future work.

Another plan is to include a development charge or improvement charge as part of the factory costs of each article sold, the money thereby obtained being placed to the credit of a fund which is available for expenses in connection with improvements. In this way each piece of apparatus bears part of the cost of its inevitable replacement by something better. In other words, the burden of payment for improvement is placed on existing rather than on future manufacture. This plan undoubtedly encourages improvement, but changes should not be made so rapidly and irresponsibly as to interfere unduly with the manufacturing departments. Proposed improvements may well accumulate in the case of an established line for, say, one year, so that mass production is not upset.

CHAPTER VII

DESIGN AND EQUIPMENT OF RESEARCH BUILDINGS

SINCE research undertaken in industry is not necessarily applied research, and university and institutional research not necessarily pioneer research, it follows that the respective types of buildings and equipment desired need not present any fundamental differences. At the same time, however, it should be borne in mind that industrial research is predominantly applied, and is frequently conducted on a manufacturing scale demanding machinery, power supply, and other resources only available to industry, while university and institutional research is predominantly academic, and conducted on a small scale. Differences, therefore, will usually exist between the types of buildings adapted to the two kinds of work.

A laboratory frequently has to be accommodated in space provided in a larger building, and the general dimensions and shape have to be accepted and the available space employed to the best advantage. While for academic research this is not a difficult matter, great ingenuity has generally to be exercised in adapting such areas for industrial research, because the scale on which it is conducted emphasizes special features of design, with regard to ventilation, ducts for supplies, and drains.

Several features should be kept in mind in designing laboratories. The convenience and comfort of workers engaged should be a primary consideration, as the best possible lighting, ventilation and heating will be an ultimate economy, and details such as adequate locker and canteen accommodation, provision for washing, reading and writing will greatly enhance working efficiency. It should be borne in mind that the building is merely the shell of the organization and is secondary, being intended to house the staff, which is the really important factor. Other features influencing design are the supply of various services to the laboratory, gas, water, compressed air, etc., the position and magnitude of fixed apparatus, such as testing machines, and of apparatus requiring non-vibrating bases. Store accommodation is very necessary, and it is advisable to plan separate small rooms for balances, for fume chambers, and for other laboratory operations. The sequence of operations should be considered as much in a laboratory as in a workshop, with a view to securing maximum economy of effort.

In designing an industrial research laboratory, the closest possible co-operation is necessary between the architect and the research director and his staff, who will be fully acquainted with the requirements as to space and working facilities, thus ensuring the best combination of utility and good appearance. Up to a certain size, a single-storey building will naturally be selected, but above this size it is necessary to consider the relative merits of several single storey buildings and a multi-storey building.

Single and Multi-Storey Buildings

The respective advantages of the two types will be readily apparent. The multi-storey building provides all the floor area required with a minimum of land. Where land is scarce, or its cost high, the tendency will be to build upwards. The multi-storey type also affords the very best facilities for access from one part of the building to another, and time is saved in the constant communication which is necessary between different sections of the department. On the other hand, the tendency is in modern ferro-concrete structures to provide little head room between floors, and in some kinds of experimental work this is an inconvenience, particularly so in the case of industrial laboratories carrying on operations or processes on a manufacturing or semi-manufacturing scale. Multi-storey buildings cannot be lighted from the top, except on the highest floor, and for many kinds of research work top lighting is an advantage. Absence of top lighting restricts the width of the building. There is much greater difficulty arising through the vibration of machinery being communicated to parts of the building where delicate operations may be in progress, and the cost of isolating any particular source of vibration on the upper floors is greater. Finally, the multi-storey building involves a greater proportion of floor area not available for active work, lost in corridors, staircases, and partitions.

The provision of working area on a ground floor equivalent to a multi-storey building involves additional expense not only for land but for drainage, site-clearance, heating, and ventilation. The facility for extension, however, is greater than in a multi-storey building—a very important consideration. In the case of single-storey buildings this can be done by putting down a separate building, by simple addition to the length of an existing building, or by the provision of one or more wings. Any of these require land in the immediate neighbourhood. Multi-storey buildings can be extended by the addition of further stories if the initial foundations are strong enough to suit whatever superstructure is ultimately contemplated.

It will be evident that, if other factors such as the cost or availability of land do not enter, the single-storey building is most appropriate for applied research, where a considerable proportion of the work may require to be on a manufacturing scale, while pure science work of a comparatively light type can more readily be accommodated in a multi-storey building. Since many variable factors enter into the question, an invariable rule is not possible. From the rules given below it is possible to determine with comparative ease what floor area is required, but the conditions of each case will determine whether this area should be provided in several single-storey buildings, isolated from or attached to each other, or in a multi-storey building.

Determination of Floor Area

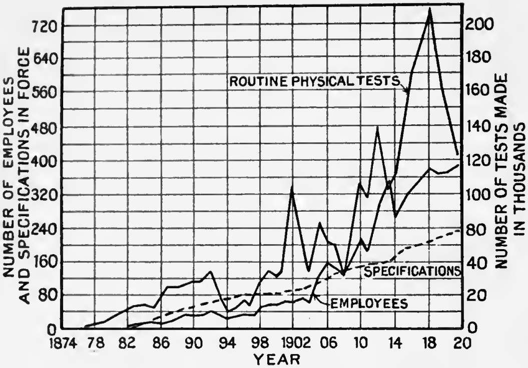
The floor area required is computed from the number of sections and of independent workers who are, or who are likely to be, employed in the organization, which is in turn dependent on the amount and character of the work to be undertaken.

The average active floor area—that is, floor area actually required for working, and excluding space required for stores, etc.—required per employee in all usual sections of a research laboratory is from 150 to 250 sq. ft. In some sections, of course, where the equipment is of a large size, as in mechanical testing, a larger area is needed.

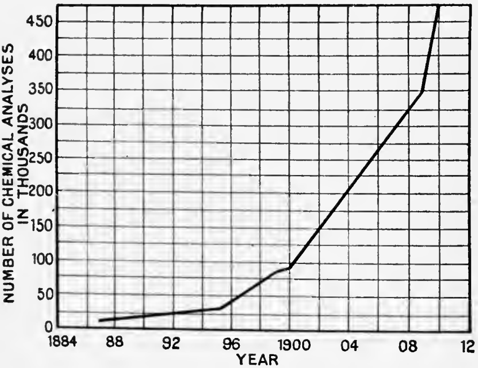
Where the lower figure is employed, any appreciable increase in the work of the organization will necessitate extension of premises. On the other hand, the higher figure represents fairly comfortable conditions, and provides some room for extension. It should not, however, be regarded as a maximum. The guiding principle should be to make the provision of premises and equipment as liberal as circumstances permit, and when financial considerations do not preclude it, an average of 400 sq. ft. of active floor space per employee—a figure commonly found in the large research institutions in the United States—must not be regarded as excessive.

From the product of the total staff and the floor space allowed per employee, the total active floor space is obtained. To this must be added 10 to 20 per cent for space occupied by stores, lavatories, heating, ventilation, and power plant. The space lost in containing walls, corridors, partitions, and stairways, will necessitate a further addition of 15 to 40 per cent to the active floor area, being under ordinary conditions about 20 per cent in a single-storey and 33 per cent in a multi-storey building. The active floor area must, therefore, be increased by 30 to 50 per cent to arrive at the gross floor area.

It should be noted that the floor area is estimated on



a. Pennsylvania Railroad Co., U.S.A.



b. F. Krupp A.G., Essen

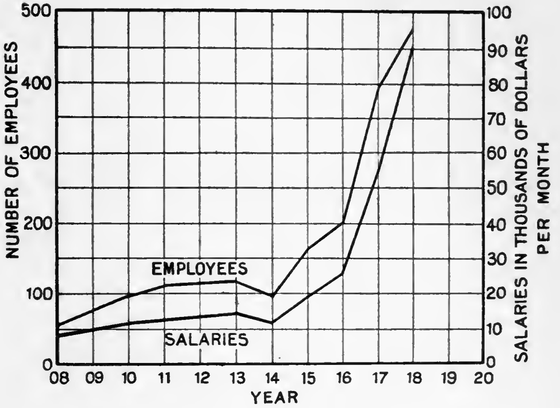


Fig. 1c. Du Pont de Nemours, Inc., U.S.A.
c. Du Pont de Nemours, Inc., U.S.A.

the amount required per employee. In some laboratories it may be found that a greater administrative staff or a greater proportion of junior or non-technical trained staff is required than in others. In general, however, the ratio between the total number of employees and those actually engaged in investigational work will not vary very greatly in different laboratories, the latter being in industrial laboratories 33% to 50% of the former.

Particular attention should be given to the possibility of extension when determining floor area, and if it is likely to be rapid, extra room should not have to be provided by restricting the floor area of workers already engaged. The manner in which work grows may be indicated by Fig. 6, which shows the growth of work and staff of the Pennsylvania Railroad Co., and the Du Pont de Nemours Co., U.S.A., and the increase in number of analyses performed at F. Krupp A.G., Essen.

Type of Building

The building employed may be either single-storey or multi-storey. In the former case, for an area up to 6,000 sq. ft., a simple single-storey building of rectangular form in plan would be selected. Up to 12,000 sq. ft., two buildings of the first type may be employed, either adjacent to or isolated from each other. Above this, a series of connected or detached buildings may be employed, the ground plan arrangement being determined by the land available. Where land is scarce, for an area between 6,000 sq. ft. and 12,000 sq. ft., a two-storey building would be desirable, while for areas in excess of 12,000 sq. ft., the number of stories would be increased proportionately. The width of a building without intermediate supports to the roof trusses is largely fixed by the roof-span, and to some extent by natural lighting.

Selection of Fabric

Important factors affecting the selecting of a fabric are elimination of vibration, lighting, future extensions, fire risk, and architectural and aesthetic requirements.

A consideration of these factors, subsequently dealt with in greater detail in relation to various fabrics and their availability in this country, suggests that for a single-storey building either a brick or reinforced concrete frame and brick fabric is to be recommended. The latter construction is cheaper than the former, and usually lends itself to more effective lateral lighting. Having in view average conditions, a flat roof has much to recommend it. It readily lends itself to partition of the building into sections ; it offers no exposed parts to corrosion and hence both the first cost and maintenance cost are low. It secures the most equable temperature under external fluctuations, and it is the best form for artificial lighting. Further, a flat roof can be utilized as a proving ground where weathering properties of materials have to be tested.

On the whole, therefore, a building in brick having a reinforced concrete frame and flat roof in the same material is recommended, and where a section requires top lighting this can be provided by a lantern or its equivalent. Many buildings, however, are provided with pitched roofs, which have some advantages with respect to natural illumination.

For two-storey and multi-storey buildings a reinforced concrete frame with concrete floor and roof forming a monolithic structure, and with brick walls and filling, most completely satisfies such requirements as freedom from vibration and facility of extension, and at the same time will meet all ordinary architectural requirements. Such a building is also fireproof and permits of excellent lighting.

Elimination of Vibration

Constant use of delicate instruments demands freedom from vibration, and its reduction depends to a large extent upon the choice of fabric. One of the most weighty arguments in favour of a reinforced concrete skeleton and flooring for two-storey and multi-storey buildings recommended above is that on account of its monolithic character it gives the least response to disturbing forces. All buildings, whatever their construction, will vibrate to some extent, and, therefore, where extremely sensitive apparatus is to be installed, apart from the selection of a fabric, precautions may have to be taken against vibration by providing more or less vibrationless supports for special apparatus. The matter is one which chiefly concerns internal construction.

The problem of vibration is twofold. In the first place, the building has to be screened from the disturbing forces set up by its own contained machinery. Secondly, special apparatus may require to be screened from disturbances communicated to the building from outside. The former necessitates the isolation of unbalanced machinery from the main structure, and this may be done by placing all such machinery on foundations independent of the building proper. For this purpose the machinery may be housed away from the main building or situated on the ground floor or basement, preferably supported by piers built from the ground and separate from the rest of the building. In some cases it may be necessary to avoid the use of line shafting, unless it is supported directly from the ground, and to provide machines with separate and self-contained electric drives. The screening of apparatus may only require the provision of rigid tables which will not vibrate themselves, and which can be placed in positions where the vibration taken up from the building will not be serious. In this case, a table top in reinforced concrete, slate, marble, or like material, supported from the floor by substantial piers in brick or concrete, forms a satisfactory arrangement. Where more elaborate precautions are necessary, it may be essential, as indicated above, to provide specially designed supports based on the ground but entirely separate from the main structure.

An example of special supports is afforded in the laboratories of André Citroën et Cie. Here special balances, photo-microscopic and electro-magnetic apparatus are placed on the first floor, and carried on marble tables. A typical table has four indiarubber feet which rest upon the tops of two piers rising through the basement from a common foundation of concrete and brick. Each pier consists of sections in brick, concrete, and compressed cork, the latter being capped by a plate on which the indiarubber feet of the table rest.

Apart from structural features, of course, much may be done to remove vibration troubles by providing apparatus such as galvanometers with flexible supports loaded with a sufficient mass.

Lighting

Special treatment of the problem of natural lighting is required in planning a research building on account of the close and accurate observation which is necessary.

It is important to appreciate the relative values of the intensity of illumination in the vertical and horizontal planes required for different kinds of work. Other than in special cases, it is reasonable to assume that the former is most important where apparatus is viewed more or less in the horizontal direction—a very frequent requirement—and that the latter is most valuable when surfaces are viewed from above. With the object of affording some guide as to the effect of the position of the windows upon these two components, the diagrams shown in Fig. 7 have been prepared.

It is assumed that the intensity of illumination is the same in all cases, that the light is diffused, and that the building and window extend indefinitely in the longitudinal direction. The ordinates of the full-line curves represent the intensity of direct illumination on the horizontal plane at a level of 3 ft. from the floor and on the ceilings, and the dotted curves similarly show the illumination on the vertical plane as projected from the left-hand side.

In Fig. 7, *a*, *b*, and *d* refer to rooms with flat ceilings, and *c*, *e*, *f*, and *g* to rooms having pitched roofs, and in every case the lighting is lateral or top lighting, but not both. In practice, of course, the walls and ceilings reflect light ; for the present purpose, however, it is not necessary to include the effect of this influence, as the object is to obtain for each case an approximate idea of the relative intensities of horizontal and vertical illumination. The ceiling illumination is plotted in order to afford some idea of its magnitude and influence. It would appear that lateral lighting, provided it is adequate, is to be preferred for general laboratory work, and this view is in accord with experience.

All the cases of top lighting dealt with show a high horizontal illumination and a comparatively small and unevenly distributed vertical illumination. The addition of lateral lighting would in every case considerably improve the distribution. Comparing the different types of pitched roofs, the saw-tooth type appears to give the most even distribution, especially if supplemented by some lateral lighting. This type of roof with north light excludes direct sunlight, and therefore has advantages in respect of both illumination and even temperature, although its span is limited to about 30 ft. In some cases a short flat roof introduced between two consecutive spans has advantages in facilitating the erection of piping for fume cupboards.

The extent of window area provided in some research laboratories varies in amount from 20 to 35 per cent of the gross floor area, with an average value of about 25 per cent. The modern tendency in design of laboratories is to provide extremely liberal lateral lighting, and in this respect, as already noted, the reinforced concrete building offers advantages.

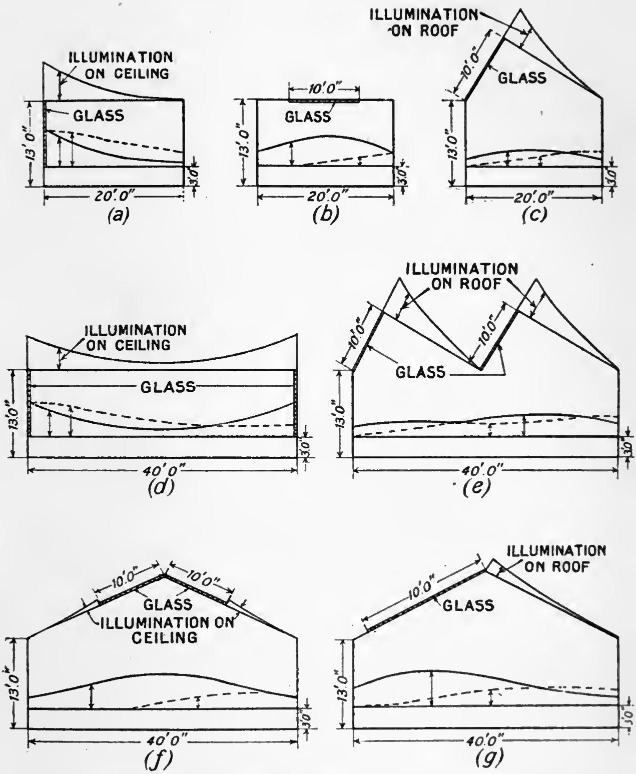
From the figures given, it is a simple matter to estimate the distribution of natural light in any ordinary combination of top and side lighting.

For artificial lighting, in order to reduce glare and to reproduce as far as possible the conditions of diffused daylight, it is advisable to adopt a system of indirect or semi-indirect lighting with white ceilings and walls to secure maximum reflection.

Laboratories, libraries, and workshops require normally an intensity of illumination of 7·5 foot-candles, although for special work, for which direct local lighting units may be employed, the required intensity may be 12 foot-candles, according to circumstances.

A satisfactory method of determining the power, number, and spacing of lighting units for rooms, offices, and corridors is the following—

To supply a room with any required intensity in foot-candles in a horizontal plane, the total number of lumens required is obtained by dividing the product of room area and intensity necessary by a co-efficient of utilization, this



—— *Illumination on Horizontal Plane 3 ft. above Floor and on Ceiling*

- - - - *Illumination on Vertical Plane 3 ft. above Floor. (from left hand side.)*

FIG. 7. NATURAL ILLUMINATION OF RESEARCH LABORATORIES

coefficient representing the fraction of the lumens of the source which reach a horizontal plane taken 30 ins. above the ground. For the case of white ceilings and walls of high reflecting power the coefficient has the approximate values : 0·4, 0·5, and 0·6 for small, medium, and large rooms and corridors respectively, when the lighting is direct (dense glass). For semi-indirect (dense glass) and for indirect (mirrored glass) lighting, these values should be decreased by 33 per cent. The total lumens thus obtained should be increased by 20 per cent for depreciation due to dust.

The number of lighting units required to produce illumination of sufficient uniformity on a horizontal plane is settled by determining the mounting height (horizontal plane to light source for direct and to ceiling for indirect lighting) and utilizing the factors given in Table I, varying with the type of unit adopted.

TABLE I

Determination of Distribution of Artificial Light Sources

Source of Illumination.	Spacing Distance. / Mounting Height.
Prismatic or Mirrored Reflectors—	
Focusing	0·75
Intensive	1·25
Extensive	2
Opal Bowls or Domes enclosing Glass Units	1·67
Semi-indirect and Indirect Units . .	1·5

The spacing distance having been obtained, the number of units is readily found, and hence, from the first calculation, the size of the individual units.

When designing the lighting installation, it is important to provide an adequate number of suitably placed wall plugs, and in some cases floor plugs may be advisable.

Semi-indirect artificial lighting, providing lamps in a translucent bowl, is good if flat ceilings are used, but care must be taken to prevent undue deterioration of reflecting power through dirt or blackening of the surface. A soft diffused light is afforded. Where pitched roofs are employed indirect lighting is not suitable unless a reflector is added above the bowl.

Protection against Fire

As far as practicable, a fireproof building should be provided, and it is admissible to equip it with the sprinkler type of automatic fire extinguishers, although in laboratories their operation causes considerable damage. In an atmosphere containing acid fumes this is not always due to fire. In all rooms where there is the least possibility of fire risk, chemical extinguishers should be available.

Arrangement of Sections

In each section of the laboratory, rooms of different sizes will be needed, and in laying out a rectangular building the larger rooms will either be placed across the full width of the building or run longitudinally, occupying approximately one-half the width of the building where there is a central corridor, and the full width in small buildings. Typical room arrangements are shown in Fig. 8. Where some rooms need to be in intimate connection with others, as in the case of the balance and fume rooms in a chemical section, these may be provided as shown in Figs. (*a*) and (*b*). It will be observed that the problem of providing rooms of different sizes is facilitated by placing a longitudinal corridor somewhat away from the centre line of the building, and in the case represented by Fig. (*c*) it is an advantage to place any columns required for the ceiling support along the line *AB*. Supervision and internal efficiency is aided considerably if it is possible to see clearly into all parts of the laboratory, and this can be ensured in the arrangement given in Fig. (*d*). The small rooms required are placed in a central corridor, leaving the main laboratory clear. The small rooms may be used for balance room, dark room, fume room, stores, and rooms for delicate work requiring freedom from temperature changes and draughts.

Flat roofs and ceilings permit any arrangement of rooms to be readily made. On the other hand, a pitched roof imposes limitations which are mostly felt in the case of single-floor buildings, where all sections are together. A single span pitched roof, however, offers no difficulties in a building where the rooms extend over the full width, but where a longitudinal division is required, particularly if by a corridor, it is inconvenient, and a roof in two spans is desirable. In this case, the wall supporting the trough between the spans forms one side of the corridor, and it is convenient to utilize the corridor for carrying the mains supplying water, gas, and electricity through the building.

In some classes of work, as in certain chemical operations, very accurate weighing and the standardization of high-precision apparatus and instruments, variation of temperature constitutes a disturbing factor. The use of a room with double walls, in a basement if available, or, failing this, with windows of northern aspect, offers advantages in this respect.

Water, Gas and Electric Supplies

Careful attention to the provision of ducts for the supplies to the rooms and discharge of drainage will generally save considerable subsequent trouble and annoyance.

For single-storey buildings, supplies will necessarily be provided in channels in the floor, and considerable ingenuity and care are required in placing furniture so that pipes can be brought up from the floor level and be accessible for inspection without appearing unsightly.

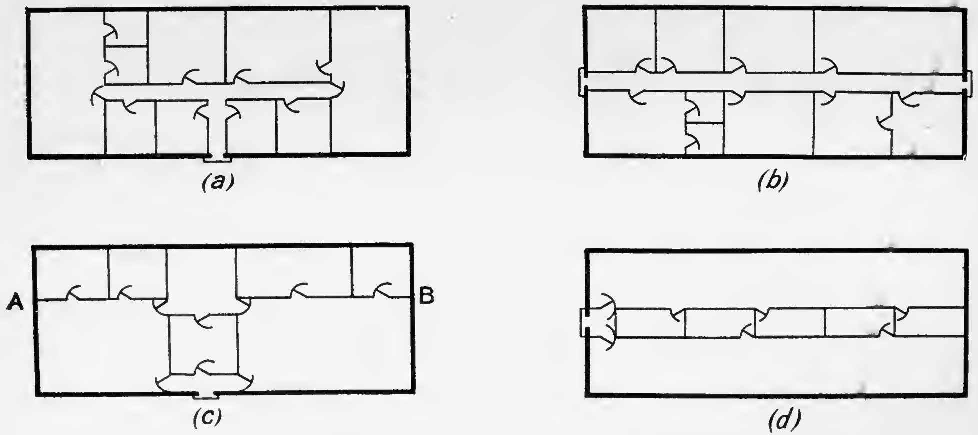


FIG. 8. SECTIONALIZATION OF RESEARCH LABORATORIES

For multi-storey buildings, all pipes, conduits, etc., should enter the rooms close to the ceiling and be brought down to benches or other points where required. The position of the ducts is shown in Fig. 9. This arrangement

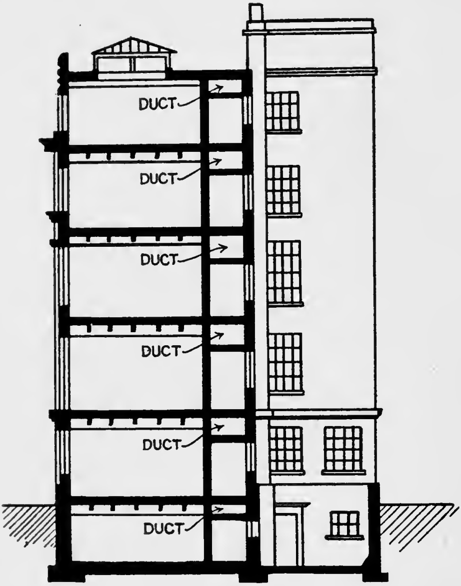


Fig. 9. Duct Arrangements, Four-Storey Research Building

is more satisfactory than bringing the pipes up through the floor or from troughs, and pipes should preferably run horizontally above the benches they are required to supply rather than underneath, as is more commonly done. The main distributing pipes and cables should be arranged to supply each floor of the building and should be situated near the ceiling and generally run along the corridor. Whenever possible, each room should be supplied by independent tappings on the main distributors.

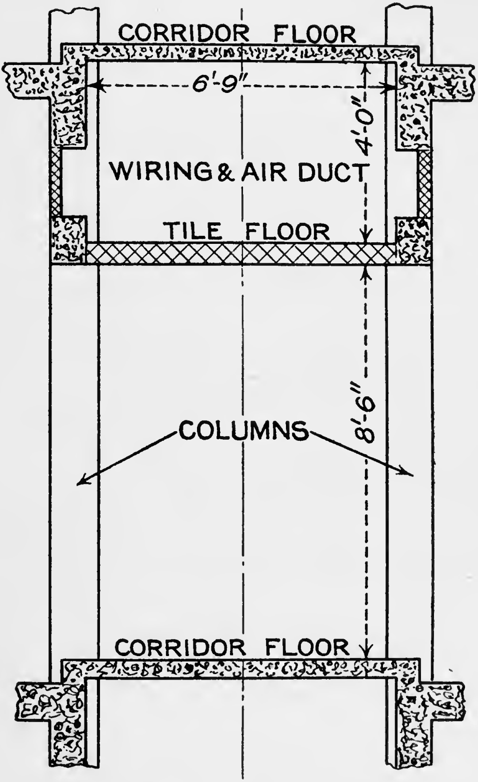


FIG. 10. DETAILS OF DUCT CONSTRUCTION

In the case of buildings where the range of supplies is not extensive, it is satisfactory to support the main distributing pipes and cables from the ceiling by hangers.

In large multi-storey buildings, however, where extensive electrical work is carried on, and where, in addition to piped supplies, a wide range of electric supply is necessary, it becomes very desirab e to have special pipe and cable ducts of s fficient size to permit men to work inside, in which all distributing pipes and cables may be carried. These ducts may also be employed as part of a forced ventilation system, suitable for multi-storey buildings, but where this is done bitumen-covered cables should be avoided, owing to fire risks. Such pipe and cable ducts are most conveniently situated above the corridors, and Fig. 10 shows a section through the duct used in the Research Building of the Westinghouse Electric and Mfg. Company, U.S.A. When ducts of this type are to be employed, a double row of columns is necessary, and the structure of the building must be arranged accordingly.

Research requiring electric currents of large magnitude, as electric furnace work, will generally be arranged on the ground floor or basement, and it is convenient to have a suitable system of ducts cut in the floors and covered by plating, in which cables may be placed. Otherwise, it is desirable to keep the floors of research buildings as free from ducts and channels as possible. In the chemical and metallurgical laboratories where special drainage facilities are necessary, it is also desirable to arrange for sinks, etc., to discharge by open-ended pipes into receptacles let into the floor and connected to the acid drains. These should be easily opened up for examination.

The building should be equipped with soil and acid drains, and it is better for the two systems to remain separate within the building and discharge through traps into a common sewer outside. Where objections are likely to be taken to the discharge of acids into the common sewers, a special treatment bed should be provided, when the necessary neutralization can be effected.

Generally, all rooms in a large building will be piped for hot and cold water and gas. In addition, it may be necessary to pipe the whole, or at any rate a part of the building with some or all of the following supplies, namely, gas raised in pressure to about 4 ins. of water ; compressed air at about 50 lbs. per square inch above atmospheric pressure ; distilled water, and an electric supply of a variety of voltages and frequencies. For special purposes oxygen and hydrogen may be supplied.

As an example of the range of supplies regarded as necessary for a large research organization, reference may be made to the Research Building of the General Electric Company, U.S.A. (*see* Fig. 22). This building is piped throughout with the following supplies, namely—

(*a*) City and river water.
(*b*) Distilled water delivered by gravity.
(*c*) Illuminating gas at both ordinary and high pressures.
(*d*) Hydrogen.
(*e*) Oxygen.
(*f*) Compressed air.
(*g*) Vacuum for experimental purposes.
(*h*) Vacuum for cleaning purposes.
(*i*) High pressure steam.
(*j*) Electric supply as follows—

From external source : d.c. three-wire, 250 volts ; three-phase, 40 cycles 120 volts.

From Research Building power plant a supply up to 12,000 amperes, voltages up to 200,000, and frequencies from 25 to 2,000 cycles.

Heating and Ventilation

A building for research purposes does not introduce any special requirements with regard to heating. In all cases the low-pressure hot-water system can be recommended on the grounds of its efficiency and greater freedom from trouble than high-pressure and steam-operated systems. If steam radiators are used, their usual position under the windows frequently interferes with the placing of bench fixtures.

For the ordinary ventilation of the building, no special provision is needed in single and two-floor buildings other than is provided by the windows, but in the case of multi-floor buildings forced ventilation is recommended, and, as already noted, where a special cable and pipe duct is provided a portion of it may be utilized for distributing the air supply through the building. Special local ventilation will, of course, be needed in the chemical and metallurgical laboratories, where fumes are produced, and usually no difficulty will be experienced in securing effective extraction by means of fans. Where the presence of precision instruments renders dust in the laboratory inadvisable, air may be drawn in through fabric filters underneath the windows. For particularly delicate work in industrial areas a plenum system combining heating and ventilation by distributing washed and warmed air is desirable.

Internal Finish

Finish and decoration of the interior will be decided by individual taste and the expenditure permissible for the purpose. Generally, however, for most sections, excluding offices and library, it is recommended that the walls have glazed tiles or bricks of a pleasing shade, or wood panelling, to a height of about 4 ft. 6 ins. from the ground, and that the remainder of the walls to the ceiling be distempered in a light colour having good light reflecting properties.

White glazed bricks or tiles extending to the ceiling are frequently used for the chemical laboratory, but if the white is considered unsuitable, opal glass may be recommended. Partitions should be of hollow tile or wood to a height of 4 ft. 6 ins. from the ground and glazed above to the ceiling.

For floors, hard wood blocks treated and laid on concrete, tiles, and special compositions have proved satisfactory, although in regard to the latter only well-tried and approved makes, capable of meeting the conditions of a research building, should be considered. Some compositions are noisy and cold and easily crack. Where a battery room is installed, an asphalt floor is recommended. Rounded corners are recommended for the junction of the walls and partitions with the floors, these preventing the accumulation of dust.

Furniture

There is no doubt that equipment such as benches, fume cupboards, and hoods found satisfactory for technical instruction purposes, has exerted an undue influence upon the design commonly employed for industrial work. The conditions in the two cases, however, are very different. In technical colleges, students have to be accommodated at a comparatively high density for short periods. This necessitates a large stock of minor equipment which must be immediately available if time is not to be lost unnecessarily in fitting up apparatus. Hence, the evolution of the usual type of bench, with its numerous drawers and cupboards. The demand made upon the fume chamber is generally not heavy, with the result that this fixture is often small, and the arrangements for fume extraction weak. In the works laboratory, where the floor space per employee is larger, apparatus in regular use is permanently set up. The large majority of the apparatus not actually in use is best kept in a store, so that the accumulation of drawers and cupboards becomes unnecessary. They tend to become filled with debris, which harbours dirt and increases fire risk. Fume chambers have at times to cope with heavy rushes of urgent work, and therefore they must be of ample capacity and of especially durable construction. The draught arrangements must, obviously, be both powerful and positive.

One or two drawers per bench meet all requirements. The bench top should consist of a material capable of resisting acids and of being readily cleaned. In a number of recent American research buildings, alberene—a soft, talc-like stone—is largely employed for bench tops and also for fume chambers and hoods. Other suitable materials are glazed tiles and rough plate-glass, but where such materials are employed it is advisable to make use of soft sheeting to prevent the breakage of delicate glassware. The bench top should be entirely free from all projections, such as gas cocks, etc. The advantage of standardization may be secured by the adoption of a unit type bench which can be built up to any length by the addition of units.

A satisfactory form of fume chamber consists of wired rough plate glass in steel framing and windows of transparent wired plate glass set in steel sashes, the whole of the steel work being protected by heavy coats of a resistant paint. In the alberene stone fume chambers, framing is unnecessary and fixed windows may be cemented directly on the stone. Wood is used for the framing of the movable windows. All supplies to the chamber should, of course, be controlled by cocks and valves placed outside, and there should be an adequate provision of hot-plates for accelerating operations.

The ventilation of fume chambers, hoods, etc., may be assisted by a fan. This may be supplemented or replaced by steam or compressed air induction jets situated at the entrance to the flues, or a jet above the chamber working on the ejector principle.

ILLUSTRATIVE CASES

In order to illustrate the design and construction of research laboratories based on the general principles indicated above, the particular cases are taken of engineering works of various sizes, the research department being housed in its own building and being responsible for the general supervision of works processes and materials in addition to research investigations. The provision required in the case of each laboratory is similar, though more specialized and on a larger scale in the bigger laboratories.

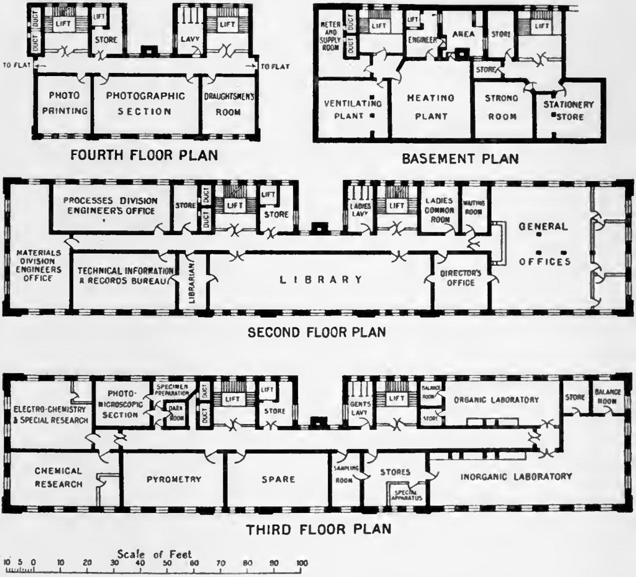


FIG. 11. FOUR-STOREY RESEARCH BUILDING

52,600 sq. ft. Gross Floor Area. Second, Third and Fourth Floors

These designs are not intended to be ready-made laboratories, as any design must depend on local conditions. They serve to emphasize the fact that such buildings must be carefully designed, preferably as separate buildings, and that in research work the best provision is ultimately the cheapest.

Fig. 1, p. 27, shows a single-storey, self-contained research laboratory for about twenty active workers, gross floor area of 5,500 sq. ft., active working space being about 3,200 sq. ft. To permit end lighting on the large testing machine the width is decreased as shown.

Fig. 2, p. 33, is a building of similar size, arranged on a different plan to permit the chemical laboratory to be separated from the remaining rooms on account of the effect of fumes on delicate apparatus.

Fig. 3, p. 41, shows a single-storey building of double the area of previous examples, connected in such a way that natural lighting is provided for both wings on all sides.

Similar accommodation for a two-storey building is shown in Fig. 4, p. 63. It will be noted that heavy work is kept on the ground floor and chemical work on the first floor where top lighting can be obtained. An example of a single-storey building of larger area than these examples is given in Fig. 12, p. 123.

Fig. 5, p. 83, and Fig. 11, p. 115, show a large research building of 52,600 sq. ft. floor area, of the type which could be maintained by an aggregation of industrial firms covering a wide range of industries, and providing for an active staff of about 150 workers; the total number, including clerical assistants, cleaners, etc., being about 250.

Costs

Pre-war costs are more trustworthy for estimating purposes than current costs based on changing and inflated prices. They represent a standard by means of which costs for other times may be determined, and in the following figures pre-war conditions are assumed.

Costs may conveniently be considered under the following heads—

Capital Costs.

Buildings.

Furniture.

Apparatus and equipment.

Running Costs.

Maintenance, including salaries.

Depreciation and Obsolescence.

CAPITAL COSTS

(*a*) Buildings. Average pre-war costs for four types of buildings for different fabrics are represented in Table II. Areas approximating to those given in the table may be obtained by interpolation. For convenience in comparison, the areas, which are gross, are given in round figures, only slightly different from the actual areas of the series of laboratories illustrated in Figs. 1–5.

All buildings are designed to be of fire-resisting construction, and Table II includes provision for heating, ventilation, artificial lighting, pipes, ducts, and drains.

TABLE II

Cost of Buildings of Different Areas and Fabrics[1]

Class.	Description of Building.	Figs. 1 & 2 6,000 sq. ft.	Fig. 3 12,000 sq. ft.	Fig. 4 12,000 sq. ft.	Figs. 5 & 11 52,000 sq. ft.
		Single Storey.	Single Storey.	Two Storey.	Four Storey.
1	Brick and steel frame with stone dressings and architectural finish	100	96	92	88
2	Reinforced concrete with stone dressings and architectural finish	99	94	87	83
3	Brick and steel frame, plain finish	92	88	83	77
4	Reinforced concrete, plain finish	90	86	78	74

[1] Prices are based on pre-war conditions.

To obtain an approximate estimate of the cost of a structure, multiply the floor area by 7·4 and then by the figure in the table, and divide by 1,000. A 6,000 sq. ft. building of Class 1 would cost approximately 6 × 7·4 × 100 = £4,440.

(*b*) Furniture. The amount of money which can be spent on furnishing any given laboratory will vary considerably according to the nature, quality, and finish of the material used. But beyond a certain point no gain save, perhaps, improved appearance is to be obtained by increased expenditure. Table III gives particulars in respect of adequate and satisfactory furniture of average construction and finish, such as is commonly employed for laboratory purposes. The figures include cost of installation.

TABLE III

Cost of Furniture and Equipment for Different Sections

Section.	Average Cost in £'s per Square Foot of Active Floor Area.		
	Furniture.	Apparatus.	Furniture and Apparatus.
Physical Testing	0·1	1·75	1·85
Workshop	Small	1·25	1·25
Chemical[1]	0·3	0·6	0·9
Photomicrographic[2]	0·25	0·4	0·65
Metallurgical	0·05	0·5	0·55
Electrical and Magnetic	0·2	0·8	1·0
Office and Library	0·5	—	0·5

[1] Includes fume room, balance room, office, and stores.
[2] Includes dark room.

(*c*) Apparatus and Equipment. Careful estimates have been made for a number of well-designed and equipped industrial laboratories on a pre-war basis (although some of these have been equipped during the war), the figures being expressed in Table III. These figures for convenience are expressed per square foot of active floor area, since the cost is given for each section.

RUNNING COSTS

(*d*) Maintenance. *Salaries.*—It is difficult to give figures for salaries, since they will necessarily vary in different laboratories. On a pre-war basis, however, the average salary for the whole range of people, including clerks, janitors, etc., as well as research workers, necessary to secure efficient working may, for the purpose of guidance, be taken as £200 per annum per worker.

(*e*) Depreciation and Obsolescence. An estimate of maintenance costs of laboratories apart from salaries is difficult to make at present, but it may be roughly taken to be two-thirds of the amount spent on salaries. The maintenance costs on this basis are included in Table IV.

TABLE IV

Capital Outlay and Maintenance Costs—General

	Cost per 1,000 sq. ft. Gross Floor Area.		Cost per Employee (occupying 225 sq. ft. Gross Floor Area).	
	£	£	£	£
Capital Outlay—				
Building . . .		600		135
Furniture . . .	175		40	
Apparatus . . .	650		150	
		825		190
Total Capital Outlay . .		£1,425		£325
Maintenance Cost per Annum:		£		£
Salaries		875		200
Maintenance . . .		575		130
Total Maintenance Costs .		£1,450		£330

Estimates are also difficult to make for depreciation and obsolescence. For research work, equipment is generally obtained to meet requirements of work in hand, and at the conclusion of the work the equipment may be virtually discarded, the figure of obsolescence being accordingly high. For routine work, the figure suggested by experience depends very largely on the care which is taken of apparatus and the degree of experience possessed by those using it. Breakages are generally high where inexperienced workers, such as many juniors and women introduced during the war, are engaged, and prevailing high and fluctuating costs militate further against any special figures being given which would be of value.

The high proportion of the total cost of maintenance which is covered by salaries renders the amount to be set aside for interest on capital, depreciation, and obsolescence relatively small by comparison.

Total Costs. By combining the figures given by Tables II and IV, costs of the four types of buildings of the sizes given, referred to in the former table, can be obtained. Table V shows the cost of a structure in reinforced concrete having plain finish.

TABLE V

Capital Outlay and Maintenance Costs for Laboratories Illustrated

Cost of	6,000 sq. ft.	12,000 sq. ft.		52,000 sq. ft.
	Type 1. Single Storey.	Type 2A. Single Storey.	Type 2B. Single Storey.	Type 3. Multi-Storey.
	£	£	£	£
Buildings	4,000	7,640	6,930	28,500
Furniture	1,050	2,100	2,100	9,100
Apparatus	3,900	7,800	7,800	33,800
Total Capital Outlay, excluding Land . . .	8,950	17,540	16,830	71,400
Total Annual Maintenance, including Salaries . .	8,700	17,400	17,400	75,500

Since space required for worker in a research building is most advantageously expressed in square feet, it has been convenient to give costs of building per square foot rather than per cubic foot. If the latter form is preferred, costs may be readily worked out from the plans. The dimensions should be taken to include the outer walls, whereas for the cost on a basis of area the dimensions inside the outer walls are taken. Heights for the five buildings illustrated, including the distance below ground to the top of the foundation, should be taken as 15 ft., 15 ft., 15 ft., 31 ft., and 58 ft. respectively. In determining present-day costs, it should be remembered that different building materials have not increased in price to the same extent.

The important facts brought out by Tables IV and V, particularly the latter, are that, excluding the cost of land, the cost of the building for the fabric assumed is somewhat less than half the total capital outlay. Further, the normal annual maintenance cost is about equal to the capital outlay. These relations—which are confirmed by published data relating to American laboratories—show very clearly that the cost of the building is of secondary importance, and therefore liberality should be shown in providing a building of ample size to cope with expansion of work. Also, in view of the cost of maintenance, of which the greater part is taken up by salaries, given a good staff it is altogether false economy to endeavour to limit expenditure on the equipment; and, further, every assistance in the way of illumination, ventilation, and good working conditions incident to the highest efficiency is a real economy.

EXAMPLES OF RESEARCH LABORATORIES

Metropolitan-Vickers Electrical Co., Ltd., Manchester

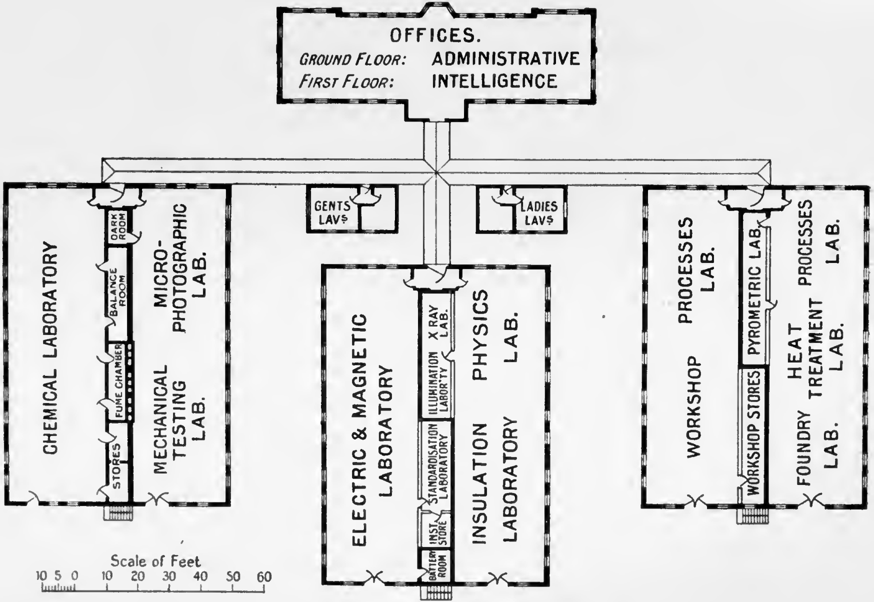
The manner in which the above principles work out in a practical example is indicated in the Frontispiece and Figs. 12–14, pp. 123–125, which show the Research Laboratories of the Metropolitan-Vickers Electrical Co., Ltd., Manchester, the construction of two of the four buildings of which are completed. These laboratories house a research organization which is closely associated with the manufacturing departments, and which is responsible for technical supervision of materials and processes involving considerable numbers of routine tests. It was, therefore, necessary to make provision in the same organization for workshops and laboratories for experimental processes on a semi-manufacturing scale, together with laboratories for precision measurements and research. Land was available for single-storey top-lighted laboratory buildings with room for extension. A block was therefore designed according to the plan shown in Fig. 12, which shows the relationship of the buildings to each other.

Fig. 13 shows the plan of the ground and first floors of the two-storey office block, the former being devoted to administration, the latter to intelligence work. The ground floor contains various offices for clerical workers, conference room, women's common room, and staff offices. The first floor contains the library and accommodates staff engaged in receiving, recording, translating, and distributing technical and other information. Fig. 14 shows the general arrangement of the laboratories, indicating provision for chemical work, mechanical testing, and photomicrography.

Floor Area. The total floor area available for the laboratories will be 20,400 sq. ft., and for the office block, 6,000 sq. ft. On a basis of 200 sq. ft. per worker, the laboratories will accommodate approximately one hundred active workers, or about one hundred and fifty, including clerical and other workers who do not need provision to the same extent.

Fabric. The laboratory buildings are of brick and steel construction, the latter being enclosed in concrete. The office block is wholly brick, with a flat roof.

Vibration. The separation of the buildings automatically removes any danger of vibration arising from the workshop and process building, where the heaviest



PLAN OF BUILDINGS

FIG. 12. RESEARCH BUILDINGS, METROPOLITAN-VICKERS ELECTRICAL CO., MANCHESTER
General Arrangement

work is conducted. In the buildings where delicate work will be conducted, as in chemical and electrical laboratories, the mechanical testing, electrical, and other machines are

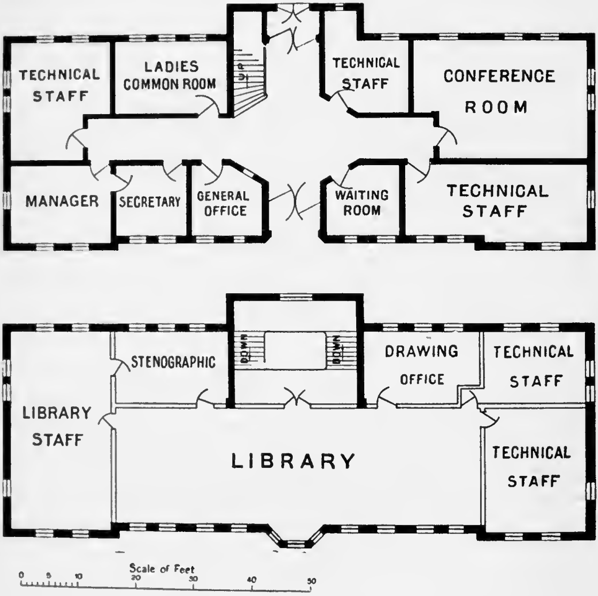


Fig. 13. Research Buildings, Metropolitan-Vickers Electrical Co., Ltd., Manchester
Office Block, Ground and First Floors

placed on isolated foundations, and where vibration is most likely to give rise to difficulty, as in delicate galvanometers and photo-micrographic apparatus, these are also placed on isolated piers.

Lighting. The natural lighting is excellent, the window

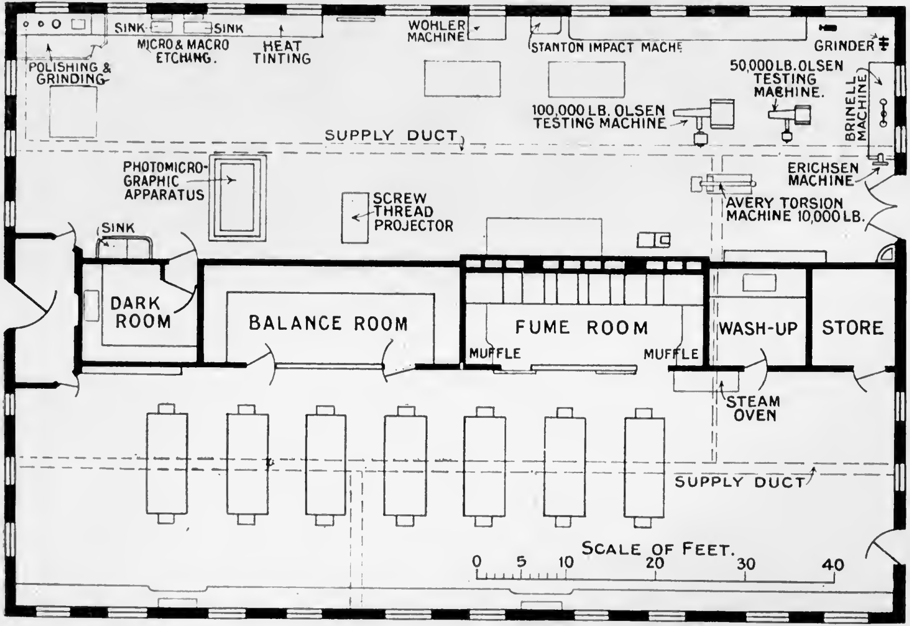


FIG. 14. RESEARCH BUILDINGS, METROPOLITAN-VICKERS ELECTRICAL CO., LTD., MANCHESTER
Chemical and Mechanical Testing Laboratories

space being ample, and additional top lighting is provided in the laboratories. The separation of the buildings by a distance equal to one half the width prevents undue cutting off of natural light at the sides. Artificial lighting throughout the offices is semi-indirect. In the laboratories frosted lamps are employed.

PROTECTION AGAINST FIRE. There is ample provision of chemical extinguishers and hydrants, but the sprinkler system is not installed as generally in outbreaks of fire in a laboratory much more damage is done by water than by the fire itself.

SUPPLIES. Supplies of compressed air, town's water, town's gas, and electric current are taken through a duct running down the centre of each laboratory, and are brought up to each point required, branch ducts being provided to the walls where necessary.

HEATING AND VENTILATION. Heating is effected by low-pressure hot water. The office block itself is naturally ventilated, the laboratories being specially ventilated with a view to the rapid removal of chemical fumes and to the elimination of dust from incoming air. Air enters the laboratories through filters under the windows, and is drawn through the main laboratory in each building into the smaller rooms, and thence to the roof through a duct by means of a fan placed on the roof at one end of each building.

INTERNAL FINISH. Panelling up to a height of 3 ft. 6 ins. is provided, and in the chemical laboratories opal glass is fitted above the benches, with plaster to the ceiling.

GENERAL PLAN. It will be noted that each laboratory is free from obstruction from one end to the other. This has been rendered possible by the adoption of a central corridor arrangement, itself naturally lighted, comprising the small rooms necessary to a greater or lesser degree in all laboratories. Thus, provision is made for balance room, fume room, stores, dark rooms, standardization rooms, etc.

FURNITURE. Furniture has been standardized as far as possible, and all unnecessary drawers have been eliminated. Apparatus continuously required is permanently set up, and adequate storage accommodation is provided for the remainder.

The examples given below will also serve to show the nature and extent of the provision made for research in all departments of modern industry, including the character of the buildings and the sequence of departments in the layout.

A. D. Little, Inc., Boston[1]

This modern laboratory is shown in Figs. 15–18, pp. 128–153. It is a consulting laboratory, the services of the staff being available to any company or individual retaining them. The bulk of the work is naturally applied research. Individual tests are carried out, together with investigations into existing materials and processes and new developments. The work is of the same type as that of a large manufacturing corporation, but generally covers a much wider field. The materials and processes of paper-making form a speciality of the company, and its success makes it an outstanding example of its type. The laboratory has a total floor space of 30,000 sq. ft. The initial outlay was $200,000 for building and $50,000 for equipment. A staff of 150 can be accommodated. With a staff of 60 the maintenance cost is $20,000 per month.

National Lamp Works, General Electric Co., Cleveland, Ohio

Fig. 19, p. 161, shows the Physics building of the laboratories of the National Lamp Works. Only pure research relating to the physics of illumination and its physiological and psychological effects on the human organism is conducted here. The floor area is 128 ft. × 38 ft. Fig. 20, p. 167, shows the Laboratory of Applied Science.

[1] In Figs. 16–17 and 23–24 the American practice of calling the ground floor of a building the first floor is followed.

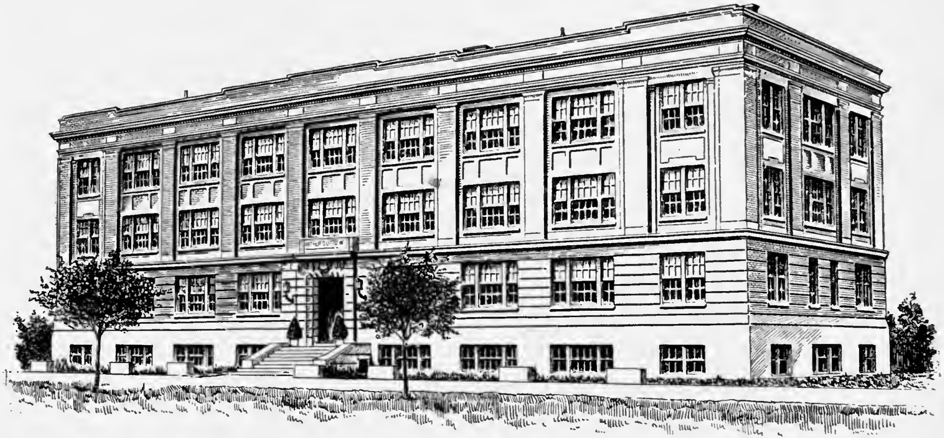


FIG. 15. RESEARCH LABORATORY OF A. D. LITTLE, INC., BOSTON, MASS., U.S.A.

(*See page* 127)

This works concentrates the whole of the research and manufacturing development work for incandescent lamps at Cleveland, investigating and standardizing lamp manufacture to ultimate details of construction of tools and appliances, which are then distributed to the various manufacturing works. The lamp industry is probably the finest example of an industry originating in and continuously developed by scientific research, and the National Lamp Works forms the most complete example for a works, forming virtually a gigantic laboratory centralizing research and technical skill and distributing manufacturing information in detail to subsidiary works. Fig. 21, p. 179, shows the lay-out of buildings, existing and projected, at Cleveland.

General Electric Co., Schenectady

This well-known research laboratory, shown in Fig. 22, p. 181, occupies five floors of the building shown, which is so arranged that the front and two side-wings enclose a courtyard, the rooms both back and front thereby obtaining good natural illumination. The laboratory occupies a floor space of 66,000 sq. ft. and employs about 150 workers.

Westinghouse Electric & Manufacturing Co., Pittsburgh, Pa.

Figs. 23, p. 185, 24, p. 189, and 26, p. 199, show the new research building of this company, exclusively maintained for pioneer investigational work, entirely separate from the other testing laboratories which are situated in the works some distance away. The building is three-storied. The basement houses (in addition to an instrument shop, machine shop and storage, goods receiving department, motor generator outfits, etc.) a ceramic laboratory with kiln and clay-working machinery, and laboratories for metallurgical work containing electric furnaces and rolling and wire-drawing machinery. The offices, library, and conference room are on the first floor, together with a metallurgical laboratory, standards room, metallographical laboratories, photographic dark room, and laboratories for advanced work on insulation, wireless development and condenser development. On the second floor there are laboratories for X-ray development, illumination, heat transmission problems; and also chemical and physical stores, and dining-room, etc. The chemical laboratories are on the third floor; in particular, laboratories for electro-chemistry, physical chemistry, organic chemistry with special reference to insulation, general chemistry with special reference to transformer, oils, etc., and analytical chemistry.

In addition to the above, there is a certain amount of space on the roof, partly enclosed and partly open, for general chemical and metallurgical work which needs to be isolated from the rest of the laboratory.

Kynoch, Ltd., Birmingham

The two-storey laboratory shown in Figs. 27, p. 203, and 28, p. 207, acts as a central laboratory for several works covering a varied range of manufactures, chemical, metallurgical and mechanical.

Brunton's, Ltd., Musselburgh

Fig. 29, p. 211, shows the laboratory attached to this firm of wire and steel cable manufacturers. It includes chemical, mechanical testing, microscopic and metallurgical laboratories, and workshop. The laboratories are being used for the initial manufacture commercially of an alternating stress testing machine.

Ioco Rubber and Waterproofing Co., Glasgow

This laboratory, shown in plan and elevation in Fig. 30, p. 215, is typical of a research laboratory attached to a manufacturing concern for the development and control of manufacture of new products, being quite separate from the works laboratory. A special feature is the provision of a technical room in which processes can be tested on a larger scale than is possible in the laboratory proper.

F. Krupp A.G., Essen

The extensive laboratories of this concern are indicated in Fig. 25, p. 193. The building is arranged so that three sides enclose a courtyard open on the fourth side, and the laboratories are very highly specialized.

CHAPTER VIII

THE CO-ORDINATION OF RESEARCH AND THE ORGANIZATION OF INTELLIGENCE

Scientific workers have recognized two principal values in research, an intrinsic value as a mental stimulus, an education, a widening of the field of knowledge, and a potential social value, not realized until the knowledge is suitably transformed and applied to everyday needs and requirements. These needs are so diverse and the body of science is so specialized that only in exceptional cases can the pure science worker even partially complete the application. This becomes the function of another type of scientifically trained worker having special knowledge of a particular industry, intimately acquainted with the state of the art and able to evaluate the possibilities of a given discovery, so that all industries may reap the benefit. No longer is the conversion of industrial managers to a better material, an improved process, or a cheaper product a speculative venture. Industry is assiduously forging the instruments whereby new applications of science may be made.

THE ORGANIZATION OF APPLIED RESEARCH

Applied research workers are being housed in appropriately designed and liberally constructed laboratories associated with specific concerns or with manufacturers' groups and associations, and these workers find at the present time unlimited opportunities for improvement by investigating in countless ways the snap judgments, necessarily hasty generalizations and tentative conclusions of a previous generation expressed in current industrial practice. The establishment of existing processes on a more efficient level will leave time and opportunity for the immediate incorporation of discoveries into industry. Industrial research is costly and suitable research men are few. The establishment of co-operative research, the development of private consulting laboratories, and the formation of industrial amalgamations tend to avoid overlapping which would be otherwise inevitable. Thus is industrial research becoming co-ordinated and organized to a coherent whole.

THE ORGANIZATION OF PIONEER RESEARCH

The relation between pure and applied research is so delicate that changes in the one are bound to influence the other, and sooner or later the question of organization of pioneer research is bound to arise. It has, in fact, already arisen and many earnest scientific workers believe that such organization is impossible, or, if possible, undesirable. Many fears regarding bureaucratic control have been expressed, and indeed, such fears for the future of research would be well founded if—as some have hastily assumed—the field of research were to be mapped out and workers allocated arbitrarily to portions of it. But organization does not mean this. True organization would aim at strengthening existing weaknesses without endangering that freedom to investigate which is the birthright of every pioneer research worker and which experience has proved to be the only satisfactory method of pursuing so elusive a thing as an idea. Such freedom means ultimately the complete adaptability of worker to subject; it implies perfect self-expression and perfect self-realization. Out of an unlimited field, work can be chosen which the mind developing it is best fitted to undertake.

True organization, which implies correlation of purpose without undue sacrifice of adaptability and flexibility, would seek to achieve the objects in view without the slightest injury to existing workers or their conditions of work, or without interference with their liberty to choose work they can best accomplish. This is the best selecting agency available. Organization which did not respect the conditions under which investigation is accomplished would fail, deservedly fail. It is, however, possible to ensure through organization that all existing *bona fide* workers should be enabled to practice research work continuously instead of intermittently, should be freed, if desirable, from the routine of university teaching, without necessarily being removed from the university, should be assisted with the best available equipment and apparatus. Organization would aim, by appropriate scholarships and methods of selection, at choosing those men and women for research who now proceed to other professions or who do not obtain opportunities of obtaining the necessary scientific training. Organized effort can be made to carry out that work of the nature of scientific hack work and routine, necessary but tedious, which is not likely to attract the unfettered student. It can seek to provide fundamental data, constants and standards relating to materials, and to publish such data freely and rapidly. The freedom of action of any worker to select his subject and develop it in his own way need not be affected. Overlapping, far from being a crime, would be recognized as a necessity. Organization can provide that full information regarding the work of all men in different parts of the globe without which the average worker is handicapped, and can thereby provide the opportunity for overlapping or for avoiding it, just as the worker desires. It can increase the probability of any particular scientific field being prospected which otherwise might remain untouched. Much of this organization will inevitably be provided by scientific men themselves. Only by its aid will it be possible to overcome the dangers of acute specialization and localized activity.

The crystallization of the two main branches of work, those of pioneer and of applied research, and the development of professional workers in each, must not be taken to imply that the two professions are sharply contrasted as regards personnel or professional environment. It has already been shown that distinction between the work done in each branch is difficult if not impossible to make. Men may pass freely from universities and research institutions to works research laboratories and *vice versa*, and in none of these is either branch necessarily exclusively practised. Further, the professionalization of research calls for consideration of the position of the scientific amateur. Fortunately, science, particularly in England, has been enriched by the devoted work of men who sought a livelihood in other spheres of activity, or who had private means. The scientific amateur, usually the most enthusiastic of men, will still find his brother workers value all the services he can render. He may find it increasingly difficult to become sufficiently specialized, but no one perhaps can so effectively study the by-ways of science. He is even less fettered than the full-time research worker.

SCIENTIFIC RESEARCH AND PUBLIC OPINION

The process of co-ordination does not cease with the establishment of closer relations between research workers themselves. The process of rendering available to the average citizen the resources of science necessitates the technologist engaged in the routine production of industry, the manufacturer, the salesman, the publicity expert, and the whole rank and file of the industrial army. Hence the importance of permeating the industrial world with the need for and possibilities of research, for establishing the fullest contact between research workers themselves and between them and the public in whose hands the future of research must largely rest. The extent of the application of science to industry depends upon fruitful contact between the applied and the pure research worker, but the development must not be hindered by conservatism on the part of workmen, employers or the public to the changes it brings in its train. The importance of liberal outlook on the part of workmen is illustrated by the manifesto issued recently by the American Federation of Labour, which is none the less important because it may represent the opinion of union headquarters rather than that of the ordinary worker, and merits quotation. The manifesto reads as follows—

Whereas, scientific research and the technical application of the results of research form a fundamental basis upon which the development of our industries, manufacturing, agriculture, mining, and others must rest; and

Whereas, the productivity of industry is greatly increased by the technical application of the results of scientific research in physics, chemistry, biology, and geology, in engineering and agriculture, and in the related sciences; and the health and well-being not only of the workers but of the whole population as well are dependent upon advances in medicine and sanitation; so that the value of scientific advancement to the welfare of the nation is many times greater than the cost of the necessary research; and

Whereas the increased productivity of industry resulting from scientific research is a most potent factor in the ever-increasing struggle of the workers to raise their standard of living, and the importance of this factor must steadily increase since there is a limit beyond which the average standard of living of the whole population cannot progress by the usual methods of readjustment, which limit can be raised only by research and the utilization of the results of research in industry; and

Whereas there are numerous important and pressing problems of administration and regulation now faced by Federal, State, and Local Governments, the wise solution of which depends upon scientific and technical research; and

Whereas the war has brought home to all the nations engaged in it the overwhelming importance of science and technology to national welfare, whether in war or in peace, and not only is private initiative attempting to organize far-reaching research in these fields on a national scale, but in several countries governmental participation and support of such undertakings are already active; therefore be it

Resolved, by the American Federation of Labour in convention assembled, that a broad programme of scientific and technical research is of major importance to the national welfare, and should be fostered in every way by the Federal Government, and that the activities of the Government itself in such research should be adequately and generously supported in order that the work may be greatly strengthened and extended.

Technical institutions and personal relationships will provide for contact between research workers. To develop a healthy public opinion another profession is needed, that of a scientifically trained person, part teacher, part journalist, better informed than both but equally capable of appreciating the outlook of those who know little of science. The need for such men is urgent, for true appreciation of science does not arise from incredulous wonder at the miraculous. Knowledge of its difficulties must precede proper comprehension of its wonders.

THE PUBLICATION OF SCIENTIFIC INFORMATION

Most scientific work when accomplished is published, and publication forms the principal channel whereby research results are communicated and most workers have attempted in the past to keep in touch with contemporary work in their own and related fields. The importance of publication in enabling research workers to achieve a measure of voluntary co-ordination of effort necessitates some means whereby present difficulties may be overcome, for rapid advance and acute specialization make it more difficult than ever for any single worker to keep fully abreast of those developments even in his own work which may be in progress at institutions in many different countries, both in the East and in the West. The increasing recognition of the value of research will constantly result in more intensive effort and closer application on the part of all research men, who cannot fail to be stimulated by the esteem they value more than financial reward. There is a general shortage of research workers, due to war losses and to the virtual stoppage of the flow of men from the universities for five years.

It will probably be argued that in much applied research the investigators are not willing to have the results published. It is true that much industrial research is conducted by those who for commercial reasons do not desire publication, such as manufacturers or manufacturers' associations. It is, however, not necessary that publication should be broadcast and general in order to prevent overlapping. In the case of British Research Associations, the Department of Scientific and Industrial Research itself proposes to act as a clearing house between the various bodies undertaking State-aided research, and from its knowledge of work in progress to facilitate communication between Associations, and thus reduce the extent to which, otherwise, duplication might occur. In the case of individual firms, industrial amalgamation has reduced very considerably the necessity for many small firms each to do similar work, and the needs of the principal groups that are able to undertake research are usually sufficiently diverse to prevent undue duplication. Where knowledge is required of a fundamental character common to such groups, it may be found expedient to obtain this co-operatively through a Research Association, State-aided or wholly supported by the industry or groups concerned. Free discussion at meetings of technical societies is another form of publication which is frequently helpful, and if undue dissemination of knowledge is considered to be economically disadvantageous, confidential meetings for free discussion, unreported by the technical press, as were common between technical staffs of different firms during the war, might obviate the difficulty. As against such a practice, which has many undesirable features, it may be noted that the Research Laboratory of the National Canners' Institute at Washington, supported exclusively by an influential group of canners distributes its results to all canners in the industry, whether

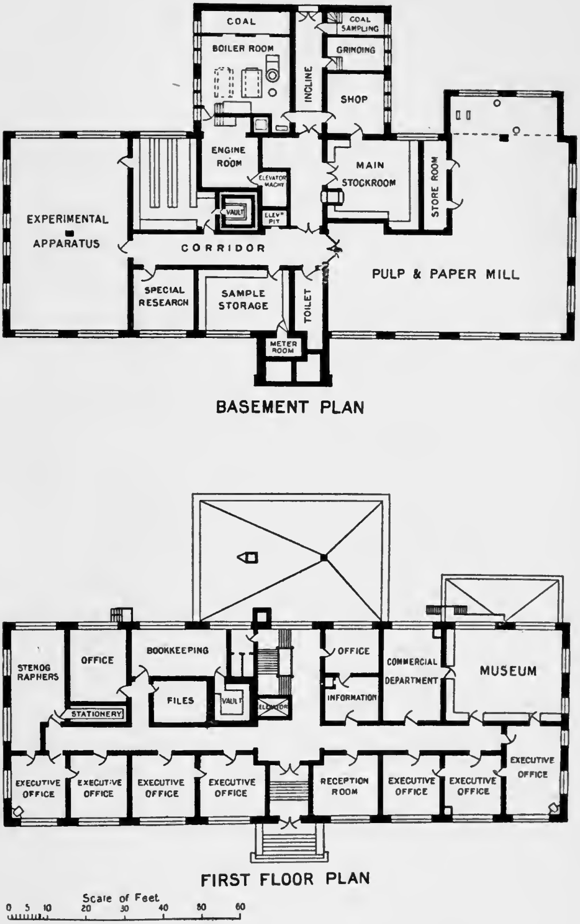


FIG. 16. RESEARCH LABORATORY OF A. D. LITTLE, INC.
Basement and First Floor

(*See page* 127)

members or not. While at the present time it may be difficult or impossible to arrange for publication of the results of industrial research, it is hoped that those who are responsible for the conduct of such work will adopt a broad-minded policy in this respect. The reasons urging such a course are many. In the first place, recognition through publication is one of the chief stimuli of research workers. Extra emoluments obtainable in industrial research, as compared, for instance, with university fellowships or lectureships, will not compensate the worker with the true research spirit if publication in any form is denied him. Wherever possible research workers should be permitted to embody the results of their work as theses for higher degrees and encouraged to publish articles in recognized technical periodicals or present papers before technical and scientific institutions This in itself is an important part of the training of the young worker, and enables him to obtain facility in presenting facts to be understood by those unfamiliar with his work. Ability to write a terse but complete report from the inception of the work to the conclusions or recommendations is rare.

It is now generally admitted that free discussion and interchange of experience and knowledge is advantageous to all parties concerned, and the interchange results in a greater gain than loss. At the same time, it must be admitted that there are manufacturers and others who habitually depend for progress upon advancement from such open disclosure of trade information. Successful manufacture rests less and less on the "trade secret," and more upon sound organization, on priority in the market, and on capable executives, and to a lesser extent than ever will a trade secret help to cover up faulty management. Those who place most trust on trade secrets are frequently those who have least to conceal. With regard to market priority, it may be noted that manufacturers who make use of the Mellon Institute, of Pittsburgh, are able to defer publication for a period of three years and even for a longer period if they can prove that they are likely to be harmed by disclosure at the end of this period.

The remaining argument in favour of free discussion lies in the comparative ease with which trade secrets may be discovered by determined and persistent investigation, and to this extent manufacturers who adopt research are able to compete successfully with those depending upon such obscure knowledge. Indeed, investigation into long established trade secrets is likely to yield even better methods or processes than the necessarily more limited efforts or the chance observation which led to the original discovery.

The type of trade secret more particularly referred to above is the practice followed in an industrial process with which those outside the factory or the industry are not acquainted because they are unfamiliar with the character of the work involved. Such processes must not be confused with those based on scientific work and carried on wholly or in part under strict secrecy because of the difficulty of detecting and preventing infringement which renders patent protection worthless.

Summarizing, it may be said that the first step to a practicable and economic degree of co-ordination of research on a national or international scale can only be secured by keeping research specialists fully informed of the progress taking place in their particular lines of investigation and in branches allied to it or dependent on it. Such co-ordination involves a much more definite and positive organization than has been comprised by the casual and unrelated efforts in the past, and may be considered in some detail.

THE ORGANIZATION OF SCIENTIFIC INTELLIGENCE

Research must be based on complete knowledge of the whole of the activities that bear on the problems under consideration. Investigators are likely to have much less time in the future for acquainting themselves with the work of others than has been the case in the past, and the growth of science, specialization, and international character of research makes this increasingly difficult. The systematic acquisition and preservation of information, therefore, necessitates a separate organization, for it becomes a specialized business with its own trained workers, and this is most effectively carried out by a specially trained staff at a much lower cost than is entailed if it is distributed among research workers.

Advantages of Documentation

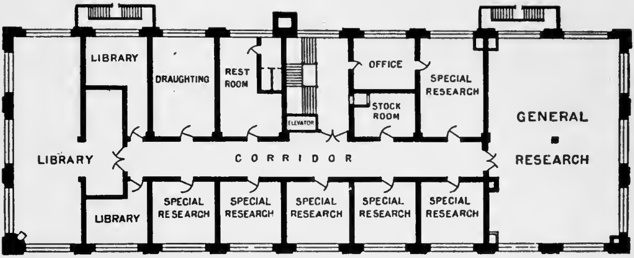
The advantages of an adequate service of information, the process of collecting, indexing, and distributing, which has been termed in France *documentation* scarcely need elaboration. It relieves the research worker of the often tedious necessity of making searches for information, and provides those who are temperamentally disinclined to examine the work of others with less excuse for such neglect. It renders unnecessary great fluency in translating foreign languages—although this is always a great advantage—and ensures that the progress of science communicated in a language not usually read in English-speaking countries (i.e. Russian or Japanese) is not neglected. Adequate knowledge of existing work prevents expenditure on its repetition—a determining factor in the research policy of an industrial organization. Bibliography exercises a profound influence over other fields of science. When new matter is assimilated and become part of the mental content of the research specialist, duly related to his previous knowledge and experience, thoughts and ideas arise in his mind which lead to further progress. It is impossible to over-estimate the inspirational value and fertilizing power of ideas thus presented. It affords opportunities to scientific workers of becoming acquainted with progress in branches other than their own. No science advances independently of others, and development in one branch is frequently delayed until the advent of an improved material or process or method of testing which forms part of the legitimate sphere of activity of another science. Documentation, moreover, may to a considerable extent offer a means of correcting the evils arising from over-specialization, and is also especially valuable to the teacher and student. In a research organization it is a primary requisite in formulating a research policy.

Finally, it offers enormous advantages in a field of work the importance of which is only just being appreciated, namely, scientific publicity. Industrial research is of little value unless contemporaneously with it methods are pursued of educating the public to know the possibilities, limitations, and achievements of science, and to welcome its advancement. In no field is this more important than in industry, where advance is likely to be most delayed by the almost incurable conservatism of the employer or worker. This work of popularization can be conducted as part of the ordinary working of the educational system to juveniles, and as part of adult education through lectures, articles, papers, and addresses to audiences of all kinds, assisted by experimental illustrations and concrete practical applications. There is very great scope for journals in this field, both for the ordinary public, the scientific amateur, and the professional man, and it is not difficult to forecast the probable development of what is virtually a new profession, comprising *vulgarisiteurs* who are engaged in journalism, public speaking, or teaching popular science. Documentation not only makes accurate presentation of such information possible, but renders this possible with a minimum delay between the appearance of the results of new work and their assimilation by the public, and only when this is literally part of the mental content of the multitude can it be said to have achieved its final object.

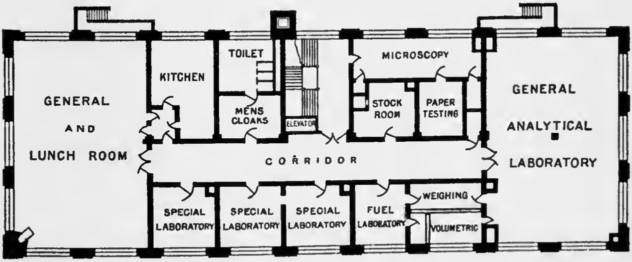
Research thus requires for its proper growth the sympathy, encouragement, and practical assistance of the community, and particularly of representative leaders of public opinion. The relative inertia of manufacturers in many directions before the war in Great Britain may be ascribed largely to a laxity arising from ignorance of the work being done by our competitors abroad. This attitude has undergone profound change during the war, and the most important problem now is to ensure that research activities are directed along the most fruitful channels. Through documentation we may largely overcome our backwardness by becoming acquainted with the progress made by other industrial countries, and so avoid the necessity of repeating much of their work.

National, Municipal or Local Basis

Assuming the desirability of the systematic collection, collation, and distribution of intelligence, the question arises of the character of the machinery by which this may be done. Superficially, the idea of such work on a national or even international scale is extremely attractive. There are obvious advantages in the centralization of such work in one place where the whole field of knowledge may be covered. On close examination, however, such a scheme breaks down completely. An analogous position is found with regard to ordinary libraries which, in general, have formed the nearest approach to organized intelligence work hitherto existing, and it is generally acknowledged that they should be widespread. The great central libraries, especially national collections such as the British Museum, are rich treasuries and store-houses of information of great historical value. They are, however, scarcely to be recommended to the student who wishes for immediate information. Beyond a certain limit, centralization of material defeats its own object, not



SECOND FLOOR PLAN



THIRD FLOOR PLAN

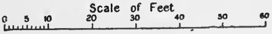


FIG. 17. RESEARCH LABORATORY OF A. D. LITTLE, INC.
Second and Third Floors

(*See page* 127)

only because of the unwieldy character of the internal organization, but because of its distance from many of those who are in need of its services.

The centralization of intelligence has, in fact, already been tried and found wanting. The Institut International pour la Bibliographie at Brussels represents an attempt to provide an index to human knowledge. At the outbreak of war it contained no less than eleven million index cards. The Institut failed to realize the hopes of its founders, partly, perhaps, because the time was not ripe for its development, but mainly owing to its inaccessibility except to those in a small area, and the delay arising from submitting enquiries by post. A difficulty also arises just as with an ordinary library. However able, courteous, and willing the officers may be, they are not in a position to appreciate the technical requirements of the enquirer, who, consequently, has to be left to search for himself. Thus, the great advantage of properly designed intelligence work—economy in time of the research worker—is lost. Unless very carefully organized and staffed, an intelligence service loses much of its value as the scope of its activities widens.

The same reasoning applies to local libraries provided by municipalities or other public bodies for general use. To the student, the small manufacturer, the teacher, the public at large, such institutions may be very valuable, particularly if they are specialized on the lines of a staple local industry, but they cannot pretend to meet the demands of experts and specialists, whose existing needs, even in one branch of science or industry, are sufficient to justify an independent intelligence service.

These considerations lead to the conclusion that intelligence work cannot conveniently be handled on a national or even municipal scale, but that in connection with scientific research an intelligence service should be provided for every private, industrial, consulting, municipal, national laboratory or Research Association interested in conducting and fostering scientific research. The laboratory or research department is the natural unit. If the laboratory carries on work which centres round a common subject, the intelligence service does the same. If the laboratory is interested in many matters having no specific relationship, the intelligence service will cover an equally wide field.

Modern Intelligence Service

The functions and organization of an intelligence service outlined below refer primarily to the needs of a works research laboratory or Research Association, but the service is not limited to research work. It may be applied to a manufacturing business as a whole, and provide that information on which business policy may safely be planned. It is applicable to a municipal or private monopoly, a railway, an educational institution, a Government department, or a commercial house. The greater the ramifications of enterprises, the more necessary does intelligence work become. It represents order and system at a point where it is most needed—in the adequate collection, digestion, treatment, recording, and distribution of knowledge affecting the work in hand. Through its assistance, policy based on unconsidered judgments, hasty decisions, and partial knowledge can be eliminated, the forewarnings of industrial difficulties, trade depressions, competition can be received and to a considerable extent evaluated.

Functions of Intelligence Service

The functions of an intelligence service associated with a technical research laboratory, industrial or otherwise are as follows—

1. Searching for and collecting information necessary in the prosecution of the work of the laboratory.

2. Translating, cataloguing, indexing, classifying, and filing or otherwise preserving such information, or reference to it, for permanent record.

3. Evaluating and abstracting this information and preparing bibliographies.

4. Distribution of information.

5. Maintenance of internal research records and preparation of research reports from data furnished by investigators.

6. Publicity work.

The information may be from public sources, such as periodicals, Government publications, patent and other specifications, or private, from co-workers, consultants, or other experts.

The field of operation in the case of a pioneer research laboratory is comparatively easily determined and comprises the sciences with which the laboratory is concerned. In the case of an industrial laboratory, the conditions are much more complex. The materials employed in the industry, its processes and products, conditions influencing the efficiency of labour, and many other matters have to be included, and the number of sources of information is enormously wider. The utility of inventions submitted, and proposals for the adoption of new manufactures under licence from an inventor or under other conditions may have to be considered.

The intelligence department should at first confine its attention to specific requests for information, as the necessary organization is built up slowly, and time is required to ascertain in what ways information may be provided automatically with the certain knowledge that it will be useful. When a request is made, general in character, it is necessary to institute a search for matter, going as far into the past as is deemed desirable, frequently to the publication of some classic paper, patent specification, or text-book. The resulting bibliography should be enlarged systematically as new matter appears in the press, or as advances are made in the research laboratory.

Such of this information as may be on file should be classified and indexed, preferably under some well-known and generally accepted system, such as the Dewey classification, which, for specialized collections, may be slightly modified, but which for miscellaneous work is best used intact, unless the collection is so special and peculiar that a totally different system is preferred. The extensions to this system which have been issued by the Institut International, Illinois University, and others, will be found helpful. A librarian skilled in the use of the system is, for a service of some magnitude, essential, as in specialized scientific work the intelligence department in a works or other laboratory will be among the first to recognize the necessity of new subdivisions of the classification as knowledge expands. It is virtually impossible to secure workers who are both technically trained and expert in library science. A suitable compromise will be found in a capable librarian, preferably a graduate, with considerable general knowledge, common sense, and intelligence, supported by the necessary translators and abstractors, together with a small force of technical men who can, without interfering with the general organization, make searches for purely technical information. Such work is excellent training for young graduates entering a laboratory, and there is no serious loss if such men are replaced from time to time, and passed on to other branches of work. Continuity is highly desirable, however, in the case of those workers responsible for the indexing and filing of data. Even with the best index, a close personal knowledge of the files is always helpful, especially if this is associated with a good visual memory.

The matter filed will comprise books, periodicals, transactions of societies, journals, pamphlets, trade catalogues, patent specifications, all in various languages, together with reports prepared from work done in the research laboratory. Considerable care is required in the selection of books, in view of the great amount of matter published, and articles in periodicals are so frequently reprinted without proper acknowledgment of the source that considerable verification of original sources is required.

CHAPTER IX

THE RESEARCH WORKER

THE staff forms the all-important and vital feature of a research organization. In scarcely any sphere of intellectual activity is work so highly individualized as in scientific research ; in none is it more difficult to substitute one worker for another, because the effort and the achievement of each worker are so intimately associated with his own mind and personality.

The character of research, both pure and applied, necessitates a wide variety of workers, differing greatly in kind of ability, training, and temperament, and it is erroneous to suppose, particularly in applied research, that only the services of men of genius can be employed. The nature of scientific discovery and invention, the types of men required for their accomplishment, and the manner in which they may be effectively educated, trained, and employed may now be considered.

DISCOVERY AND INVENTION

The distinguishing characteristic of research work is the continuous demand made on the creative faculty in the endeavour to reveal new truth, i.e. a discovery. Causes are ascertained underlying the effects which appear as manifestations of natural phenomena, in order to achieve a complete understanding of the working of natural law.

Invention, on the other hand, aims not at the disclosure but at the practical application of a principle, which may be fully or only partially apprehended. The inventor is concerned with immediate ends, with the limited problems of materials and methods. He may study and work scientifically, but only so far as his problem demands; he is not concerned with or attracted by observations leading to side issues, however interesting they would be to a scientific worker. Instead of pursuing experimental work with a view to arriving at an indeterminate conclusion, the inventor directs the experiment to yield a predetermined result.

The Inventor

While inventive capacity characterizes some men more than others, its practical expression is very largely determined by immediate environment. The most important part of an invention consists in the apprehension of the unawakened need which the invention is to satisfy. It is therefore scarcely surprising that, except in rare cases, as for example, Edison, invention is not a profession continuously followed, a circumstance which affords a fundamental distinction between it and scientific research. Discovery involves a long and specialized training which hampers a worker as an inventor in so far as it keeps him in a scholastic environment during those impressionable years in which he might learn to sense the needs, the appreciation of which predetermines invention as ordinarily understood. A research worker, a discoverer, may be an inventor in the strict sense, for he may develop a new device or instrument or method of testing, but this is, as a rule, incidental to his normal work.

A considerable and increasing proportion of modern invention is carried on by technologists—engineers, chemists, metallurgists and others—in the ordinary pursuit of their professions, and represents the normal process of improvement and adaptation in the materials and methods of the industry concerned, and between the modifications of the experienced technologist and the attempts of the inexperienced amateur every kind of invention is comprised.

Modern industry develops considerably through invention, can, indeed, develop in no other way ; but increasingly the inventions will be made largely as a matter of course as a consequence of discovery, rather than be achieved in advance of a full understanding of the underlying principles made clear by a lengthy process of trial and error. Consequently, little is to be expected in an industry from the

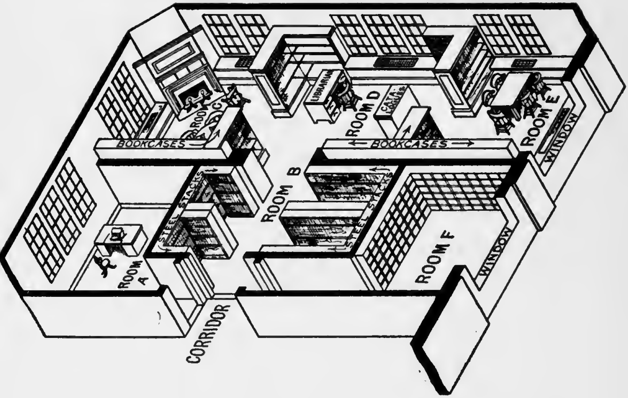


FIG. 18. RESEARCH LABORATORY OF A. D. LITTLE, INC.
Isometric View of Library
(*See page* 127)

inventor who is not a scientific specialist and who desires to concentrate exclusively on invention. He scarcely finds a place in a research organization.

The Discoverer

Discovery may be pursued by two methods, which demand sufficiently different mental characteristics broadly to distinguish and differentiate scientific workers. The first may be termed the fundamental method, which is theoretical, frequently mathematical; the second is empirical and experimental, differing, however, from the ordinary methods of the unscientific amateur in being systematically pursued and in leaving no possibility unexplored. The two methods may be admirably illustrated by the respective works of Newton and Kepler. The former was primarily an abstract thinker who tested the validity of his conceptions by experiment. The latter, determined to find the law in obedience to which planets swing round the sun, tried practically every mathematical equation which suggested itself to him before finding a solution.

The theoretician is able to discern almost intuitively the principles underlying natural laws, the experimenter is distinguished by manipulative skill and by interpreting results in a more limited if theoretically more complicated field. Some experimenters are accomplished in applying principles to practice, i.e. as inventors, others handle effectively and systematize large masses of complex results, others provide accurate constants and standards.

The actual process of discovery pursued is similar for each type, but the theoretician takes the facts on which he works from existing knowledge, while the experimentalist determines his facts by appropriate trial or relies on a pure speculation. The difference between the two types will be made clear by consideration of the *modus operandi* of discovery, as it will be evident that the former method is suited to broad generalizations, and the latter to conclusions covering a more limited range. To the former belong some of the magnificent scientific prophecies which it has been the privilege of an experimentalist, with the aid of special apparatus and skill, to verify, such as that of the existence of electric waves by Clerk-Maxwell. The existence of a co-ordinated mass of scientific knowledge achieved by experiment renders the possibility of such prophecies progressively greater.

Occasionally the ability for both is found in one person; the capacity for abstract thinking, wide range of knowledge in several sciences, and the balance of a truly philosophical mind coupled with the instinct for detail, careful observation, rigid accuracy, patience and skill of the experimenter. Faraday, Kelvin, and Darwin are illustrative examples. Both require genius, but genius of a different order. When a theoretician has little patience or skill in experiment, his work frequently lies in the field of the philosophy of science and the unification of scientific knowledge.

SYNTHESIS OF IDEAS IN DISCOVERY

Since the progress of industry is bound up with research, it is of the utmost importance that research workers achieve their highest degree of efficiency and be subjected to no restricting influences. Some degree of comprehension of the normal process of discovery is desirable in order to ascertain the extent of these restricting influences in industrial work.

Education consists in the deliberate creation of a distinct mental environment in order that the presentation of ideas to the mind may be organized. Modern educators base their practice substantially on the principles of Herbart, who considers that the mind itself, having no capacity initially to receive or produce anything, is of much less importance than the supply of ideas to the mind. Under the influence of successive ideas the mental content is modified and the mind reacts differently to succeeding ideas. Initially, according to the Herbartians, ideas, not being innate, enter the mind only through the senses; but, in a mature person, they may arise through conscious reflection. In this case one idea succeeds another in the focus of consciousness through natural associations between ideas, a mental group of ideas each linked in sequence with others, so that one calls up the succeeding one in the chain, being termed an "apperception mass." The creation of apperception masses is the main function of education, and naturally the larger, more numerous and better arranged these are, the broader is the education afforded. The masses existing when an educand begins to think for himself and to become a conscious self-educator are widened by experience and by conscious reflection. They are vitally necessary in the process of observation and experiment required of research workers, for they supply that existing knowledge and understanding which are essential to fullest observation. The lack of apperception mass explains why untrained workers are unable to observe details readily apparent to the skilled eye, and the presence of unusually large masses in the same manner is the reason for a discovery by one man from observations overlooked by others. The influence of so-called casual or chance observations leading to discoveries is considered later, but it may be observed here that while unexpected phenomena may be met in scientific research, the opportunity of making the necessary observations only occurs to those trained to receive and make use of them. To others the phenomena would be unobserved, or, if observed, not understood, and dismissed from the mind. Since observations are limited to those which our apperception masses can use, there are no chance observations in the ordinary sense. They can only be made by minds already prepared. Since no two people have precisely the same experience, the same thing to different people conveys different ideas. Herbart considered ideas as either similar, disparate, or contrary. Similar ideas, when presented to the mind, fuse to form a stronger idea. Contrary ideas oppose each other so that the two cannot be in the focus of consciousness simultaneously. Disparate ideas are non-comparable, but combine to form a complex idea. If, therefore, two complex ideas are presented to the mind at the same time, the similarities in both combine; the contrary elements oppose; the disparate elements form a new complex.

Professor Adams illustrates the process by imagining a countryman seeing for the first time a porter's two-wheeled barrow at a railway station. It naturally calls up in his mind the wheelbarrow he uses at home. The similar elements in the two complex ideas, such as carrying, pushing before, two-handledness, woodenness, and other resemblances, fuse to form a stronger idea of a wheelbarrow. On the other hand, the two-wheeledness of the new barrow differs strongly from the one-wheeledness of the more familiar article, the ideas being disparate, and complication results. These two ideas cannot be combined, and they are arrested at this point, but the conception of the wheelbarrow is permanently widened.

The Process of Discovery

The possibility of discovery is therefore dependent upon the presence in the mind of suitable, preferably large, and well-arranged apperception masses arising from previous experience. These are naturally very largely dependent upon education, not necessarily for providing the masses themselves, but for the acquisition of methods of thinking and of classifying ideas, of mental alertness in absorbing them. The new facts required to give rise to ideas are afforded by experimental work, the theoretician deriving his selections from the work of others, the experimenter determining those he requires for himself. These ideas are linked with existing masses and new or wider conceptions result by the process indicated. This, however, is not accomplished without a high degree of mental effort.

With a degree of self-analysis rare even in a discoverer, the distinguished French physicist Poincaré has given his own interesting experience to support his theory of the process of discovery, which is in such close accord with common experience as to warrant acceptance. The relations between facts are expressed by definite laws, and since the universe contains an infinitude of facts, he suggests that the dominating factor in discovery is the selection of appropriate facts between which a relationship has to be established. Facts which continually recur, the simplest facts, are those most interesting to the scientific worker. Discovery consists in constructing new and useful combinations of selected facts, such combinations suggesting themselves to the mind of the discoverer by virtue of the harmony which exists between them as a consequence of their relationship. This harmony or concord appeals to the sense of aesthetic beauty.

Poincaré relates that for a period of two weeks he spent a portion of each day endeavouring to prove that there was no function analogous to what he afterwards termed Fuchsian functions. After a restless night, during which a host of ideas were surging in his mind, he found that he had established the existence of one class of Fuchsian functions, derived from hypergeometric series. During the night two hitherto unrelated ideas coalesced to form a new conception. The verification on rising was rapidly completed. Guided by analogy with elliptical functions, he then endeavoured to represent these functions by the quotient of two series, and succeeded in forming Theta-Fuchsian series. At this moment a period of rest supervened in the form of a railway journey, and without warning or preparation, but with absolute certainty, the idea came to him that the transformations he had used to define Fuchsian functions were identical with those of non-Euclidean geometry. Later the suggestion was verified. Subsequently, without suspecting any connection with his previous work, he studied arithmetical questions, but failed to achieve any result. During a holiday the idea came, characterized again by conciseness, suddenness, and immediate certainty, that certain arithmetical transformations were identical with those of non-Euclidean geometry.

From this result he deduced that there were other Fuchsian functions than those corresponding with hypergeometric series, and succeeded in forming all these functions but one, which still baffled him after long and persistent effort. Another involuntary rest period took place on account of military service, and during this, quite suddenly, while crossing a street, the solution came to him.

This experience was quite normal and usual in other researches, and is confirmed by other scientific men, and it is permissible to conclude that the process of discovery is as Poincaré indicates. There is little doubt that the conscious mind merely reviews the selected facts during the first period, and that the unconscious mind takes the results of this apparently fruitless work and achieves the necessary combination.

Poincaré endeavours to explain the operation of the unconscious mind, which appears to work with a far greater degree of certainty than the conscious mind, by the suggestion that the former is not inferior to the latter, not automatic, is capable of discernment, selection, divination and that the aesthetic sense is influenced by the beauty of and concord between the most harmonious combinations, which are thereby impressed on the consciousness. The unconscious mind never gives a ready-made result, only a point of departure for something new. The characteristic features of the process appear to be, firstly, a period of intense mental application, in which the facts concerned —the selection of which is of paramount importance—are marshalled in the mind, followed by a period of rest or of application in another direction, in order that the unconscious mind may have an opportunity of completing the process by precipitating a new relationship between them only requiring verification, and which springs to the conscious mind with the suddenness of illumination. It is therefore, to a considerable extent true that the apparently unproductive and idle moments of reflection and meditation may be the most fruitful of all ; that a worker denied by pressure of other duties of adequate opportunity for freedom from activity, even in working hours, is not being placed in a favourable position for discovery. Furthermore, while these steps can readily be taken in a research organization to ensure the highest productivity of workers, it must be borne in mind that no amount of intensive application of these principles will necessarily result in discoveries.

Research work is a speculative adventure in which effort, time, or money have to be staked without expectation of reward. Much work may and almost certainly will be abortive, although to the right type of worker negative results have their value. In other cases, investigations may lead to results which are of scientific interest but of little immediate commercial value.

Scientific discovery is an art, the conditions of success in which may to some extent be externally controlled ; if success may not be commanded it may be more effectively ensured by observing the conditions.

The Empirical Worker

The experimenter approaches a problem from a slightly different aspect. He deliberately limits the number of facts with which he has to deal by endeavouring to establish possible correlations between selected facts experimentally. The results obtained frequently reveal relationships which suggest further experimental work. Frequently no regular variation is discovered, while in other cases a relationship only holds good for the particular conditions and within the limits of the experiment. The relation so determined is generally expressed by a curve, and any interpolation or extrapolation has to be very judiciously conducted. Such work frequently involves considerable drudgery, but this is necessary when the number of conditions or variables to be considered in any given case is greater than can be taken into account on a theoretical basis. Each variable has to be isolated, and the effect of its regular continuous variation separately ascertained, and the final effect of two or more simultaneous variations can then occasionally be predicted. In some cases the number of conditions to be considered is so great that it is helpful if assumptions are made to simplify the treatment and to make it amenable to theoretical discussion, a mode of procedure scouted by the "practical" man.

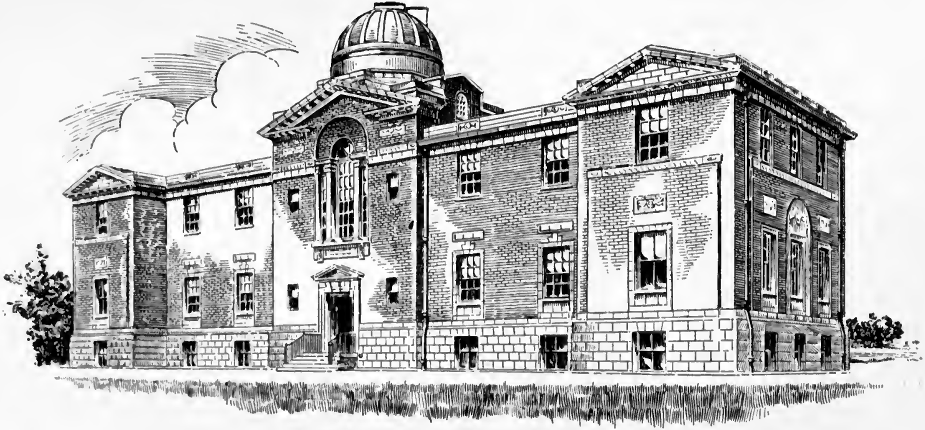


FIG. 19. RESEARCH LABORATORY, NATIONAL LAMP WORKS, GENERAL ELECTRIC CO., CLEVELAND, OHIO, U.S.A.

(*See page* 127)

It must not be supposed that theoretical and experimental workers are clearly differentiated. There are in between both extremes all grades of workers, differing slightly from each other in ability, and whose natural aptitudes have been profoundly modified by education, training and experience. Nor does it follow that a worker will succeed in one branch as well as in another. Theoretically he may, but practically his apperception masses in the two branches differ considerably. On the whole, however, a worker, by a process of self-realization and self-selection, finds for himself in what line he is most likely to succeed.

Chance in Scientific Discovery

Attention has frequently been drawn to the apparently fortuitous character of many discoveries, in which a worker has been pursuing an investigation with one idea and has achieved a totally unexpected result, or has made a discovery through a chance observation. Röntgen, for example, discovered the rays which bear his name from the observation of an actinic effect on a photographic plate which occurred while he was working in a dark room. In any form of enquiry or exploration it would be remarkable if the unexpected was not frequently encountered, and research is the art of making use of the unexpected. The occasional casual observation—the success of which always receives more attention than that of hundreds of regular observations—can only be seen and used and its causes traced by a highly trained observer. Countless happenings every day would lead to discoveries of the first importance if observed by a scientific investigator, but they are either not seen or are dismissed as curious and left unexplained. Chance observations, therefore, do not in any way detract from the prestige of discovery, and the occasional fortuitous event should not blind those responsible for encouraging research to the fact that science is steadily forging the weapons whereby it can predict and prophesy, a condition which will render the unexpected increasingly rare.

To work aimlessly, without definite policy, in the hope of making a chance discovery is to court failure. Just as it has been said that a straight line extended from any point through infinite space would sooner or later meet a star, so a consistent research programme will ultimately reveal a discovery, the magnitude of which may be small. As to what may be chosen to work on, Dr. Whitney has significantly said: "The equilibrium between mental and material conception is so sensitive that anything which to the fair mind seems possible is to the trained persistence permissible." The fair mind implies, of course, the mind educated to evaluate carefully the possibilities and to such a mind a chance effect is automatically followed by an examination of the cause.

CHARACTERISTICS OF RESEARCH WORKERS

It has been emphasized by several scientific workers, notably Sir Michael Foster, that achievement in science does not demand abnormality of mind so much as a peculiar normality in observation, patience, and pertinacity; not unusual qualities so much as usual qualities developed to a very high degree. The imposition of the severe discipline of intellectual work on the temperament usually suited to discovery, leaving a mind which has fashioned for itself delicate mental instruments for probing and exploring the unknown, results in many cases in a sensitive and highly-strung nature which is little adapted to the asperities of industrial life, sometimes too accustomed to the individual point of view readily to co-operate with others in a team. Those workers who are engaged in industry frequently adapt themselves to the conditions met in a works during the period in which they acquaint themselves with industrial practice.

While research specialists are highly individualized, considerable harm has been done to the prospects of utilizing their services in industry by the assumption that they possess a kind of artistic temperament which will respect no bounds of discipline or restraint, and which makes their control in a team a matter of considerable difficulty, especially in a large works, where the less enlightened, eager to criticize where they cannot follow the example of the more enlightened, require exceptionally tactful treatment. While the temperament of the average research worker does not militate against his success in a works, a research director has to exercise considerable discretion in making allowances. A research worker seldom embarks on his career purely as a means of making money, for, while golden returns may accrue here and there, it is far too speculative. He finds himself committed to it by his aptitudes, predilections, experience, and training, and is unable to avoid thinking about his work in his leisure time. He may spend considerable time in preparing for and attending meetings of scientific societies. Rigid enforcement of a time-table may, therefore, not only be unjust but actively harmful, and will almost certainly be resented, because no pressure is needed to keep a research man at his work, even if it should on occasion demand his attention night and day for an extended period.

It is necessary to bear in mind that genius is not essential in a research worker. Well-trained, energetic and capable, but otherwise ordinary men will form the bulk of a research staff. There is room in the field to be covered for all varieties of capacity. "The edifice of science needs its masons, bricklayers and common labourers as well as its foremen, master-builders and architects. In art nothing worth doing can be done without genius; in science even a moderate capacity can contribute to a supreme achievement."[1]

[1] Bertrand Russell, *Science and Culture.*

Factors Influencing Originality

The above considerations indicate that originality is largely dependent on the manner in which natural aptitudes are modified by education and training. Since originality is a matter of degree some of the influences adverse to originality may be noted.

With some workers, existing knowledge appears to act as a handicap rather than as a stimulus to development. They take present knowledge for granted and attach a conventional value to it. This leads to an uncritical acceptance of current ideas and to a point of view of the providential nature of things scarcely conducive to change. Two causes may be assigned to such an outlook. If education is of the character of short-sighted cramming, knowledge is very superficial, and, in the case of science teaching, acquaintance with the history of science is almost entirely lacking. Ideas are, therefore, static rather than mobile, apperception masses are attenuated, and the fundamental requisites of a truly scientific mind—keen, critical intelligence, dispassionate analysis, and the spirit of enquiry or curiosity—are lacking. Such cases are sufficiently numerous to arouse in some minds serious misgivings as to the adverse influence of any form of education on originality, especially when the acute observation and fresh vigorous expression of untutored but unpreoccupied minds is encountered. The fault, however, unquestionably lies—far more, perhaps, than is generally realized—not in education but in that form of adolescent instruction which frequently passes for it. Excessive preoccupation with reading also hinders originality.

Closely associated with this form of mental inertia is the state of mind induced by routine, particularly the routine of a profession, which has been termed "Professionalism."[1] The professions, using the term in the broadest sense, are conservative and do not welcome criticism, especially from outside. This feeling, together

[1] *See* F. H. Hayward, *Professionalism and Originality* (1917).

with an inability to appreciate the characteristics of the creative worker, or the impulse which compels him to be active in particular directions, largely explains the coldness with which original work is viewed by the Civil Service, by business men and professional workers. It is part of the suspicion largely due to the lack of understanding with which the creative artist and the professional man regard each other. It is the specialist over-rating his speciality by underrating that of others.

Originality shows itself by early promise, and, with advancing experience, should be maintained until age begins to dull the memory and the faculties, or until physical vigour is diminished.

As yet, women have not proved their capacity to be accepted as original research workers to the same extent as men, and it is difficult to determine whether this is because women are fundamentally without the necessary capacity or whether education and training are not yet appropriate. There appears to be no reason, however, why women who have graduated in science and have received training in research method should not accomplish good work in original investigation.

EDUCATION, SELECTION AND TRAINING OF RESEARCH WORKERS

Sufficient has been said to indicate that the education of research men from the earliest years is of almost incalculable importance. Education may fail miserably or succeed magnificently in strengthening natural aptitudes, arousing the spirit of enquiry and in providing that broad outlook required as a basis of acute specialization. On the whole, while educational theory has begun to recognize the importance of the individual, there is still far too little attention to individual requirements. The difficulty is present in the elementary and secondary schools owing to large classes, while in the public schools the pressure of school opinion in favour of a uniformity of taste, manner,

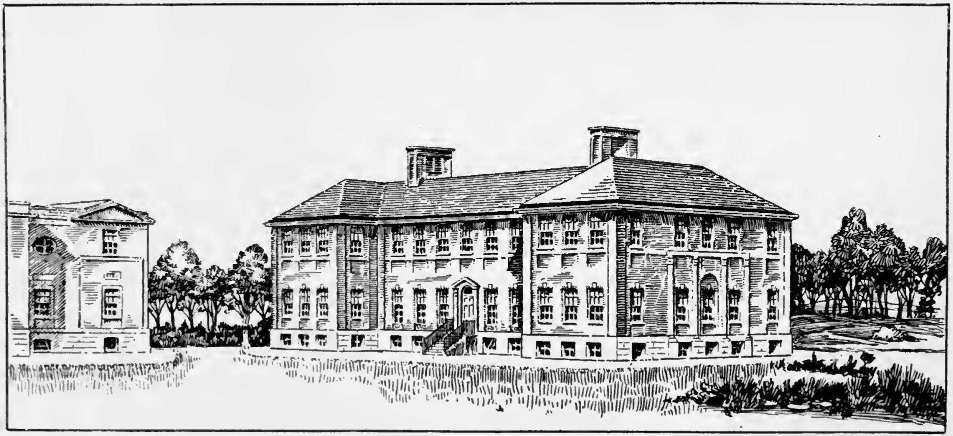


Fig. 20. Applied Science Laboratory, National Lamp Works, General Electric Co., U.S.A.

(*See page* 127)

and level of attainment—even at the cost of considerable harm to personality—is equally as disastrous in its tendency towards regimentation. In endeavouring to recognize and develop qualities peculiar to the individual, it is not necessary to go to the other extreme—no less dangerous—of private tuition, as the ideal to be aimed at is the unfolding of personality to its highest degree, to the utmost benefit of the community as a whole. There must, therefore, be an equilibrium of social contact and individual growth—neither being sacrificed to the other. This applies with equal force to all those being educated, but for research workers the benefits would be peculiarly valuable. Some writers, such as Dr. A. N. Whitehead, consider the whole end of the educational machinery to be the development of genius, but, while admitting the enormous benefit to be gained by what may be termed the intensive production of genius, it is doubtful whether the education of the rest of the community can consistently be subordinated to that few, partly because genius is of no value to a community unless its possessor recognizes on ethical grounds his obligations of service to the community. Genius is sufficiently self-conscious, as a rule, to warrant not less emphasis on this obligation than at present exists, and this is most effectively secured by corporate life and games.

The modification of educational work in the direction of recognizing individual abilities and predilections, through more elastic curricula and examination conditions, constructive handicrafts, less rigid insistence on attendance at prescribed courses of lectures and the like, will assist in the education of the potential research worker.

Training of Research Workers

Ability in research work generally manifests itself to teachers during a student's college career, partly because it is associated with a very high standard of general intelligence, which is indicated by a relative ease in passing examinations. The laboratory work invariably associated nowadays with all science courses offers opportunities of picking out students with capacity for experimental work, both in constructing or setting up apparatus and in taking observations and deducing results.

The present method of training research men by associating them for a period after graduation with the professor under whom they have studied, has many advantages. The professor is able to work over a much wider field than if he operated alone, while the student has ready access to his leaders' experience and knowledge. The plan is suitable for men who are entering any form of research institution, national laboratory, Research Association, or works research organization.

It is desirable, however, that students entering industrial research should have an opportunity of acquainting themselves with the practice of the industry with which they are to be associated. This may be done by entering a works after graduation, if no practical experience has been previously obtained, for a period of apprenticeship of about two years' duration, designed to afford not skill in operations but a general knowledge of the organization and manufactures of the company. Special attention may be given to those branches of work involving applications of the science to which the apprentice has given most attention. The period may be spent immediately after taking the master's degree or, preferably, immediately after taking the bachelor's degree, the student returning to the university for that training in research method obtained during the preparation of the thesis for the master's degree.[1]

Apprentice courses of this type have been common in the case of engineering students, but not for chemists, metallurgists, physicists, etc., whether for research work

[1] *See Engineering Education*—Arnold, 1920, a report of the Education Committee of the British Electrical and Allied Manufacturers Association.

or for works control, and may be advantageously extended to the latter.

Recently a large industrial concern has arranged, in order to minimize the period of training required, to establish relations with the various universities by which a student leaves the university on graduating, spends the long vacation in the works, and undertakes the preparation of the higher thesis either in the works research department or in the university, or both, as may be expedient, this year counting as one of the two years of the apprentice course. Generally, a works research organization, and, to a lesser degree, a Research Association, requires a considerable range of workers, even among the technically trained staff, from the routine analyst at the one extreme to the original investigator at the other. This range is extremely convenient, because there is always some uncertainty, in appointing a new member of the staff as to his ultimate place in the organization, even after he has been under close observation during the training period, and a worker can be tried in various capacities on pure routine work, on works problems demanding practical experience, common sense, constructive ability, and tact in dealing with men, on experimental investigations, or on work predominently theoretical in character.

The percentage of technically trained men and women on the staff of a research organization depends to a considerable extent on whether it undertakes pure research solely or whether a broader ground is covered. The figure is invariably smaller than is commonly supposed, as, if highly salaried research workers are not to be unduly burdened with trivial duties, it is necessary to have clerical assistance, artisans for constructional work, janitors, etc.

If provision has to be made for routine testing, care should be taken to train workers so that a minimum number of highly skilled people is required, but this is much more easily accomplished in laboratories having a few types of tests only, as in a steel works research laboratory, than in a more complex laboratory such as pertains to a general engineering works. The practice of permitting juniors to enter a laboratory to do cleaning, storekeeping, and record filing is to be deprecated, as these occupations, which are very suitable for women, are only prevented from becoming a blind alley for a boy at the expense of making him a semi-trained, semi-educated scientific worker. No laboratory worker should be accepted with less qualifications than matriculation or intermediate certificate, and part-time facilities for day study should be granted. Otherwise, tests vital to the success of an expensive investigation may be jeopardized by being performed in an empirical and rule-of-thumb manner. The opportunities for study at secondary schools are now such that little hardship would be entailed in any aspirant to scientific work, however humble his circumstances, if such attendance were made a condition of employment, while the growth of science demands at least this limited degree of education for any work connected with a laboratory.

The apprenticeship course for college graduates has many valuable advantages. It not only affords men trained in principles the means for rapidly acquiring experience, but it gives the research staff opportunities of keeping young men under observation for an extended period, during which their predilections and strong points may be noted. When the time arrives for making the apprentice a member of the permanent staff, it is possible to give him the work for which he is most suited by aptitude, training, and personal taste. It need hardly be added that no apprentice should be confined to a single department. In order that he may appreciate the interdependence of parts of an organization and obtain a coherent picture of the whole, a learner should see the working of administrative, accounting, purchasing, engineering, commercial, and research sides of the business. Senior officials of the company may with advantage lecture on their respective activities to college apprentices, The research department staff should not only avoid stratification into grades, but it should avoid exclusiveness, real or apparent. The research department can do much to permeate industry with men trained to appreciate scientific method by taking apprentices for a short period as part of their training, and by transferring members of its staff, if desirable, to the engineering or manufacturing departments.

Employment of Research Workers

It will be clear from the above discussion that a works research organization, while in some respects somewhat complex, cannot be conducted with quite the rigid enforcement of discipline common in works departments as a whole. While the staff of a research organization must conform with the works practice with regard to hours and conditions of working, considerable latitude and discretion must be given to the director in dealing with his staff, because the thinking function inseparable from research cannot be confined to particular hours. At the same time the appearance of privilege must be sedulously avoided.

In connection with investigations required, great benefit accrues from the discussion of details at regular conferences, so that the whole weight of experience of the staff can be brought to bear on any given problem.

The chief problem of the research director is to maintain the freshness of view, enthusiasm, and keenness of his staff, and it therefore follows that they must not only be engaged on work which they find interesting, but they must be freed from all preoccupation arising from insufficient remuneration or uncertainty regarding security of tenure.

Considerable discussion has taken place regarding methods of paying research workers. It has been felt in some quarters that effective recognition of work done can only be made by means of a bonus on the commercial value of a development. This plan of remuneration, however, is totally unsuited to the ordinary works research organization. Work done is seldom the product of one man exclusively. It is built up co-operatively by many minds each doing a share, and it is practically impossible to assess the share of each. Furthermore, it is unfair to differentiate between one worker and another, equally capable and deserving, one engaged on work which does not lead itself to commercial exploitation, the other on a subject which does. The research director thus compelled to distinguish between members of his staff engaged in scientific work or between an administrative worker and a scientific worker is placed in an extremely invidious and, indeed, untenable position, because the internal influences tend to favour excessive secrecy, suspicion, and individualism where free discussion and unreserved co-operation are essential. If it is desired to reward a research department for a good result, a bonus should be given to the whole staff, to be divided at the director's discretion. Preferably the recognition should come to deserving workers through increased responsibilities and salaries.

It may be felt that in view of the character of research work industrial laboratories are best established away from the factory and its atmosphere. Apart from the serious disadvantages arising from the inability to make use of works services and supplies and the resulting higher maintenance costs, it is doubtful whether such a course is in the interests of research workers themselves. The continuous action and reaction between science and industry, theory and practice, is such as to make industrial life a very desirable *milieu* for research. The proximity results in a constant stimulus to research men which is ever providing suggestions and ideas for further effort, and current practice to some extent replaces the professor who guides the destinies of the young research worker. The importance of an isolated observation, often by a mind untrained in the science which develops it, in acting as a nucleus for scientific work has already been mentioned. Industrial work is frequently practised by men of a lifetime's experience who can help enormously men who hope to aid industries through research. Indeed, the effective combination of practical experience and theoretical knowledge is one of the most pressing problems in industrial research, and the value of practical experience in dealing with industrial problems can scarcely be overestimated.

The research department is essentially a staff department the services of which are applicable at any point in the organization, and which has relatively little responsibility for routine production. It is desirable, however, that facilities should be given for members of the staff of other departments to work out special problems in which they are interested, being transferred temporarily, if necessary, to the research department for this purpose. The concentration of experimental work in one department need not mean its concentration in the hands of the normal research staff provided steps are taken to maintain adequate records of work done, and short spells on experimental work act as "refreshers" for the staffs of other departments. Similarly an interchange of members of the research staff with those of the "line" departments is desirable when it is practicable, particularly among junior men.

Publication of the Results of Research

The advantages gained by free internal discussion are also to be gained in a wider sphere by publication. There is nothing to be lost and a great deal to be gained by rapid publication of the results of academic research, and it should be the policy of a research director to encourage the preparation of papers, which should be delivered to a recognized technical society or institution, or printed in a recognized technical or scientific periodical. Meticulous care should be taken to give every worker the fullest credit for any suggestions due to him, and the majority of research workers probably value the privilege of publishing their work more than any other advantage extended to them.

In industrial application, publication has frequently to be delayed until it is covered in a patent specification, or, in some cases, has to be permanently withheld. In such cases the worker recognizes fully the importance of avoiding premature disclosure. Discontent is only likely to arise when facilities for publication are refused even when they would result in no active harm.

Research Workers and Patents

The question of patents is also controversial. Many scientific workers, particularly those outside the manufacturing industries, feel very keenly the policy of enforcing the assignment of patents to the company with which they are associated. In practice, however, patent protection is sought in a relatively small number of cases on technical grounds alone. Frequently commercial reasons dictate the desirability of a patent being taken out. In others, the protection is a pure speculation which does not even yield the fees involved. Most patents are of comparatively little value except to an existing manufacturing organization.

The patent actually arises out of the research worker's employment and is due to opportunities which occur in the performance of duties for which he is paid. To maintain continuity, a company must retain the right to use, even to use exclusively, patents taken out by employees irrespective of the financial arrangements made between the company and the inventor. It has been shown by experience that where a company does not consider a proposal for protection worth pursuing, the employee seldom exercises his option to take out the patent on his own behalf. This is partly due to lack of interest in commercial application, partly to the speculative character of a patent, which may fail for various reasons even when technically sound.

The difficulty of apportioning credit on collective work also applies on patent questions as with remuneration. Reward for patents is, therefore, probably best given and will probably be best appreciated in the form of a salary increase. The returns on many patents are too intangible remote or disappointing to make royalties popular. In cases of a strikingly successful specification due to one worker or a small group of associated workers, a royalty payment may be arranged to the mutual satisfaction of the parties concerned. The name or names of the inventor should always be associated with that of the company in the specification, so that credit is given to the actual inventor.

Research Director

The director of a research organization requires not only the qualities of a research worker, but those of an administrator. Scientific training of a high order should be combined with considerable practical experience of the industry concerned, preferably in its commercial, technical, and manufacturing aspects. He must have a wide knowledge of men, be tactful in handling them, and able to inspire them with enthusiasm he himself must feel. He must be primarily a leader. In no way will his capacity be more demonstrated than in the manner in which he attracts and retains the services of able men.

The problem of a research organization is to obtain and direct the best available men to the problems confronting it, and the organization is merely the method adopted to secure the most suitable man for a given investigation, to shield him from other work until it is completed, and finally to ensure that the proper use is made of the results achieved. More than in any other branch of industrial work the difficulties of a research organization are those associated with selecting, training, retaining and directing the personnel.

CHAPTER X

INTERNATIONALIZATION OF RESEARCH

Two tendencies have been abundantly manifested within the last few years. The first is the steady progress in all industrial countries towards recognition of the importance of research, followed by provision from national, local and private funds for its pursuit under proper conditions; the second is the association of research workers in different countries into an international movement for the advance of scientific work unhampered by restricting influences arising from differences in race and language. Science is not national, and the free publication of scientific memoirs places all workers in all countries on the same level. Any restriction on such publication would be fatal to the progress of science. One country may betray less enterprise than another in securing the economic advantages accruing from the application of discoveries, whether its own or those of others, to its industrial arts; attention has been repeatedly drawn to the efficient industries of Germany, buttressed by science, while Great Britain, with an even more distinguished record in discovery, neglected the applications. In the designedly brief notes given below some indication is given of the principal research institutions in the leading industrial countries classified, for purposes of ready comparison, under the headings adopted for research agencies in Chapter III.

NATIONAL RESEARCH INSTITUTIONS

Great Britain

In this country, apart from the work which has been developed at the National Physical Laboratory, the tendency has been to avoid the establishment of Government-controlled laboratories except those maintained for routine

13—(1830)

testing arising out of the operation of various Acts of Parliament relating to customs, excise, food, drugs, and the like. Such research work as has been deemed necessary has been encouraged at the universities, or at privately endowed institutions which have become national in character. Even in the most recent developments associated with the Department of Scientific and Industrial Research existing machinery is used as far as possible, and in the new Research Associations Government control is slight.

The research recognized as worthy of encouragement from national funds or required for public purposes, performed at universities and other suitable laboratories, has been subsidized or paid for by the Government Department directly concerned. Thus the Rothamsted Experimental Station has conducted very valuable agricultural research. This tendency to make use of existing institutions rather than to create fresh laboratories is very desirable, and should be borne in mind in comparing British with American and German practice. The Department of Scientific and Industrial Research is purely administrative, acting as the official department for the Advisory Council, which encourages individual workers with grants and aids research associations. The action of the British Government in founding the Imperial Trust has been very widely followed by the Dominions and also by some of the Allies.

The chief contribution to new institutions has been the laboratories of the Fuel Research Board, which, in pursuing its policy of investigating British fuel resources and their proper exploitation, has established a Fuel Research Station adjacent to the East Greenwich Gas Works of the South Metropolitan Gas Company. The area leased is about five acres, one acre of which will be occupied by the laboratory buildings, a complete account of which, with plans and photographs, is given in the Report of the Fuel Research Board for 1918-19.

1. Engineering Building
2. Sales
3. Lamp Laboratories
4. Accounting
5. Canteens
6. Power Plant and Purchasing
7. Administration
8. Physical Research Laboratory
9. Applied Research Laboratory
10. Nela Lamp Division
11. Garage
12. Experimental Engineering Division
13. Mechanical Laboratory

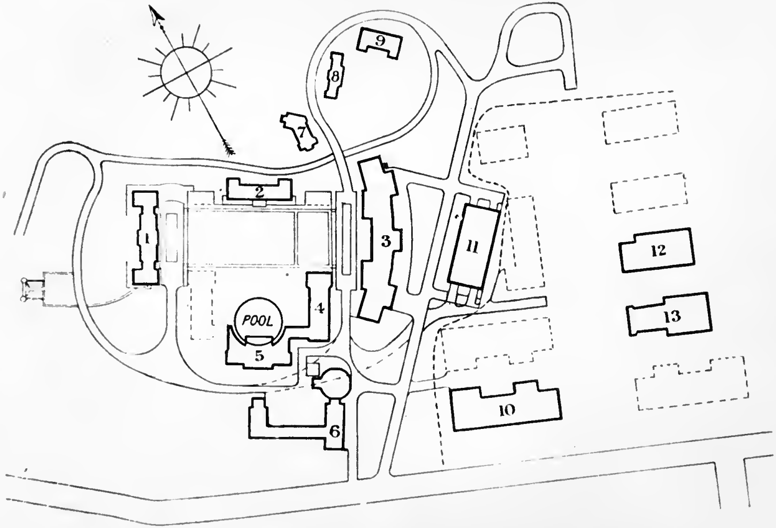


FIG. 21. GROUND PLAN OF EXISTING AND PROJECTED BUILDINGS, NATIONAL LAMP WORKS, GENERAL ELECTRIC CO., U.S.A.

(*See page* 129)

National Physical Laboratory. The National Physical Laboratory was founded in 1901 at Bushey House, Teddington, largely through the energetic activity of a few members of the Royal Society, and for many years was conducted by an Executive Committee nominated by the Society. Prior to the war it had an annual income of £40,000, of which three-fourths was earned in fees paid—chiefly by Government departments and industrial firms—for work done on their behalf. The Treasury granted £2,000 of the remaining sum, which was made up by donations or grants from industrial concerns, scientific societies, and other bodies interested in furthering the work of the laboratory, either generally or in connection with specific researches. Since its foundation the laboratory has grown continuously, and to accommodate the work of the various departments which have grown, not only in size and staff, but also in number, considerable extensions have been undertaken. The buildings are in no way pretentious.

Since the foundation of the Department of Scientific and Industrial Research and the establishment of the Imperial Trust, the property and income of the laboratory has been in the charge of the Imperial Trust. The scientific control of the laboratory is still exercised by an executive committee appointed by a General Board containing representatives of all the great scientific and technical institutions and Government departments. For purposes of administration the executive committee is considered by the Department of Scientific and Industrial Research as a Research Board, the functions of which are referred to in Chapter III, and the committee was appointed a Research Board in order that the Department might assume financial responsibility for the laboratory without interfering with its scientific direction.

The laboratory is under the administrative control of a Director, assisted by Superintendents of the great departments, Physics, including Heat, Optics, Sound,

Fig. 22. Research Laboratory, General Electric Co., Schenectady, U.S.A.

(*See page* 129)

X-Rays and Tide Prediction; Electricity; Metrology; Engineering, including Aerodynamics; Metallurgy and Metallurgical Chemistry; and the National Tank. Each department has a number of principal assistants, and other grades of senior and junior assistants, observers and skilled workers.

The main work of the laboratory comprises the measurement and determination of standards, the commercial testing of instruments and appliances for which an N.P.L. certificate is required, and in the conduct of researches in pure and applied science. The commercial testing is mainly done at the request of and paid for by industrial firms, while the research frequently arises out of requirements expressed by various technical institutions and other representative bodies.

The work of the laboratory increased enormously during the war, the staff and income expanding proportionately. During the year 1917-18 the income was nearly £104,000, the staff increased to 532, the salaries totalling £78,000. During 1919-20 the expenditure was £153,000, of which one-third was provided from testing fees.

Davy-Faraday Laboratory, Royal Institution. The Royal Institution, established by Royal Charter in 1800, has maintained research professorships for many years in various branches of natural science. The Davy-Faraday Laboratory, named after two famous workers at the Royal Institution, was endowed by Dr. Ludwig Mond, and the present distinguished Director is Sir James Dewar.

Woolwich Arsenal Research Laboratory. The Research Department at Woolwich is controlled by the Army Ordnance Board, and is not connected with the manufacturing departments in the Arsenal grounds. While national in the sense that it is supported by national funds the work done is exclusively that required by the Army Ordnance Board, and resembles that of an ordinary industrial research laboratory, covering two chief branches, explosives and metals, the latter including X-rays, physical testing and metallurgy. Some confusion arises from the fact that a part of the Arsenal, originally a Royal Laboratory for mixing gunpowder, and now a manufacturing department, is still known as the Royal Laboratory. It has no connection with the Research Department, but carries on metallurgical work arising from its normal manufacturing work.

DEPARTMENT OF THE GOVERNMENT CHEMIST. This Department is mainly concerned with routine tests and investigations required in connection with customs and excise, Government stores, and with various Acts concerned with food, drugs, fertilizers, etc. Investigations are carried on for various Government departments and enquiries arising in connection with Parliamentary Committees and Royal Commissions are dealt with. A number of provincial laboratories exist for customs and excise work. The staff numbers about 130.

GENERAL POST OFFICE ENGINEERING DEPT. The advance of the telephonic and telegraphic arts in Great Britain is largely directed by the Research Section of the G.P.O. Engineering Dept.

Canada

In June, 1916, the Dominion Government established by Order in Council a Committee of the Privy Council, consisting of six responsible Ministers, to be responsible for all funds provided by Parliament for the promotion of scientific and industrial research. At the same time an Honorary Advisory Committee, representing scientific and industrial interests, was appointed to be responsible to the Committee of the Privy Council. An Act formally establishing the scheme was passed by the Dominion Parliament in August, 1917. The Honorary Advisory Council for Scientific and Industrial Research, comprising eleven representatives of the scientific, technical and industrial interests of Canada, was charged with the following duties—

(1) To take a census of research agencies, Governmental, university, institutional, industrial, or private; to tabulate the lines of research being pursued, and the man power engaged, and to co-ordinate these lines to prevent overlapping.

(2) To acquaint themselves with technical and scientific problems confronting industry and to bring them into contact with research agencies; to link up the resources of science with labour and capital employed in production.

(3) To study scientifically unused resources, and the waste and by-products of industries.

(4) To study ways and means of increasing the number of research workers.

(5) To create a sound public opinion on research.

To overcome the difficulty of distance, a separate committee was established for British Columbia. Associate committees of specialists have been formed for particular branches of work, such as forestry, mining and metallurgy, and chemistry. The Council aids researches by grants to advanced students and research workers. Information bureaux for the industries are being established at the principal cities.

The establishment of a National Research Institute at Ottawa, having functions similar to those of the National Physical Laboratory or the Bureau of Standards, is in active progress. A Parliamentary Committee reported strongly in its favour in 1919, and its recommendation has been adopted by the Canadian House of Commons. The cost of building is estimated at $600,000. The plan by which research for industry will be fostered is that of providing laboratory accommodation and supplies for associations of firms desiring to undertake co-operative research.

Fig. 23. Research Laboratory, Westinghouse Electric and Manufacturing Co., Pittsburgh, U.S.A.

(*See page* 129)

FOREST PRODUCTS LABORATORIES. Laboratories for the study of forest wealth, planned on the lines of the U.S.A. Forest Products Laboratories at Wisconsin, were established in 1915 by the Dominion Government at McGill University. The Forestry Branch is aided in directing the laboratories by an Advisory Committee. The annual vote is £12,000.

Australia

In March, 1916, the Commonwealth Government established the Advisory Council of Science and Industry to further proposals for a permanent Institute of Science and Industry. The functions it exercises are very similar to those outlined above for Canada. A large number of special committees sit in connection with questions of industrial interest, some of which are permanent. The Institute will be a corporate body, but conducted by the Minister for Trade and Customs, and responsible to Parliament, which will make the necessary appropriations, and the bill authorizing the foundation of the Institute is now being passed.

The proposals with regard to the Institute are that it should be controlled by three highly qualified salaried Directors, comprising a financial expert, and two scientific men ; and that an Advisory Council should be formed for each State to advise the Directors regarding the work of the Institute. The work will include standardization, a bureau of information, and research in agriculture, mining, metallurgy and manufactures. Five national laboratories are to be established for the work, one for industrial standards relating to materials and measurement, one for technological research in industrial chemistry and metallurgy, and the remainder for plant and animal industry and forest products.

New Zealand

The Government has passed a National Efficiency Act, establishing a Board, one of the duties of which is to enquire into the necessity for scientific research with respect to the maintenance, development and standardization of industries, and a scheme has now been recommended to the Government for adoption. It provides for the establishment of a Board of Science and Industry, with a Minister of Science and Industry as Chairman, for the purpose of encouraging and co-ordinating scientific and industrial research in the Dominion. The Board would hold funds in trust, and it is proposed that the Dominion Parliament should vote a sum of not less than £100,000 for the first five years. Local Committees would be formed to deal with the Board on subjects concerning its activities.

South Africa

In October, 1916, the South African Government appointed an Industries Advisory Board of industrial and commercial men and representatives of labour. In February, 1917, the Board advised the formation of a Scientific and Technical Advisory Committee to deal with research and technical matters referred to it by the Board. A Committee of ten was constituted by the Government, the functions being similar to those outlined above for Canada, involving co-ordination of research, survey of economic resources, encouragement of co-operative action in research, standardization, educational work and collection of data from all sources. The Industries Advisory Board and the Scientific and Technical Committee have now amalgamated as the Advisory Board of Industry and Science.

India

The chiefs of the great scientific and technical departments of the Government of India, agricultural, forestry, geological, etc., form a Board of Scientific Advice which to some extent co-ordinates the research carried on in these departments. The Government has approved of the recommendation of the Indian Industrial Commission that an Imperial Department of Industries should be established as a separate department of the Government, and a Board of Industries and Munitions is preparing the way for the permanent department.

The Chemical Services Committee has recommended the establishment of an Indian Chemical Service, and further suggests the foundation of a Central Research Institute at Dehra Dun, and of provincial research institutes under the control of the local governments, the activities of which would be co-ordinated by the Central Institute.

United States of America

Bureau of Standards. The Bureau of Standards was established by Act of Congress in 1901, and now occupies an area of 16 acres of land at Washington, the total cost of land, buildings and equipment being about £285,000. The annual expenditure is about £125,000, the staff being about 400, three-fourths being scientifically trained. The Bureau undertakes all work in connection with the development and comparison of standards of all kinds, including length, time, mass, quality and performance, and the determination of physical constants, which is done through seven main divisions, weights and measures; thermometry; pyrometry and heat; electricity; optics; chemistry; metallurgy and structural materials. The Bureau is of great assistance to industrial concerns, Government and educational institutions, to the research of which its work is fundamental, and issues various publications embodying the results of its work in the form of scientific reports, technological papers and popular circulars.

Bureau of Mines. This branch of the Department of the Interior was established in 1910, to improve and render less wasteful the extraction and utilization of mineral products, and to safeguard those working in the mining industries. Its headquarters are at Pittsburgh, the appropriation for these being £100,000, and there are

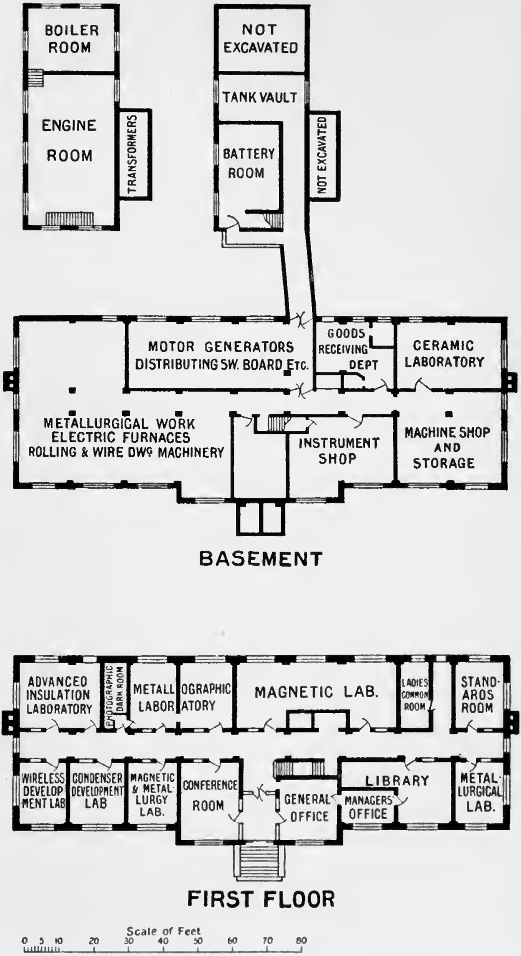


FIG. 24. RESEARCH LABORATORY, WESTINGHOUSE ELECTRIC AND MANUFACTURING CO., U.S.A.

Basement and First Floor

(*See page* 129)

five divisions: mining; metallurgical; mineral technology; fuels and mineral technology; petroleum and natural gases; and chemical research. Considerable work is done in co-operation with State bodies, universities and firms. The Bureau proposes to maintain experiment and safety stations in mining areas. It publishes reports, bulletins and circulars similarly to the Bureau of Standards.

Department of Agriculture. The interest of the Federal Government in agriculture dates from 1839, and the Department was founded in 1862, to acquire and disseminate information relating to agriculture and to distribute seeds and plants. It now controls the Weather Bureau and Forest Service, and administers legal regulations relating to foods and drugs, etc. About 15,000 people are employed, and the expenditure in 1915 was over five million pounds. Two thousand are engaged in investigation and research. The work is done in seventeen main divisions, and research was not until recent years clearly differentiated from other work. Now, however, it is separate from the regulation and routine work and the educational work, and is determined by an Advisory Committee of heads of departments.

The Morrill Act, 1862, granted each State an area of land, the proceeds of the sale of which went to form a fund for the purpose of endowing a college to teach branches of learning related to agriculture and the mechanic arts. This provision was increased in 1890, and again in 1908 by further Acts, all of which are administered by the Board of Education. In 1914 there were 69 of these "land-grant" colleges, owning property valued at over 32 million pounds, and having an income of nearly seven million pounds. An Act of 1887 provided for an Agricultural Experiment Station to be attached to each land-grant college, the work of which is co-ordinated by the Department of Agriculture through an Office of Experiment Stations.

The Forest Service of the Department of Agriculture is responsible for administering and protecting national forests, and one of the three divisions is the Research Branch, established in 1915, which conducts sylvicultural investigations at eight Forest Experimental Stations, and various other economic and statistical studies, and which is responsible for the Forest Products Laboratory, established in 1910, at Madison, which required £30,000 to build and costs £28,000 per annum to maintain. In this laboratory studies are made of timber and all its products, with a view to obtaining data relating to mechanical and physical properties, to prevent waste, and to conserve timber resources. There is full co-operation with the wood using industries. The staff numbers about 100, about half of whom are technically trained.

NATIONAL RESEARCH COUNCIL. The co-ordination of research work and research agencies in the United States is undertaken by the National Research Council, to the activities of which reference is made below.

France

The Chamber of Deputies has adopted a Bill establishing a Department of Scientific, Industrial and Agricultural Research and Inventions in the Ministry of Public Instruction. The object of this department will be to co-ordinate and encourage pure and applied research. The control will be vested in a Council of 70 or 80 members, nominated by the Senate, Chamber of Deputies, Academie des Sciences, and other scientific, technical and labour organizations and Government departments, and the Council will elect an Executive Council of nine members appointed for a year at a time. The Minister for Public Instruction will appoint a Director as a permanent officer of the Executive Committee. The work of the department follows the lines already adopted by the British scheme, and it will absorb the functions of the existing Board of Scientific and Industrial Research and Inventions. The Ministry of Public Instruction has also founded an Institute for Pure and Applied Optics in Paris to assist the optical industries in France.

CONSERVATOIRE DES ARTS ET METIERS. This laboratory was based on the German laboratory at Grosse Lichterfelde, but an authority no less than M. H. Le Chatelier states that it has deviated from its original aim, and that in spite of Government grants, it does not conduct investigations of general fundamental value. The Academie des Sciences recently formed a Commission to consider the question of ways and means to employ in the establishment, among other things, a national laboratory of physics and mechanics. The laboratory of the Conservatoire des Arts et Metiers has an annual income of about £10,000, one-half of which comes from the Government.

INDO-CHINA. At the end of 1918 the Governor-General created a scientific institute at Saigon for the investigation, development and exploitation of the produce of soil and waterways of Indo-China.

Germany

A characteristic feature of German research institutions is the extent to which they are specialized to meet the needs of one trade or industry. The funds for their support are drawn frequently from all sources, imperial and state grants, industrial associations and private donations, and this renders decision as to whether an institution is privately or state endowed very difficult to make. Furthermore, new research institutions are frequently founded on existing premises at a high school or technical college.

AERONAUTICAL INVESTIGATION DEPT., BERLIN. This institution was founded in 1912 by the Imperial and State authorities and interested firms, and supported chiefly by imperial and state grants. Its aim is to further aviation in Germany, and sections exist for motor testing, propeller testing, aeroplane testing and aeronautical research, instrument testing and material testing. During the war it manufactured flying material and maintained a testing

FIG. 25. LABORATORIES OF F. KRUPP A.G., ESSEN, GERMANY

(See page 131)

course at Schonefeld. The technical staff numbers about 30, and the remainder of the personnel about 85. Its income and expenditure for 1917–18 amounted to about Mk445,000.

MATERIALPRUFÜNGSAMT-GROSSE LICHTERFELDE. Founded originally in 1870 as the Royal Prussian Experiment Centre, the present institution was built during 1901–04, at a cost of 65 million marks. It forms the materials testing laboratory of the Technical High School at Charlottenburg and undertakes scientific investigations into the properties of materials and their improvement. Material testing is carried out for payment. The principal sections are for testing of metals, building materials, fibrous materials, metallurgy, general chemistry, oils and other fluids, rubber. Of the staff of 229 workers, 75 are academically trained. In 1913 the institution spent Mk646,000 and received Mk268,000. The ground area is about 120 acres, of which about 3 acres are covered with buildings. The relations of the institution with manufacturers and their associations are very close and cordial.

PHYSIKALISCH-TECHNISCHE REICHSANSTALT, BERLIN. This well known institution, the precursor of the great national standardizing institutions, was founded in 1887 at the instigation of Wernher von Siemens. It conducts research in pure and applied physics for the solution of important problems, and is the standardization centre for Germany. The principal sections are for optics, electricity and heat. The institution controls various testing centres throughout Germany for electrical apparatus, and glassware, etc. Its general work is analogous to that of the National Physical Laboratory. In 1919 the staff numbered 160. In 1918 the expenditure was Mk754,000, and receipts Mk93,000. It may be noted that the highest authority for weights and measures is the Imperial Weights and Measures Office, Charlottenburg.

GOVERNMENT HEALTH OFFICE. This office, supported by the State, is an important connecting link between pure science and public life in so far as it applies the results of research in medicine, biology, etc., to practical uses in sanitation and veterinary work. The staff numbers over 150. An Institute for Industrial Hygiene was also founded in 1908 by private enterprise, to cover the whole field of industrial hygiene and accident prevention.

GOVERNMENT TELEGRAPH EXPERIMENT OFFICE. The technical advance of the telegraph and telephone services is in the hands of this office, founded in 1888 as the Telegraph Engineers' Office of the Government Post Office. The staff numbers about 100.

INSTITUTE FOR LIGNITE RESEARCH. This institute is in process of foundation at Freiburg by the Kingdom of Saxony. It aims at carrying out experimental work in lignite and its products, and their value and use.

RADIUM INSTITUTE. Saxony also established in 1911, at Freiburg, an institute for research and instruction in and testing of radium and radio-activity. The radioactivity of certain waters, stones and minerals is investigated.

CERAMIC LABORATORY OF THE ROYAL MANUFACTORY, BERLIN. This laboratory, formed in 1878 for porcelain manufacture, had Seger for its first director. It aids all branches of the ceramic industry, both by scientific investigation and by study of existing materials and processes of the industry. Several other centres for ceramic research also exist.

BAVARIAN INDUSTRIAL LABORATORY. At Nuremburg a remarkable laboratory exists, subsidized largely by the State of Bavaria, and having an income of over Mk450,000 per annum. It possesses chemical, mechanical testing, and electrotechnical laboratories, etc., for the purpose of performing tests and investigations for industry. Branches of this laboratory have been founded at Augsburg, Bayreuth, and elsewhere.

Austria

Photographic and Printing Research Institution. The State founded in 1888, at Vienna, and supports a small institution for the investigation of photography, photo-chemistry and allied subjects. Authorities, firms, or private individuals may have investigations carried out at fixed rates. The equipment includes all forms of photographic and printing processes.

National Technical Laboratory. This institution, corresponding with the Physikalisch-Technische Reichsanstalt of Berlin, was established at Vienna in 1909, by the State. It is an executive branch of the Ministry of Public Works, and undertakes standardization, material testing, etc. The Director is assisted by a sub-committee of experts nominated by the Ministry of Public Works.

Italy

The Italian Government has established a National Research Council, with offices at Rome, of about 40 members, representing official, scientific and industrial interests. The objects of the Council are similar to those of the analogous bodies in other countries, and its work will fall in seven main divisions according to the branch of science covered. The Experimental Institute for Aeronautical Research will be carried on by the Council, but it is intended to make fullest use of existing institutions. Industrial experiment stations have been or are being established for the study of new industrial processes, the development of new applications and the training of personnel for the industries. Two have been created at Milan for paper and fats ; two at Naples for leather and ceramics ; and one at Reggio Calabria for essential oils and perfumes. Three others at Rovigno, Milan and Rome respectively, are planned for sugar, refrigeration and combustion processes.

Japan

National Laboratory. In 1917 the Japanese Government was empowered to grant a sum exceeding £200,000, payable in instalments over a period of ten years, to establish a national laboratory for scientific and industrial research at Tokio, to apply modern methods to Japanese industries. The Imperial Household granted £100,000, and through further donations a sum considerably exceeding half a million sterling is available. The principal work will be done in electricity, chemistry, electro-chemistry, mechanical engineering and metallurgy. The control will be exercised by a General Council of 50, ten being managing directors and four business managers. The organization is associated with the Department of Agriculture and Commerce, and, until laboratories can be built, the new institution will have accommodation in the universities of Tokio, Kyoto and Sendai.

PRIVATELY-ENDOWED INSTITUTIONS

Great Britain

Rothamsted Experimental Station. The original laboratory was founded some 70 years ago by Sir Benjamin Lawes, a Hertfordshire landowner, who was assisted by Gilbert. These were pioneer workers in agricultural research, and Lawes left a considerable sum of money for the endowment of the laboratory. The buildings have been extended several times.

The laboratory undertakes investigations of a purely general character affecting the growth of crops. Some fields have been watched for over 40 years, and this enables the influence of the innumerable variables affecting crop production to be estimated. Prior to the war the laboratory had about 30 high class research workers. This Experiment Station has served as a model for analogous institutions in many parts of the world.

Lister Institute. This Institute, founded in 1892, was intended primarily for the study of rabies and investigation of diseases of animals and men with a view to their prevention rather than cure. In this way, by determining and eliminating causes, maladies due to rabies, hydrophobia, Malta fever, scurvy, tetanus, trench fever, have been enormously decreased and in some cases abolished. Its work is analogous to that of the Pasteur Institute in Paris.

National Radium Institute. This Institute was founded for the purpose of undertaking research on radium and of developing its applications to medicine, and works in conjunction with a hospital in which practical tests on suitable cases can be conducted.

New Zealand

The trustees of the estate of Thomas Cawthorn, broadly interpreting his will, have decided to erect at Nelson a research institute, under the advice of an honorary advisory board of scientific men. The work will be both technical and scientific and will relate to the industries of the Dominion. The sum of £240,000 is available for founding and endowing the institute.

United States

National Research Council. In April, 1916, immediately prior to America's declaration of war on Germany, the National Academy of Sciences, founded in 1863, offered its services to the President, and was immediately asked to organize the research agencies of the country. In September, 1916, the National Research Council was formed, a federation of governmental, educational, privately endowed and industrial research agencies. This development corresponds with the Advisory Council for Scientific and Industrial Research in Great Britain, but while the Government departments have representatives in the National Research Council, it has no official character. In effect, the scientific societies and bodies of the United States

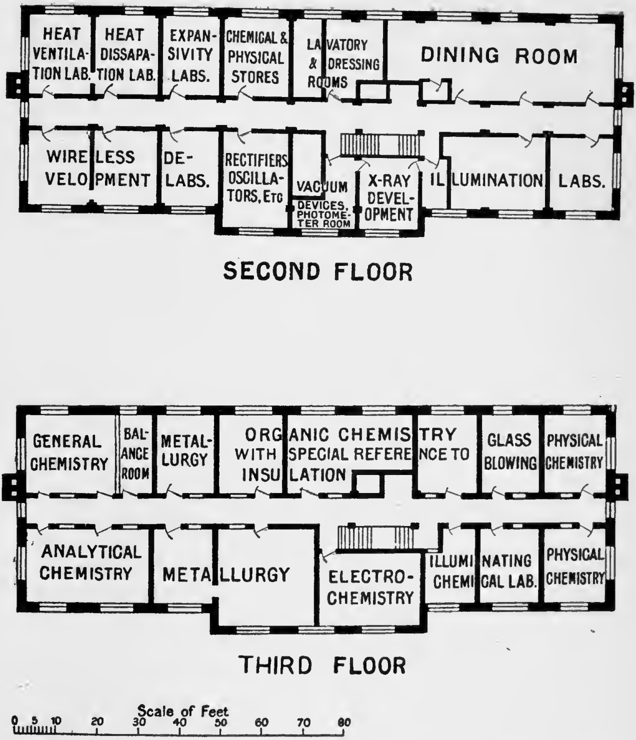


FIG. 26. RESEARCH LABORATORY, WESTINGHOUSE ELECTRIC AND MANUFACTURING CO., PITTSBURGH, U.S.A.

Second and Third Floors

(*See page* 129)

have organized their research activities and have federated to give the fullest means of co-operating in the promulgation of research. It is thoroughly representative, and strongly opposes centralized control or direction of research. It was provided with offices and permanent staff and funds by having the resources of the Engineering Foundation, a body founded by the principal engineering societies, placed at its disposal.

Smithsonian Institution. This Institution at Washington was founded in 1846, with a fund of £100,000, to increase and diffuse knowledge. It makes grants to research workers and initiates scientific projects, in which it acts in a semi-official capacity in administering many such projects now supported publicly.

Carnegie Institution, Washington. Founded by Carnegie in 1902 by a gift of bonds of value two million pounds, which was later more than doubled, the present income of this Institution is £220,000. It encourages research and discovery and their application in a most liberal manner, by providing facilities for research work, by assisting workers, and by producing books. The administration is entirely separate from sections for research and publication. There are research laboratories for experimental evolution, botany, embryology, marine biology, nutrition, terrestrial magnetism, geophysics, meridional astronomy, Armenian history, economics and solar physics.

Rockefeller Institute, New York. This institution for medical research, especially the treatment and prevention of disease, was endowed in 1901 by J. D. Rockefeller. In 1907 the endowment had reached £700,000 for buildings, and £2,100,000 for maintenance, in addition to large sums for specific purposes.

There is a Board of Trustees and an Advisory Board of scientific directors, and a General Manager relieves the Director and scientific staff of all administrative duties.

RESEARCH CORPORATION. This corporation was founded in 1912 to operate the Cottrell patents for the electrical precipitation of suspended particles, and to apply any profits arising therefrom to the advancement of scientific research. Dr. Cottrell, now Director of the Bureau of Mines, had the intention of making past discovery the parent of future advance. The assets of the corporation in 1917 were over $200,000, and Fellowships are offered of annual value of $2,500 to prosecute research.

France

L'INSTITUT PASTEUR. This institution was erected by admirers of Pasteur, for the purpose of furthering his work. It has an income of £40,000 per annum. About twenty research laboratories and their staffs are supported out of its revenue, together with a hospital receiving 1,500 patients per annum. Depots for the preparation of serum, supplied gratis to the medical profession, and four branches of the institute in France and the colonies are also provided for.

COMITE CENTRAL DES HOUILLIERES. Founded twelve years ago to promote investigations into safety in mines, these laboratories have an income of £4,000, and buildings cost £20,000. There is a staff of four engineers and chemists with other workers. The work of this body, formed with the express purpose of assisting an industry directly, is illustrative of the gain accruing to science as a whole, as much valuable work has been published on combustion of gases and properties of explosives of a purely theoretical character but necessary to the elucidation of the main issue.

Germany

KAISER WILHELM GESELLSCHAFT. This German society for the promotion of scientific work was founded on the anniversary of the centenary of Berlin University. It is closely associated with the universities and technical high schools and also with the Government. Several institutions for the prosecution of scientific research have been built and endowed in various parts of Germany, directed by scientific men of world-wide reputation. The buildings hitherto erected have cost £130,000, and there is an annual income of £14,000, one-third of which is provided by the State. All those mentioned below are at Dahlem, a suburb of Berlin, unless otherwise stated.

Industrial Physiology. Founded in 1913, this institution deals with problems that arise in industrial physiology, and with the feeding of the nation.

Biology. An institute for Biology is being built, surpassing in magnitude all other laboratories of the association.

Chemistry. Founded in 1911 by agreement between the Kaiser Wilhelm Gesellschaft and the Union for the Progress of Chemical Experiment, and built 1911–12 on a site provided by the Prussian Ministry of Finance. The institution is free to conduct any chemical research the director and leading officers desire. Three sections are at present working dealing with applied chemistry, inorganic chemistry and radio-activity. The staff consists of about twenty technically trained chemists. A council of nineteen members is responsible for administration, a committee of five, including a representative of the Prussian Ministry of Public Instruction, acting as executive. The scientific work is directed by a committee of twelve members. The annual expenditure is Mk120,000–150,000. The cost of buildings and equipment was Mk1,100,000.

Physics. Founded in 1917, this institute is accessible to anyone engaged on research in physics if the Board agree. Prof. A. Einstein directed the institution for a time.

Physical and Electro-Chemistry. Founded in 1911, this laboratory investigates the fields of physical and electro-chemistry, and carries on certain branches of applied science dealing with the protection of miners

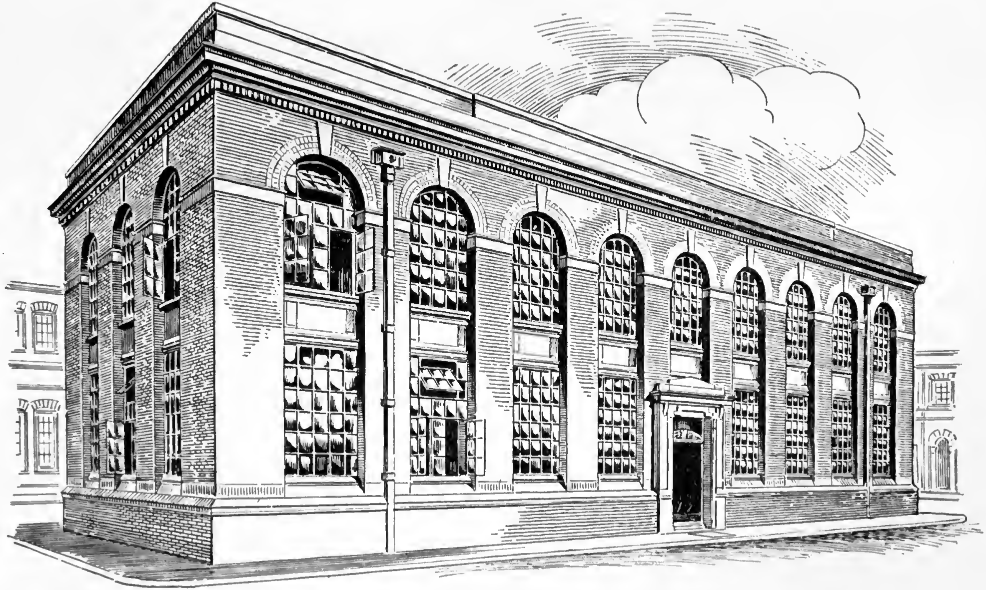


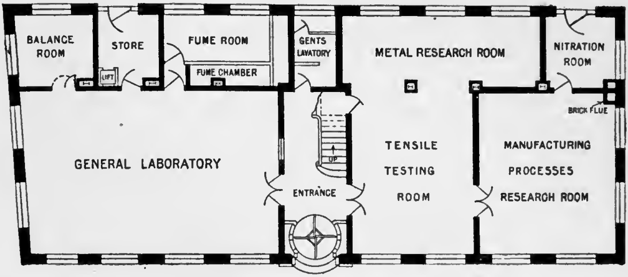
FIG. 27. RESEARCH LABORATORY, KYNOCH, LTD., BIRMINGHAM

(*See page* 130)

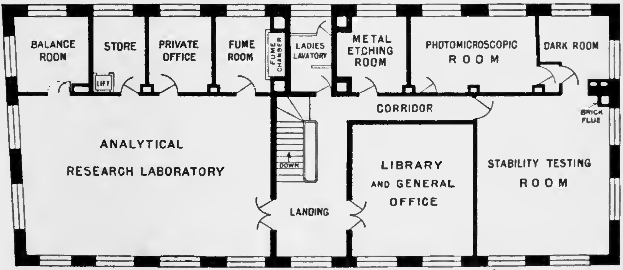
Fuel Technology. In 1917 a society was founded in Berlin for promoting research in combustion processes, particularly the vaporization and burning of fuel and the transformation of heat into mechanical work. Committees have been formed for the different products, coal, coke, peat, wood, combustible fluids, combustible gases, and for thermodynamics and thermo-chemistry; prime movers; furnaces, etc. This society is controlled by a board, comprising five to fifteen members, the president being a Minister of State.

Illuminating Gas Research Institution. Founded in 1906 for the purpose of affording practical instruction in gas engineering and supply and for investigations into gas manufacture, this institution was extended in 1914. It is supported by the German Association of gas and water technologists and by the gas industry, being managed by a commission appointed by the association. There is a staff of about ten, and a yearly expenditure of Mk30,000. The institution is attached to the Technical College at Karlsruhe, on a site presented by the town, and includes a distillation plant in addition to laboratories.

Of other institutions in Germany supported by associated industrial interests, aided by the State, for conducting research required by industry, the following deserve mention. The fermentation and starch trades formed an investigation centre in Berlin in 1874, and this has continuously expanded. It is supported by a number of agricultural and manufacturers associations, and training courses are conducted for brewing and distilling engineers. The staff numbers ninety-three officers, and the buildings are attached to the Agricultural College. Also attached to the Agricultural College is an institute for the sugar industry, built in 1903, but originally founded in 1867. The unions in the beet sugar industry support the institute, but the buildings and site belong to the State. Training courses for workers in the industry are conducted, together with experimental work in chemistry, physics and biology



GROUND FLOOR PLAN



FIRST FLOOR PLAN

FIG. 28. RESEARCH LABORATORY, KYNOCH, LTD., BIRMINGHAM
Ground and First Floors
(*See page* 130)

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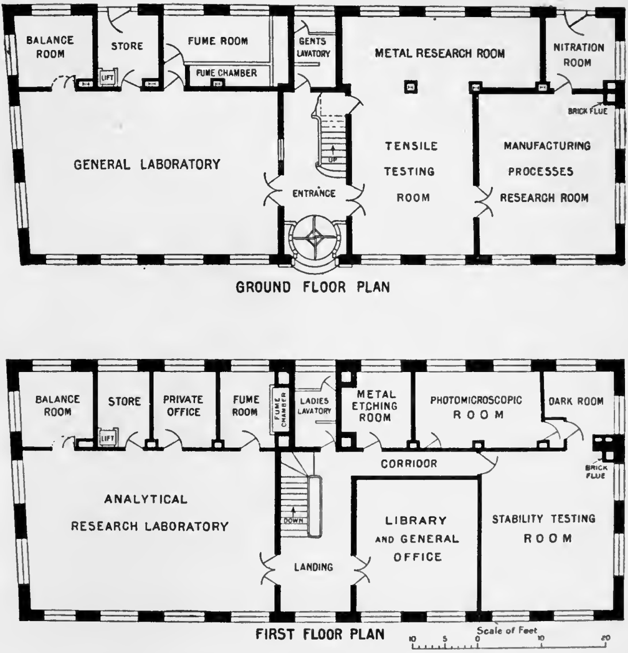

FIG. 28. RESEARCH LABORATORY, KYNOCH, LTD., BIRMINGHAM
Ground and First Floors
(*See page* 130)

applied to the industry, A third laboratory attached to the Agricultural College is that for cereals and flour, founded by the Flour Millers' Syndicate, with the aid of the State, in 1899, and with new buildings completed in 1907. The Association for the Cultivation of Moors, founded in 1883, developed a Technical Section in 1911, to conduct experimental work in peat. This work is also very heavily State-subsidized. In 1908 the German Structural Ironwork Association founded an experimental centre for testing and research on structural members. The annual expenditure is Mk3,000 to Mk5,000.

Austria

Steam and Heating Research Institution. An institute was established in 1907 at Vienna by a Boiler Insurance association, with the consent and support (Kr. 5,000 per annum) of the Ministry of Public Works. It is directed by a committee of Government representatives and the association's officers, and undertakes investigations, experiments and tests on steam and heating technology.

Belgium

Fondations Solvay. These laboratories, founded by Solvay, to whom was due the Solvay process for making soda, are situated in the Parc Leopold at Brussels. The Institut de Physiologie was founded in 1892, and the Institut de Sociologie in 1901, with which was associated in 1903 L'Ecole Superieure de Commerce. The Institut de Physique for research on the ultimate constitution of matter was founded in 1910, with an endowment of one million francs to be spent in thirty years, not more than one-third to be employed for administration. The foundation of an Institute of Chemistry is under consideration.

Italy

Maritime Laboratories. The German zoologist Dohon, struck by the zoological wealth of the Bay of Naples, founded a centre for the study of fauna, supported by the City of Naples and various governments. The staff of fifty carries out many important scientific investigations. The annual income is £8,000.

Denmark

The Danish brewer Jacobsen amassed a fortune through his appreciation of Pasteur's work applied to brewing, and on his death he bequeathed his brewery to the Carlsberg Foundation, the profits being devoted to the maintenance of a research laboratory.

UNIVERSITIES

All universities conduct research in some form, and those—the large majority—which have faculties of pure and applied science carry on research in both these fields. Some have or have had special schools founded by a prominent worker who has occupied the professorial chair. The modern universities that have grown in great industrial centres, largely financed by local and national funds, are naturally very closely associated with predominant local industries. There are also some prominent technical schools and university colleges which, while not possessing university rank, carry on valuable research work.

The universities of Birmingham, Durham, Manchester, Liverpool and Sheffield, for instance, reflect local interests. As examples of special schools, may be mentioned the Department of Glass Technology, at Sheffield University, and the Central Technical School for Pottery at Stoke-on-Trent.

At some American universities the work of the Experiment Stations attached to the universities, such as the Engineering Experiment Station at Illinois, have conducted work of great value. The Mellon Institute of Industrial Research, associated with the University of Pittsburgh, has developed a new method of providing facilities for the study of specific industrial problems, financed by interested manufacturers, by university graduates.

Several of the technical high schools in Germany, notably Charlottenburg, Stuttgart, Chemnitz and Munich, carry on commercial testing for the industries. Many of these institutions are not associated with universities, and their students lack the wider opportunities and broader culture afforded by corporate university life.

RESEARCH IN INDUSTRY

Many industrial firms possess laboratories for the purpose of conducting routine tests on materials in course of manufacture, or facilities for testing finished products. In some cases these laboratories go no further, but in others they undertake the solution of works problems, even though the experimental work is not termed research. Some works make provision for definite investigations for the improvement of their products in the form of a Testing and Experimental Department. It is, therefore, very difficult to differentiate between the works laboratory running as a routine department engaged in aiding regular production, and the research laboratory, which also assists production from a much broader point of view, being prepared to undertake scientific investigations of a high order to do so, as there are gradations of all kinds in between.

The difficulty is heightened still further by the fact that in some firms the research department is rigidly separated from the productive departments and is not allowed to consider manufacturing problems, while in other cases the department supervises materials and processes and undertakes the routine testing incidental to such control, being intimately associated, therefore, with the manufacturing departments. Again, in some cases, the research department is associated with the testing and inspection of finished products, and with the remedy of breakdowns in service.

The actual responsibility depends much on the character

Fig. 29. Research Laboratory, Brunton's, Ltd., Musselburgh, Scotland

(*See page* 130)

of the industry, the personnel in charge of the work, and on the general view taken by the directors of the purpose of the research.

A few illustrations may be given of firms who undertake research work on some scale. In Great Britain may be mentioned Lever Bros., for soap and allied products; Boots Pure Drug Co., for drugs and fine chemicals; British Dyes, Ltd., for coal-tar products; Metropolitan-Vickers Electrical Co., Ltd., for electrical machinery and steam turbines; Kynoch, Ltd., for explosives and mechanical products; the Osram-Robertson Lamp Co., for electric incandescent lamps; the Brown-Firth Laboratories and Hadfields, Ltd., for steel; Brunner, Mond & Co., for heavy chemicals; Chance Bros., for optical glass; Adam Hilger, Ltd., for scientific instruments; Nobels, for explosives; Rhondda Research Laboratories, for coal; Burroughs, Wellcome & Co., for fine chemicals; and Tootal, Broadhurst, Lee & Co., for textiles.

Among the continental firms who have research laboratories may be mentioned Andre Citroën, makers of gears and automobiles; Krupp's, whose laboratories built in 1908, cover a ground space of 39,000 sq. ft. and provide 118,500 sq. ft. of working space; Badische Anilin Fabrik, for dyes and synthetic nitrates; Zeiss works at Jena, for optical glass; and the Laboratoires Lumière, Lyons, for colour photography. An interesting consulting laboratory is the world famous ceramic laboratory founded in 1876 at Berlin by Seger and Agron, now conducted as a limited company by Seger, Cramer & Co. It occupies a four-storey building and has a staff of over 130 people. The German Association of Cement Manufacturers devotes £3,000 per annum to scientific research. In 1912 a research on composition of cement was carried out at Gross Lichterfelde, for which the Association provided £1,000.

A limited liability research company was founded in 1898 at Menbabelsberg by a number of firms engaged in the manufacture of powder, explosives and munitions. Research is conducted in the sphere of activity of the firms concerned, particularly on the chemistry of explosives. The personnel numbers about thirty.

In the United States may be mentioned the General Electric Co., and the Westinghouse Electric and Manufacturing Co., for electrical machines and allied products; the Eastman Kodak Co., for photographic material; the H. K. Mulford Co., for drugs; Du Pont de Nemours, for explosives; Vacuum Oil Co., for oils. A. D. Little, Inc., of Boston, acts as consultant for industry and possesses fine laboratories. Commercial investigations are also undertaken by Electrical Testing Laboratories, New York.

There are a number of miscellaneous institutions engaged on work of a standardizing character, which is worth mentioning in view of the relation between research and standardization. The Birmingham Proof House, for the testing of guns and firearms, was established in 1813, by special Act of Parliament, primarily for the safety of the public. The Manchester Chamber of Commerce Textile Testing House was established in 1895 for the conduct of standardized tests on textile fibres. Parallel institutions are found in the United States (such as the Underwriters Laboratories, Inc.), and in Germany (such as the Textile Testing House at Chemnitz).

Two interesting types of industrial laboratory have been founded in Birmingham. The City Gas Department has a laboratory primarily for the benefit of local users of gas who may wish to extend its application, or to obtain advice as to methods, types of furnaces, etc. The Midland Laboratory Guild is a co-operative laboratory maintained for the conduct of works control tests for several subscribing but financially independent firms engaged in the non-ferrous industry. The resources at the disposal of each firm cost less than would be required if each maintained a separate laboratory.

SCIENTIFIC AND TECHNICAL INSTITUTIONS

It is noteworthy that until recent years some of the largest and most consistent supporters of scientific research and progress have been scientific men themselves through their professional institutions.

Royal Society. The Royal Society has for many years aided individual research workers by grants from its funds, and has been in receipt of £4,000 per annum from the Treasury to facilitate this.

Conjoint Board of Scientific Societies. While the Conjoint Board does not aid researches itself, it represents a large number of affiliated institutions, 116 in number, many of whom do so.

British Science Guild. This propagandist body, founded in 1905, endeavours to co-ordinate industry, science and education. It promotes and extends the application of scientific principles to industrial and general purposes, maintains the position of the scientist in relation to the Government, and assists in creating that public opinion without which scientific progress must remain academic only. An excellent illustration of its work in this direction was provided by the Scientific Products Exhibition in London and the Provinces, in 1918 and 1919.

Royal Society of Arts and Manufactures. Founded to advance the application of science to arts and manufactures, and carrying on its work through numerous regular lectures by experts.

British Association. The British Association for the Advancement of Science has generally been able to support private researches to a limited extent, largely through the small surplus left from the Annual Meeting of the Association.

Other Institutions. Other institutions, representing one particular science, have in many cases aided researches at a particular laboratory, or have actually organized researches themselves. The Institution of Mechanical

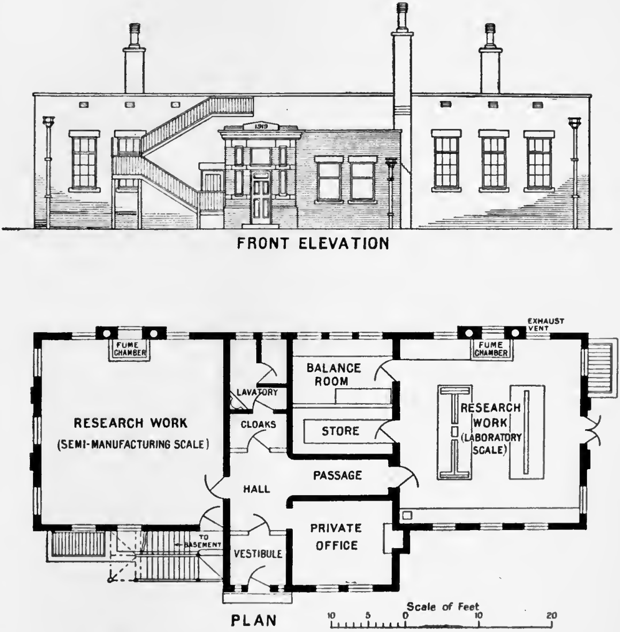

FIG. 30. RESEARCH LABORATORY, IOCO RUBBER AND WATERPROOFING CO., GLASGOW

Elevation and Ground Plan

(*See page* 130)

Engineers thus provided funds for the research in alloys, supervised by the Alloys Research Committee, while the Institution of Electrical Engineers has assisted researches in Buried Cables, Insulating Oils, and others. The Iron and Steel Institute and the Institute of Metals have also aided researches, the former through the Carnegie Fund, by which researches of applicants are aided.

ACADEMIE DES SCIENCES. The French Academie des Sciences distributes each year £6,000 in prizes for scientific research.

SOCIETE D'ENCOURAGEMENT POUR L'INDUSTRIE NATIONALE. This body fills a similar place in French industry to that occupied in England by the Royal Society of Arts, on which it was based. About twenty years ago the society commenced subsidizing industrial research which was systematically directed towards definite ends. Each line of research is followed according to a fixed programme under the direction of a member of one of its committees, and in this manner remarkable results have been achieved for the money expended. Out of an annual income of £4,000, about £600 is set aside for research. Tanning, ceramics and metallurgical problems have been dealt with.

VEREIN DEUTSCHER INGENIEURE. This society is one of the strongest technical societies, if not the strongest, in the world, comprising about 25,000 members. Through the Emperor, its former director, Peters, procured the creation of the degree of Docter of Engineering at the technical high schools, in spite of the opposition of the universities. Out of an annual expenditure of £60,000, the Verein devotes £4,000 to subsidizing industrial research, allotted by a committee of twelve members. About one hundred reports arising from these subsidized investigations have been published at a cheap rate. The work is generally entrusted to men of proved capacity working at institutions possessing complete equipment.

OTHER RESEARCH ENDOWMENTS. Various agencies for encouraging scientific research carry on their function by offering prizes, such as those of the Nobel trustees. Recently, the Paris Academie des Sciences came into possession of the funds placed at its disposal by Loutreuil for encouraging scientific research. The income of the legacy is dispersed by a commission of six members of the Academie, the president, two permanent secretaries, and three members elected by the Academie, one of these being from mathematical science and a second from physical science. This commission is obliged to receive proposals for research from a larger advisory commission, including representatives from all the important scientific bodies in France and all scientific men the president of the Academie designates. The plan of separating executive authority and advisory body is considered extremely wise.

INTERNATIONAL RESEARCH

Science transcends all boundaries set by frontiers or language, and the inevitable result of the growth of research in all countries will be an increasing communication and interchange of information that will facilitate the formation of international groups for the encouragement of research. The conferences and meetings which will follow will form a powerful internationalizing force. The tendency has been shown by the series of conferences which led to the production of the International Catalogue of Scientific Literature, the Congresses in Applied Chemistry, international work on standardization and testing of materials, and by the Brussels Conference held in July, 1919.

Such an international movement is inevitable, and its benefits will be felt not only by science but by the whole commonwealth, since it involves a wider area of contact between nations and a fuller understanding of other points of view. In the past traditional influences in science teaching, the views of men of outstanding genius and differing national temperaments have combined to produce points of view in certain matters of scientific controversy which were distinctly national, but it isbecoming increasingly difficult to differentiate schools of thought by means of national boundaries. The greater the facilities for study and teaching at foreign universities, the greater the difficulty will become. In this way science will become an international and humanizing force which cannot fail to exercise enormous influence on the progress of civilization and the future of mankind.

CONCLUSION

British industrial supremacy was originally founded on the native ingenuity and inventiveness, business capacity and energy of her people. The qualities of mind and heart which distinguish the race found expression in a high code of business morality, in sterling workmanship, in world-wide enterprise in marketing. Character and capacity went hand in hand. The industrial growth of competitors was inevitable, and the development of other great industrial countries, notably Germany, shows a marked correlation between progress achieved and the extent of application of scientific research. It is profitable to consider whether the conduct of our industries on a strictly scientific basis will result in any weakening of that strong practical sense, doubtless innate, but strongly reinforced by experience, which is so commonly found in all grades of workers in our industries. Will it remove, or tend to remove, that ability to improvise and to adapt, which renders the British such a great race of amateurs, in the best sense of that term? For several reasons the query must be answered in the negative. Doubtless in some cases the development of industry through research renders empirical knowledge, born of experience—whether it be the skill of the craftsman, the designer or the industrial administrator—less necessary than knowledge of principles, or scientific knowledge, but this state of affairs is inevitable, and will continue, for it is characteristic of man's progress through the ages. Furthermore, the region of greatest initiative and industrial enterprise at the present time is the United States, where the Americans have unreservedly adopted research in industry to such an extent that European tribute to the States increases every year, and there is no reason to suppose that the result is anything but beneficial to America in all directions. Scientific research is a positive asset which can be utilized to aid such other advantages as we possess. Indeed, those qualities which distinguish the scientific mind—thoroughness, resource, adaptability—are predominantly British, and our distinguished record in pure scientific discovery indicates what may be expected when the country is thoroughly organized to undertake applied research.

So far as meeting foreign competition is concerned, the cheapest labour in modern industry is that of the most highly-paid, highly-skilled, and most intelligent workers. The most profitable industry is that which incurs judicious expenditure on the prevention of waste of material, time and energy in its operations by their scientific analysis and reduction to a minimum. By scientific research this country can revitalize flagging or moribund industries and maintain a high standard of living and employment for its workers.

Science will therefore enable British workers of all grades to make more conscious in industry those qualities which have contributed to success in the past. The possibilities of development between the constituent parts of the Empire in methods of transport, in the wide range of natural resources available, in the economic location of productive enterprises, as well as in many other directions, are such as to warrant enlisting all the aid which research can give. If it is undertaken systematically there is no doubt that Britain will reap a reward from research in industry comparable with, and possibly exceeding, that of other great industrial nations.

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ABBREVIATIONS

WHERE the names of periodicals are not given in full, the following abbreviations have been employed—

Amer. Mach.	American Machinist, London
Brit. Assoc.	Annual Report, British Association for the Advancement of Science, London
Bull. Amer. Inst. Min. Eng.	Bulletin, American Institute of Mining Engineers
Bull. Soc. d'Encouragement	Bulletin de la Société d'Encouragement pour l'Industrie Nationale, Paris
Chem. Age	Chemical Age, London
Chim. et Ind.	Chimie et Industrie, Paris
C.M.E.	Chemical & Metallurgical Engineering, New York
C.T.J.	Chemical Trades Journal, London
Elecn.	Electrician, London
Elec. Rev.	Electrical Review, London
Elec. Jour.	Electric Journal, Pittsburgh
E.T.Z.	Electroteknische Zeitung, Berlin
Elec. Wld.	Electrical World, New York
Engr.	Engineer, London
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