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THEIR PLANNING
AND FITTINGS

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LABORATORIES
THEIR PLANNING AND FITTINGS

BY

ALAN E. MUNBY
M.A., F.R.I.B.A.

WITH AN HISTORICAL INTRODUCTION
BY THE LATE

Sir ARTHUR E. SHIPLEY
G.B.E., Sc.D., LL.D., F.R.S.

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PREFACE TO THE FIRST EDITION

SHOULD this little book prove of service the credit for its genesis must be given to the enterprise of the publishers. In justification for its appearance all that need be said is that search has not revealed any work now in print published in this country which endeavours to deal with laboratories in a manner calculated to bring a building committee, a professorial staff and their architect onto common ground for what is essentially a joint undertaking. In so large a field limitations have had to be decided upon, and these pages are confined to the consideration of buildings and fittings for what may be termed educational science as contrasted with technical and workshop requirements. After some general remarks on initiating schemes, an attempt has been made to deal with the specific requirements of chemistry, physics, biology and geology. This is followed by descriptions and illustrations of some recent designs of various magnitudes.

The author is indebted to a great many contributors who have either given up time to show him their buildings, or furnished drawings or information for the illustrations; he is also under much obligation to the few published works available for reference, and it is hoped that due acknowledgment has been made individually in the text for this valuable help. In addition his special thanks are due to Sir Arthur Shipley, ex-Vice-Chancellor of Cambridge University—one of the most progressive of our educationalists—for the valuable historical introduction which he has contributed to the book; to his friend Mr. Arthur Hutchinson for advice and help in connection with the examples at Cambridge, and to his assistant, Mr. J. R. Smith, who has made by far the larger number of the actual drawings for reproduction.

A. E. M.

9 Old Square, Lincoln's Inn,
London, W.C.

PREFACE TO THE SECOND EDITION

DURING the interval which has elapsed since the first edition of this book was published considerable advances have been made in all branches of natural science, and though this progress has not involved corresponding changes in laboratory equipment, the author has found it necessary to alter and add to the book so materially that it has had to be entirely re-cast. While changes incorporating new matter will be found in every chapter, information on the biological sciences has been most extended in an attempt to describe in some detail the requirements of the newer off-shoots of biology which have now attained such importance.

The services necessary for laboratories which should be regarded as a first essential are also described at greater length in the light of recent developments, while in the chapter devoted to designs a number of old examples have been replaced by illustrations of more modern buildings, and acknowledgment to those who have contributed will be found in this final chapter.

There is still no consensus of opinion among scientists as to what the material equipment in fittings and services should be for a given subject, nor has the author succeeded in raising any general interest in this topic. His task, therefore, as regards the newer branches of science has been somewhat difficult, and he feels that the process too often adopted of following some recent design, with perhaps the idiosyncrasies of a particular specialist which may be much out of place in another situation, can hardly be the best or most economical method of procedure. With some acceptance of basic generalizations, a great deal of " spade work " would usually be saved which must otherwise recur on the erection of every important laboratory building.

A. E. M.

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HISTORICAL INTRODUCTION

BY

THE LATE SIR ARTHUR E. SHIPLEY, G.B.E., Sc.D., LL.D., F.R.S.

MR. ALAN E. MUNBY has asked me to write an Introduction to his work on Laboratories. The work is a very serious contribution to a very difficult subject, demanding highly technical and expert knowledge. This the author has, and he has produced a book which will have a permanent effect on all institutions where laboratories are being built.

Roger Bacon (1214-1292), the Franciscan monk of Oxford, was the first to teach " the only true method by which the advancement of scientific learning can be effected, *e.g.* the methods of experimental science—

SINE EXPERIENTIA NIHIL SUFFICIENTER SCIRI POTEST."

Roger Bacon must have had a laboratory, for he clearly distinguished between speculative alchemy and practical alchemy, the latter of which he regarded as more important than the other sciences because " it is productive of more advantages ". Several spots in or about the city of Oxford have been pointed out as his " studies or laboratories ". Roger Bacon was, of course, persecuted by the Church, and spent many a long year in confinement. Much that he did has been lost to us and some of the claims of his admirers have not been upheld ; but nothing can detract from the fact that he stood at that time far ahead of all other leaders of thought.

As time went on the astronomer gradually broke away from astrology, and the chemist and physicist ceased to be necromancers and occultists. But for a long time many of them, even some of the most learned, were half impostors. Browning surrounds us with the atmosphere of the laboratories of the middle ages in one of his songs in "Paracelsus," half genius and half quack :—

Heap cassia, sandal-buds and stripes
  Of labdanum, and aloe-balls,
Smeared with dull nard an Indian wipes
  From out her hair : such balsam falls
Down sea-side mountain pedestals,
  From tree-tops where tired winds are fain,
  Spent with the vast and howling main,
  To treasure half their island gain.

And strew faint sweetness from some old
  Egyptian's fine worm-eaten shroud
Which breaks to dust when once unrolled ;
  Or shredded perfume, like a cloud
From closet long to quiet vowed,
  With mothed and dropping arras hung,
  Mouldering her lute and books among,
  As when a queen, long dead, was young.

And in his "Laboratory" we can almost see what was going on and realize that the necromancer was not far from the poisoner :—

Now that I, tying thy glass mask tightly,
May gaze thro' these faint smokes curling whitely
As thou pliest thy trade in this devil's smithy—
Which is the poison to poison her, prithee ?

Grind away, moisten and mash up thy paste,
Pound at thy powder—I am not in haste !
Better sit thus, and observe thy strange things,
Than go where men wait me and dance at the King's.

That in the mortar—you call it a gum ?
Ah, the brave tree whence such gold oozings come !
And yonder soft phial, the exquisite blue,
Sure to taste sweetly—is that poison too ?

Perhaps the Astronomers with their Observatories and the Anatomists with their Dissecting-rooms were the first habitually to use special buildings set apart for the pursuit of their subjects. Later the Chemists and the Physicists followed suit. By the fifteenth century physics and chemistry were also demanding special facilities for research. Leonardo da Vinci (1452-1519) probably had a delightful jumble of a studio and a laboratory, for he was both a great artist and a great man of science. During the sixteenth century the great Belgian anatomist Andreas Vesalius (1514-1564) had broken loose from the bond of the written word which had strangled research for a thousand years, and had looked at the structure of the human body for himself; he taught only what he could himself see and what he could make his pupils see. Without knowing it he was a disciple of the Great Oxford forerunner, Roger Bacon. Under him Anatomy was the first of the natural sciences to break loose from the scholastic domination which had hitherto ever placed authority above experiment. " To look with the eyes is to confound the wisdom of ages," as Walt Whitman reminds us.

During the time of the Tudors a Chymist's, or as they called it, an Apothecary's shop was largely a Laboratory; but not so much for teaching, beyond what an apprentice or two may pick up, as for the compounding of chemicals and drugs.

The Doctors then, as some do still, made up their own medicines and dispensed them.

A typical example of the physician's laboratory was that of Jonathan Goddard, an M.D. of Cambridge, who was doctor of Cromwell's army and was made by Cromwell, Warden of Merton College :—

" When he was ejected his Wardenship at Mert. Coll. (which was in 1660) he lived mostly in that of Gresham, where (being an admiral Chymist) he had a Laboratory to prepare all Medicines that he used on his patients, besides what he operated for his own satisfaction."

Pepys records how at Whitehall Charles II had his "little elaboratory, under his closet, a pretty place," and was working there but a day or two before his death, his illness disinclining him for his wonted exercise. The King took a curious interest in anatomy; on May 11, 1663, Pierce, the surgeon, tells Pepys " that the other day Dr. Clerke and he did dissect two bodies, a man and a woman before the King, with which the King was highly pleased ". Pepys also records February 17, 1662-1663, on the authority of Edward Pickering, another story of a dissection in the royal closet by the King's own hands. As we have seen from the case of Charles II, in the Stewart times laboratories were found in the houses of the great, but they were laboratories in the main for research and not for teaching. Probably they were connected with the museums of " rarities " which many great noblemen then possessed.

One of the earliest laboratories for teaching in our country that I have been able to trace was that of " Peter Sthael of Strasbourg (a Lutheran, a great hater of women, and a very useful man) ". He was brought to Oxford by the celebrated Robert Boyle, so often referred to as the father of chemistry and brother of the Earl of Cork. Boyle's laboratory is shown in a charming picture in Dr. Gunther's fascinating " Early Science in Oxford ". Sthael's classes grew from three in 1659 to six in the following year, and to over a dozen in his third year. Amongst his pupils were John Wallis, Professor of Geometry, Christopher Wren and John Locke, who was, it is sad to read—

" A man of turbulent spirit, clamorous, and never contented. The club wrote and took notes from the mouth of their master, who sat at the upper end of a table ; but the said J. Lock scorned to do it ; so that while every man besides of the club were writing, he would be prating and troublesome."

Now who would ever have thought that of the author of the " Essay Concerning Humane Understanding " ?

In 1664 Sthael seems to have retired to London, and there he died, though before his death he had returned to Oxford for a short period. It is worth noting that the fee for the lectures and practical work was then much as it still is, at any rate in Cambridge, £3 for the course.

The first laboratory that I can trace in Cambridge was founded by Francis Vigani (1650 ?-1712) some years later. Vigani was a Doctor of Verona ; about 1683 he came to reside in Cambridge, and soon became an acknowledged teacher with a high reputation. In 1703 he was invested with " the title of Professor of Chemistry "—as one " who had taught Chemistry with reputation in Cambridge for twenty years previously ". He was our first Professor of Chemistry, unpaid.

At that time Masters were indeed Masters, and the celebrated Dr. Bentley, Master of Trinity College, was domineering over, bullying, fighting, and at times but not at all times cowing his Fellows. The Master was desirous of annexing the College bowling green and adding it to the garden of the Master's Lodge—in fact, this high-handed attempt was one of the charges made against him to the Bishop of Ely in 1710.

The scheme was strongly opposed by the Fellows, and eventually Bentley had to abandon his design. At the east end of the bowling green was part of the old King's Hall, and amongst its rooms was a chamber that Bentley called the "Lumber-Hole," and in this chamber or chambers a laboratory was fitted up for Vigani who had recently been appointed Professor of Chemistry. The following Order, the terms of which are said to have been selected with the express purpose of preventing any future encroachments by the Master, shows that the laboratory occupied the ground floor of the old buildings of King's Hall, on the east side of the bowling green :—

"Febr. 11th 1706-7. Orderd . . . y^t the low Chamber under y^e Old Hostle adjoyning to y^e Gate be made and fitted into a Laboratory for y^e use of Chymistry, and Physics and Philosophical Experiments; and y^t it never be converted to any other use."

A contemporary pamphlet gives some account of the feeling that was aroused by the attempt of Dr. Bentley which ended so happily in the establishment of the first Cambridge chemical laboratory. The pamphlet describes the efforts of the Master to capture the bowling green, and it concludes with some rather disparaging remarks as to the courses that were given there :—

"For if the Design had not miscarry'd, Then had this old Lumber-Hole been an Elegant Green-House for Dr. Bentley: But since they wou'd not do That, He resolved He'd be even with 'em for their Stubbornness; and if it cost them a Hundred Pounds the Lumber-Hole should be made, and Constituted, and for ever after call'd, an Elegant, Chymical Laboratory. I am none of those who glory in running down Chymical Observations and Experiments; but yet with regard to this so famous Laboratory of Ours, I have talk'd with those that have gone the Courses, and they All seem to be of Opinion, That as those matters are manag'd, the Learned World is not like to reap any mighty Profit or Advantage from anything that is There taught."

The establishment of Vigani's laboratory is often put down to Bentley's great desire to improve the teaching in the College and University. But I am afraid the above recitals put a somewhat other and certainly less favourable view on the proceedings. In spite of the order "y^t it never be converted to any other use," the "Lumber-Hole" has been converted to other uses and is now part of the Bursar's Offices.

But one could write a book on the history of laboratories, and I fear my readers would weary if I continue on this one topic. Let us take a great leap and come down to my own experiences as a student forty years ago.

When I began to study Botany in 1879 at St. Bartholomew's Hospital the only attempt at practical work was to hand flowers round in the lecture room, which we sometimes dissected, but I am afraid more frequently threw at the lecturer. In the following year, when I came up to Cambridge, apart from the Medical School there were recently constructed laboratories for the teaching of Zoology and Physiology; but excepting the Herbarium or "Hortus siccus" there was no laboratory for teaching Botany. That came very little later under the management of Mr. S. H. Vines, who has but just retired from the Sherardian Professorship at Oxford. The Mineralogical Laboratory, if it existed at all, was a small appendix to the museum of minerals. The Cavendish Laboratory, however, was then, as now, doing work which has made it the Mecca of all physicists throughout the world. The Chemical Laboratory was there also, but ill-housed and inconveniently arranged. The Engineering Laboratory hardly existed, though there was a room or two in which wooden models constructed by Professor Willis were housed. All that is changed, and Cambridge has now a finer set of laboratories for teaching work as well as for research than any other University in the Empire. If I have any criticism to make of them, it is that there is a want of spaciousness in their staircases and passages. Charles Lamb used to say that the turn-stile leading into Lincoln's Inn Fields was made so narrow because such very fat people used to get through. Perhaps the same reason accounts for the straitened dimensions of some of our passages and staircases. Then again there is a plentiful lack of lifts, and this wastes a great amount of time and energy.

Huxley (1825-1895) gave an enormous stimulus to practical work when in the 'seventies he started his classes at the Royal College of Mines, South Kensington. It was he who systematized the teaching of what is called elementary Biology. He recognized the fundamental unity of plant and animal life, and he illustrated his lectures by the study of types first of all of the simpler forms of unicellular animals and plants, and gradually passing through the more lowly multi-cellular organisms he at the end arrived at the mammal and the flowering-plant. He was aided by a brilliant staff of demonstrators, amongst whom I may mention Sir William Thistleton Dyer, late Director of the Royal Gardens, Kew; Professor S. H. Vines and Professor Newell Martin, who carried Huxley's ideas beyond the Atlantic, and first started in the United States the modern system of laboratory instruction in elementary Biology to large classes. From Huxley's laboratory the light spread to France and Germany and other parts of the Continent, though for a long time Britain, as she so often has done in scientific matters, led the way.

As a system grows old it tends to ossify, and to some extent this is true of the teaching of elementary Biology. The schedule for the First M.B. has hardly changed since I first began teaching in Cambridge University in 1884. Too much attention was then given to details and too little to broad generalizations. The course of preliminary biological science at Edinburgh gave a much wider view of animate nature than was given, at any rate at one time, by the study of a limited and unvarying list of type forms. A student who passed through the ordinary M.B. elementary Biology could emerge at the end of it believing that a whale was a fish and having but little or no knowledge of adaptation, symbiosis, natural selection, marine life and other fascinating aspects of plants and animals. It is true that the Edinburgh student did less practical dissecting, but he used the museum more.

The sort of teaching I have tried to indicate has now spread from the University and University Colleges to the schools, and most schools that can possibly afford it have now fairly well-equipped laboratories for the boys and girls to work in. This has been a very heavy strain on the resources of many poorly endowed institutions, and very great self-sacrifice has been needed to provide the necessary buildings.

I have two or three suggestions to make to those who are responsible for constructing laboratories and lecture rooms. Perhaps the most important refers to the relative positions of the magic lantern and the screen on which the pictures are shown. In nearly every lecture room I have been in, the lecturer faces the lantern and turns his back toward the screen. Hence, when he wishes to point out features in the picture he has to twist round, and then his back is turned upon his audience. Now, if the lantern were placed in the far corner, to the left of the lecturer, and the screen in the near corner on his right, he could more or less face the pictures and his audience at the same time. The only way to overcome the present difficulty is to arrange a looking glass in front of the lecturer to reflect the pictures. This plan was suggested to me by Dr. A. C. Haddon, and it works very well, but it gives the audience an erroneous idea of the lecturer's memory as he recites the long list of slides seen by him only in the glass, without turning to look at the screen.

The second great difficulty in building laboratories is to get the maximum of light, and on this I have a word to say. If the " splay " of a window be not at right angles to the wall, but slope outward from the edge of the window to the inner surface of the wall, and if it be painted white, a very great increase in the illumination of the room is brought about, with but a small loss in the strength of the outside wall.

Thirdly, for classes which require microscopes, the front seats next to the window are at a distinct advantage over the second or third rows further back in the room. Now, if V-shaped tables be constructed, whose bases are as wide as the width of the windows, five or seven students at each table can get a very adequate light of almost equal intensity ; and the broad base of the V takes up only about as much space as two laboratory places set at a table parallel with the outer wall and immediately fronting each window.

Another point—a small one, it is true—is that the lecturer should be able to lower and turn up the light of the room from his lecture table. In the room in which I am at present lecturing the attendant has to run up and down some steps to do this, a process which is disconcerting to the taught as well as to the teacher.

We have seen that the great monk, Roger Bacon, said that the advancement of science can only be effected by methods of experiment. His teaching fell on deaf ears. Three hundred and fifty years later his namesake, Francis Bacon (1561-1626), in Elizabethan times re-affirmed this great principle, and from Francis Bacon's spacious time till now it has never been forgotten.

The gap between the mediæval science which still obtained in Queen Elizabeth's time and the Science of the Stewarts was bridged in a way by Francis Bacon. He was a reformer of the scientific method. He was no innovator in the inductive method ; others had preceded him, but he, from his great position, clearly pointed out that the writers and leaders of his time observed and recorded facts in favour of ideas other than those hitherto sanctioned by authority.

Bacon left a heritage to English science. His writings and his thoughts are not always clear, but he firmly held, and, with the authority which his personal eminence gave him, firmly proclaimed, that the careful and systematic investigation of natural phenomena and their accurate record would give to man a power in this world, which, in his time, was hardly to be conceived. What he believed, what he preached, he did not practise. " I only sound the clarion, but I enter not into battle " ; and yet this was not wholly true, for, on a wintry March day, 1626, in the neighbourhood of Barnet, he caught the chill which ended his life while stuffing a fowl with snow, to see if cold would delay putrefaction. Harvey, who was researching whilst Bacon was writing, said of him : " He writes philosophy like a Lord Chancellor ". This perhaps is true, but his writings show him a man, weak and pitiful in some respects, yet with an abiding hope, a sustained object in life, one who wrought through evil days and in adverse conditions " for the glory of God and the relief of man's estate ".

Though Bacon did not make any one single advance in natural knowledge—though his precepts, as Whewell reminds us, " are now practically useless "—yet he used his great talents, his high position, to enforce upon the world a new method of wrenching from Nature her secrets, and, with tireless patience and untiring passion, impressed upon his contemporaries the conviction that there was " a new unexplored Kingdom of Knowledge within the reach and grasp of man, if he will be humble enough, and patient enough, and truthful enough to occupy it ".

In conclusion, may I say, that in my opinion this book will be a real help to those engaged in investigating the secrets of Nature—to all those who are in Francis Bacon's sonorous words working " for the glory of God and the relief of man's estate ".

A. E. SHIPLEY

CHRIST'S COLLEGE LODGE,
March 10, 1921.

[*From an Engraving dated* 1822.

An Early XIXth Century Design for a General Laboratory.

AUTHOR'S INTRODUCTION

THE history of natural science teaching in this country forms a marked illustration of our national conservatism, and even to this day the number of our public men who personally know anything of this field of study, and are thus in a position to appreciate its value, is so small, that science has yet to take its due place as a national factor in this country. For while it is probable that no one would deny the value of science for those destined for technical pursuits, there are many who entirely fail to appreciate its value as part of a general curriculum. When one reflects that only a quarter of a century separated the design shown in the frontispiece from the birth of the Science and Art Department, it seems strange that three times this interval has not, as regards public appreciation, carried us further to-day. The exhibition of 1851 is usually regarded as the starting-point of science training, but even 1889, the date of the Technical Instruction Act, found science in most of our schools a thing apart, taught to a few specialists, an attitude which probably Clifton College can claim to have first endeavoured to dispel. As the result of grants and private munificence, university education in science has much developed in recent years. These advances, however, must be regarded not as contrasted with our previous position, but in the light of what other countries have been doing, and unless we are to fall behind other nations we must inculcate that spirit of science which shall seek to infuse the immense stores of knowledge of the intimate workings of the natural world into our mode of life and into our industries.

Science is based on experiment, and experiment, always arduous, can be enormously assisted by adequate equipment which means the saving of valuable time during the all too short years which the researcher has before him, and this book tries to indicate the nature of the equipment necessary.

CHAPTER I

SCOPE AND INCEPTION OF BUILDING SCHEMES

SCHEMES for supplying the material requirements of education and research in Natural Science differ so widely in extent and character that any generalizations within reasonable compass are not easy. As stated in the preface the scope of this volume is limited to what may be termed pure science for educational and research purposes, the demands of which may range from fitting a school laboratory to a complete building of university or research type designed for one or more specific subjects. While not professing to deal with the special needs of what is known as "technical work," it will be found that the requirements for the early stages of such work, which consist largely of pure science centred round some trade, are practically covered, while a good deal of advanced technical work is more a matter of special plant and apparatus than of buildings of a different order.

In a small secondary school it is usual to find one or two laboratories, a lecture room, which is sometimes an ordinary classroom fitted with a suitable table for demonstrations, and in addition, a store, preparation room, and balance room, while in the larger secondary schools, where two or three branches of natural science are taught, several lecture rooms and three or four laboratories with preparation and store rooms, small rooms special to the respective subjects, and perhaps a master's laboratory and private room are found. In schemes of university type each branch of science is naturally made a complete unit, and is often in a separate building entirely distinct and self-contained. Sometimes, indeed, this unit system is applied to branches of a particular science. Thus, one building or floor, complete with all its main and subsidiary rooms and staff, may be required for Physical and another for General Chemistry. This unit system has undoubted advantages where it is justified. It not only admits of entirely independent use of a department or all departments together, each under its own scheme of work, but it defines the spheres and responsibilities of the teaching staff in a manner calculated to give an incentive to progress.

It must not be forgotten, however, that not only the initial building outlay of such a system but the running cost in staff and upkeep is a serious factor. A compromise between the unit and the fused systems may often be satisfactorily attained when neither seems applicable by retaining separate main rooms, such as lecture theatres and laboratories, while certain rooms not in such general use, such as balance rooms, dark rooms, libraries, and those not directly used by the students, are so planned as to be available in common by two or more departments.

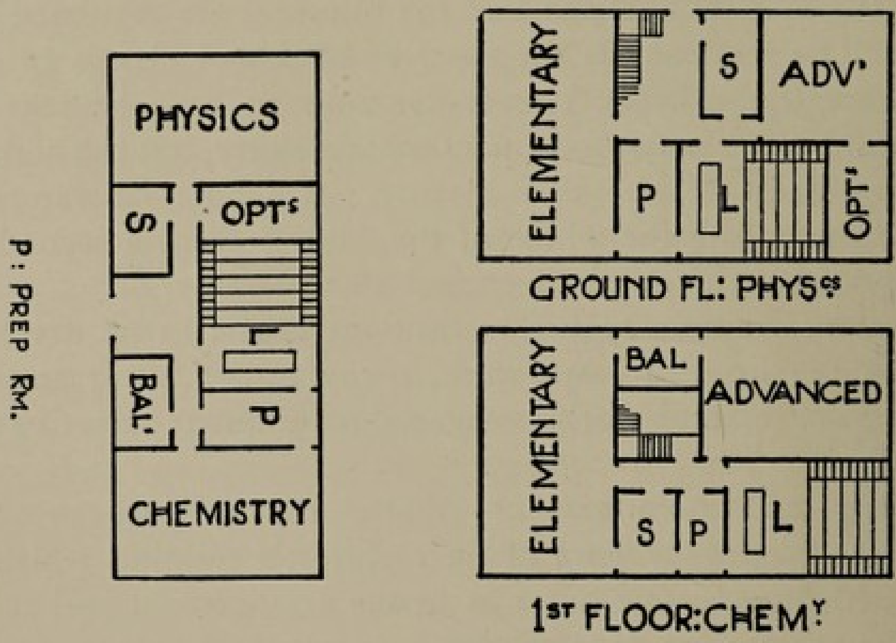
Subjects and Numbers—For the benefit of those not conversant with educational programmes a word may be said upon the divisions of natural science. Opinions differ as to the relative merits of the branches of science as educative training, but Physics, Chemistry, and, at present less widely, Biology, are usually regarded as the most suitable fields for school courses, often preceded by a course of general science which, while inculcating some of the fundamental principles of the above subjects, is often mainly concerned with physiography or mensuration. Physics, essentially a science of measurement, is well designed not only to teach habits of accuracy and reasoning, but to awaken an interest in all natural phenomena dealing with the various forces of nature upon inert matter, and its applications to all kinds of mechanical and electrical appliances are direct and numerous. Physics is for convenience usually subdivided into Mechanics, Heat, Electricity, Magnetism, Light and Sound, the first three being perhaps most amenable to advantageous elementary treatment for large laboratory classes. Chemistry, which investigates the composition of materials and the relation and properties of their component parts, is essential for a proper understanding of the natural changes in the world around us, while the artificial production of useful substances has recently received great stimulus in this country. It is divided into Inorganic and Organic Chemistry, the latter, concerned with the products of animal or vegetable origin and those of mineral origin containing carbon. Though this distinction is giving way to the inroads of Physical Chemistry, Organic work forms a prominent feature of all advanced study. Biology, which is concerned with the life processes and structure of plants and animals, offers not only a field of direct interest in natural surroundings, but provides great educational openings in the matter of classification and minute observation. Botany and Zoology, embraced under this heading, have in recent years made great advances, involving laboratory work drawing on chemistry and physics, which has formed new branches of science (see Chapter IV). Another subject which, though it seldom finds a recognized place in a school curriculum, plays an important rôle in many university courses is Geology, and perhaps no country in the world offers such a diverse field for this study as our own.

If the building is entirely independent, the provision to be arranged can be based solely on the anticipated size of classes, a matter, however, often as much bound up with the personality of the staff as with the needs of the district. Where attendance is compulsory, however, as in a school, it generally happens that the numbers are regulated by other subjects. The tendency is for the size of school classes to decrease, and in secondary schools, twenty-five may perhaps be taken as the average number ; a junior form may contain thirty, but the higher forms will often consist of less than twenty. A school laboratory should usually accommodate the whole of the largest class, a second teacher being provided if the numbers exceed about twenty.

Laboratory work in higher institutions seems to be developing at present on the lines of team work, many rooms being arranged for small groups of research workers engaged on different parts of a common problem.

Planning and Arrangement—While the general principles of planning are essentially part of an architect's training which cannot be dealt with here, a few notes as to the arrangement and relation of the various rooms and departments may prove of value. One of the first things to be recognized by a layman is that a successful plan can seldom if ever be utilized without very considerable modification in another situation. Questions of slope of the ground, aspect, surroundings, and location of entrances and exits all have to be regarded in the design of a building, and no two sites present similar conditions for all these factors. Hence even for similar conditions for work and accommodation, utilization of a previous plan is never completely possible. The relations and sizes of different rooms are, however, matters which admit of some generalizations. The following line diagrams show the kind of way in which ideas on planning may be expressed on paper for the architect to translate into practical form. Fig. 1A shows two laboratories with a lecture room between them, off which is a preparation room and balance room adjoining the chemical laboratory, while off the physical laboratory is an optical room and a store near the entrance. Fig. 1B shows a two-story building with a small complete physics department on the ground floor and chemical department on the first floor. Plans of larger buildings will be best dealt with as actual examples in Chapter VI.

Where a complete administrative series of rooms is provided, it may be desirable to have a separate access for the staff, for the students, and for goods, but entrances should not be more numerous than really necessary, as every external door involves a certain amount of atten-



FIGS. 1A and 1B.—Diagram Plan of Simple Buildings.

dance. Means of exit should always admit of two alternative ways of escape in case of fire or panic, and if external doors cannot open out, a matter sometimes difficult to arrange happily, they should stand open during working hours and an internal door or pair of doors adjoining such exit should be provided either to open out or swing. Much saving in corridors may often be effected by centralizing main entrances and staircases, but as far as corridors are necessary these should not be too narrow, as they are frequently used by large numbers together ; the habit of lining corridors with cases or lockers, if not designed for this purpose, is to be deprecated. Though rooms should not be used as passage ways a good deal of communication for the staff and attendants between different rooms will be found necessary, as it is desirable to reduce as far as possible the need for carrying apparatus through passages. Symmetry in the arrangement of both the rooms and the fittings in them will assist order, and the more simple and straightforward the plan of the building and its contents the better will it be in the working. It will not usually be found necessary to urge an architect to produce a symmetrical plan, because in formal planning symmetry is of great assistance in the design of suitable elevations. A building of any magnitude should have at least one axis, departments being balanced on such axis as far as possible with due regard to the central location of any rooms which have to be used in common by different departments.

In large buildings the adoption of a unit area will not only assist in working out the plan and the constructional requirements (usually thereby simplified), but will much help in decisions upon space allocation in arranging the necessary schedule of accommodation upon which the architect must base his initial drawings. For example, 12 ft. of frontage and 18 ft. in depth might be decided on as suitable for a single working laboratory for research or for a private administrative room. A series of such rooms may then be visualized along a corridor, with one or more such units devoted to various purposes as appropriate. By the use of an eccentral corridor with rooms on either side, two units, one being of greater depth, may be adopted, the second say 12 ft. by 24 ft. Such a deeper unit in multiple would cater more happily for general offices or laboratories of magnitude.

Whether rooms are placed on both sides of the main corridor will depend on several factors. Light and air are obviously improved by the single room system, and with rooms arranged round a central court of no great size internal corridors may be impossible, more particularly if there are several stories. For an extended building external corridors mean much further distances to travel and add considerably to the size of the structure. When the corridors can terminate at both ends in large rooms, such as general laboratories and lecture rooms, the additional cube is of course reduced. Generally, however, large buildings on open sites are found with internal corridors lighted at intervals by staircase windows, and sometimes by end windows, but in some degree dependant upon light borrowed from adjoining rooms by screens and fanlights.

Administrative rooms should be near the main entrance. Here should be found the general offices, waiting and secretary's rooms, porter and telephone, while visitors' cloakrooms should not be far away. The directors' room and board room should be in touch with this department, but should be safeguarded from intrusion by callers until their credentials have been transmitted.

Separate cloakroom and sanitary accommodation should be provided for the professorial and clerical staff. Such arrangements for students may involve considerable space and accommodation below the principal floor in connection with the students' separate entrance.

The location of the main lecture theatre, which may run through two stories, should be considered in reference to its possible use on public occasions, and if such use is intended, private sanitary accommodation should be arranged behind the platform end. The requirements of a cinematograph sometimes involve constructional considerations of some magnitude and compliance with statutory regulations.

Staircases and lifts should be arranged to admit of good distribution and circulation, and to provide alternative means of escape in case of fire or panic. Large laboratories will usually occupy terminal situations off corridors, and should not be passage ways. Their accessory rooms and associated staff and research rooms should be grouped to reduce travel to a minimum.

Provision for the considerable number of service pipes, floor drains and ventilation flues may have some bearing at an early stage on planning. Vertical shafts alongside main piers much assist in carrying services together from floor to floor, while the lesser light necessary for corridors as contrasted with rooms gives an opportunity for large horizontal ducts over false ceilings above such passage ways.

Aspect is important, but must be considered in relation to surroundings. For example, a laboratory, not a lecture room, should be placed on a noisy side of the building, and there may be rooms seldom used except in the evenings, which might most suitably occupy rear ill-lighted positions in planning on restricted areas. Aspect is also related to the subject taught, for example, rooms for microscopic work require in this country a steady north or north-east light, and for horticultural botany an open south aspect. A great deal of light is required for all science work, observations in every subject being at times of a very minute nature, and as wall space is always required abundantly for fittings, rooms sufficiently lofty to give both ample wall and window area are necessary. Top lighting, often required, necessitates further provision for warming, and may be trying in very hot weather, but as most students are absent from the end of July to well into September the latter objection carries less weight in educational buildings than would appear due to it at first sight. The provision for artificial light must also be on a much more generous scale than for an ordinary room, the actual sources of light being, however, screened from the eyes and directed on to the fittings upon which illumination is required.

Floors for Subjects—As to the floors to which, in storied buildings, different uses should be allocated, heavy machines, furnaces benefiting by good draught, rooms wanting an equable temperature, stock and like rooms not frequented by students, usually find a place in a basement. In small buildings physical laboratories, on account of vibration, generally occupy a ground floor, though in the vast majority of cases this is by no means essential. Chemical departments, though this adds to outlay on drainage, are most often found on upper floors, while biological subjects, where concentrated and quiet work is more in vogue, and where light and sun are of especial importance, are most suitably disposed on a top story where access to a flat roof is often obtainable.

Use of Old Buildings—It is not likely that any attempt will be made to utilize old buildings erected for other purposes for science teaching in any very permanent or extensive scheme, though in exceptional circumstances, where the lighting is, or can be made, adequate and any difficulties as to drainage, ventilation, condition of flooring and other kindred matters, can be overcome, there is no reason why good laboratories should not be produced by such means. It will seldom be found, however, that a series of rooms planned for other uses will fulfil the working requirements of a department, and chemistry is less amenable than other subjects to the limitations of an old building on account of its greater requirements in the matter of drainage, ventilation, and supply services. In a small scheme where new buildings could adjoin old, and funds are not available for more adequate provision, advantage might be taken of existing rooms for conversion into lecture rooms, or for some branches of physics, and given suitable light and aspect, biology. Store rooms, workshops, and any rooms of an administrative nature might also find a home here. Generally speaking, however, a science building to work well should be designed *de novo* for its specific purposes.

Expansion—In these days of rapid progress, changes and expansion in any science building must be looked for. The nature and extent of the fittings and service supplies in laboratories render alterations often somewhat difficult, and though the relative claims of the present generation and posterity should be fairly assessed, bearing in mind that the character of the latter are necessarily problematical, it is well to conceive boldly even if immediate realization can be only partial. This will prevent an unorganized growth of buildings difficult to work in later years. In a new centre, or where the probable growth of industries suggests an increasing population, provision for expansion is, of course, particularly necessary, but it may also easily happen that in some old-established institution which has possessed almost constant numbers for generations, some cause, such as a change to more liberal views on education by those responsible for the curriculum, may involve a large increase in science teaching. It is in fundamental matters of this kind that a building committee holds great responsibilities, and some view upon them should be arrived at and made known before the architect puts pencil to paper; indeed, he may often be usefully brought into such deliberations. If subsequent internal alterations are probable, many of the partition walls can be constructed so as to be capable of removal, by the provision of steel work, to relieve these partitions from floor loads. This, of course, involves increased initial cost, but much less outlay and disturbance than would be caused by the subsequent introduction of steel work to effect such removal after the building is completed.

Construction—Science buildings should generally be constructed in a solid and substantial manner, to admit of the adequate installation of drainage, ventilation ducts, and supply services, reduce fire risks, and minimize vibration. There is, however, no reason why a building wholly on the ground floor should not be of an almost temporary character if desired, and though this is not generally to be advocated, since the dignity of a building has no little effect upon the mind of the student as to the standing of the subjects taught within its walls, it may sometimes happen that immediate accommodation is necessary with very limited funds, while ground is readily available. The fittings in such a building may, of course, be either also temporary, or be substantially made with a view to subsequent use in a permanent building. In this connection a word of warning may be given against the purchase of temporary buildings on another site for transport and re-erection, without adequate advice. These are sometimes available at what appear very tempting prices, but the cost of removal and re-erection is generally considerable. One of the most difficult things to make a layman understand is the cost of altering and re-using old material, both in buildings and fittings. The point generally lost sight of is that time is often worth more than the old material which is not usually amenable to the operations of any machinery but involves individual hand labour. It is thus often cheaper to reject perfectly sound work than to subject it to considerable alteration.

The most suitable materials for the construction of the shell of the building and their relative cost depend very largely on the magnitude of the project and on local conditions. The choice usually lies between reinforced concrete, a steel frame, or an ordinary brick building. This is hardly the place for a discussion of these structures. In the case of a large symmetrical building, the two former types possess advantages in admitting of the reduction of wall thicknesses to the lower stories and generally of greater rapidity in execution; but the exterior clothing, if in brick or stone, certainly presents no saving. For small buildings these modern methods present no financial advantage over simple brickwork. As an example, it may be of interest to state that the cost of a steel frame and brick building for that portion of the science buildings for Highgate School on Southwood Lane, illustrated in Fig. 91, Chapter VI, were worked out as alternatives, and that this, though a three-story building in London, proved to be of less cost in ordinary brickwork, and was so constructed. This, of course, does not mean that a good deal of steel was not used in this building. Thick walls have some advantages in decreasing vibration effects where delicate physical work is in question. Fire-resisting floors, as contrasted with joists and boards, are always desirable. Some form of hollow terra-cotta block floor is very suitable, and will prove more sound resisting than a solid concrete floor.

Windows—Much can be said for the ordinary wood windows which slide up and down, known as double-hung sashes; but in large openings, such as are usually required, to make such windows manageable the casings necessary to split them up into pairs of reasonable size obstruct light, hence the advent of the metal window, which can take a great variety of forms. It is usually impracticable on account of air currents to have windows in laboratories opening at or very near bench top level, hence the lowest panes should generally be fixed; intermediate panes, not too high, may be hinged casements and top lights pivoted or hung horizontally at top or bottom and operated by gear or cords. Panes should not be small, and clear glass should be used in all situations in which obscure glass is not imperative.

Internal Surfaces—As regards walls, glazed bricks and tiles, though permanent and washable, add very materially to the cost of a building. In situations subject to bacteriological consideration or to defilement terrazzo in small material suitable for vertical surfaces is preferable, and makes an excellent cleanable surface. If alteration in the rooms or fittings are at all likely, the difficulty of reconciling different wall surfaces which may thus be thrown together must be considered. Plastered walls may be either painted or distempered, such application being periodically renewed. Bare brick walls show very little saving compared with plastered walls, reflect less light, and are not so cleanly. Around certain fittings, however, where walls are likely to be soiled, an impervious, washable surface is always desirable. In working rooms, corridors, and lavatories plastered walls should have dados 4 to 5 ft. high generally in Keene's cement on a backing of portland cement, or finished in the latter material, though this is usually less satisfactory. Vertical wooden boards about 3 ins. wide on the walls at convenient distances apart, preferably finished flush with the wall face, or sockets built into the walls to receive bolts, may be provided where much shelving is anticipated.

As regards paint, it must be remembered that the gases of a chemical laboratory very rapidly blacken lead paints. Zinc paints may be specified, but titanium paint has a better body and remarkable covering power. This is titanium oxide made up in oil, and is quite white in colour. Its successful use depends upon freedom from adulteration by cheaper materials.

As to floor surfaces, those subject to hard wear and much change of temperature, but not to the action of acids, such as heating chambers, furnace rooms, and certain stores, are best finished in cement and fine granite chippings, known as granolithic cement, which forms, however, a cold and tiring floor for general work. Asphalt makes an excellent if unattractive surface for floors subject to much wet or acid splashings, and its elasticity is sufficient to admit of its adaptation to slight movements or shrinkages which almost invariably produce some cracks in continuous brittle surfaces. It is, however, subject to considerable indentation, even with light sustained loads on small areas, and if this is expected a specially hard asphalt should be called for. In the main rooms, laboratories, lecture and subsidiary working rooms—wood blocks of hard wood, pitch pine, or deal are generally used, and while these make an excellent floor it is open to question whether narrow-tongued boards, similarly laid on a solid bed, are not better, as having fewer joints and being easier to clean. The use of ordinary linoleum of really good quality may be commended for many situations, and sometimes old wood floors may be " cleaned off," that is, planed level, and covered with this material with excellent results. Unfortunately, linoleum is soon damaged by alkalis such as caustic soda, but in physical and biological laboratories, balance rooms and places not subject to rough wear, it forms a quiet and very cleanable floor, and as it can be laid on an ordinary cement floor surface, it is economical. Owing to its tendency to expand when laid, fixing should be delayed as much as possible. Granular compressed cork laid as " tiles," about half an inch thick, makes an excellent wearing and pleasant surface, though rather expensive. Rubber, unless thick enough to become costly, really possesses little resiliency, and is not as clean in use as is often imagined. Tiled floors are cold and noisy; terrazzo (mosaic) floors, though very suitable for corridors, are cold and readily attacked by acids. Finally, there are many patent floors on the market which can be applied in a plastic form to any surface in a layer about three-quarters of an inch thick, which when trowelled smooth gives a continuous surface, the warmth and elasticity of which varies with their composition. These floorings are usually composed of sawdust (often coloured with ferric oxide or ochre) and cement, usually including magnesium oxychloride, which mixture sets to a hard solid with water. Magnesium oxychloride is always liable to contain free magnesium chloride, a deliquescent body which in the presence of moisture rapidly corrodes metals in contact with it. Although these floorings possess attractions, they present many cases of failure due to cracking, lifting, and undue wear. A recent improvement reducing these defects is the production of blocks of such material laid like wood-block floors.

A point often overlooked is the necessity for settling the nature of all floor surfaces before the architect has to specify the floor construction and levels, that is during the preparation of the contract drawings, as owing to the different thicknesses of these finishes, subsequent changes may involve expense even if no surface has actually been laid, and will sometimes be impossible without small differences in level between adjoining areas.

Necessity for Co-operation—For the successful carrying out of any building scheme, proper collaboration between the organizers, the architect, and the teaching staff is most essential, and so many misunderstandings arise through lack of appreciation of this fact that something may be said legitimately on the subject. It is often stated, and with some justice, that the ideal committee is a committee of one, and a building scheme, if not in the hands of one individual, should certainly be relegated to a very small special committee, which will formulate the requirements in outline and call in their architect at a very early stage. If the teaching staff already exists its views should be voiced before any instructions are issued to the architect, and if not, it is highly desirable to make some appointment in advance of any building, so that the scheme of work can be arranged and the actual requirements fore-shadowed as much as possible, otherwise, unless some member of the building committee is both an educationalist possessing an intimate knowledge of the requirements of the subjects to be provided for, and is, in addition, prepared to devote a great amount of time to the problems calling for solution, the architect is often imperfectly informed as to what is necessary. A building committee should be prepared to work very hard until it knows what it wants and has enabled its architect to embody these ideas in a good set of sketch plans, after which it should define the extent to which it desires to call upon his services, and having done so and accepted the necessary tenders, under the architect's advice, it should leave him thoroughly in touch with the head of the staff of each department, when, save for the control of unforeseen changes necessitated in the scheme, it may feel that its duties are very largely over.

Obtaining Tenders—The material necessities for teaching science may be grouped under three heads: the buildings, the fittings, and the apparatus, and the allocation of responsibility under these headings should be properly defined and may vary in different cases with the magnitude of the scheme, the views of the building committee, and the personal attention and knowledge which the prospective working staff can contribute to the details of the problem. The design of the building, including its internal surface finishings, and decorations, and the supplies for heating, lighting, ventilation, power, and other services are the province of the architect, who will obtain competitive tenders based on his drawings and specifications, and unless the outlay is trifling (under £1000) will instruct a surveyor to " take out quantities," that is to dissect the prospective building and measure it up, placing the brickwork, stone, timber work, and so on, in groups in the form of a bill to which the builders tendering can attach their prices. In works of any magnitude, since builders obtain only perhaps one contract in every twenty for which they compete, this labour of dissection is too great to admit of tendering against other firms were it thrown on the builder himself, hence the necessity for " quantities," the cost of which is usually included in the building tender. This cost is, of course, much more than repaid by the decreased cost of the building obtained as the result of competition.

Responsibility for the Fittings—Fittings include all fixtures and technical furnishing requirements in the building necessary for its intended uses, apart from actual experimental apparatus. Students' benches, lecture tables, fume cupboards, sinks, desks and seats, dark blinds, brick-built combustion benches and the like, cupboards and shelves for storage and the working terminations of supplies such as gas and water taps, electric fittings and fans, come within this category. These are generally dealt with in one of two ways: they are either placed in the hands of the architect, or some firm or firms who sell such goods are called in and given a large measure of freedom as to what is supplied. To deal with the latter case first, the responsibility of detailing requirements and the necessary negotiations are here thrown upon the building committee or the science staff, and though the special experience of these firms is undoubtedly valuable, there are in this country not a great number who possess facilities for conducting such work as part of their own businesses, which are usually more concerned with the manufacture and sale of actual laboratory instruments and apparatus. If, with a very proper wish to obtain the financial benefit which usually accrues from competitive tendering, it is decided to ask several firms to give a price for the fittings, it will be found that the necessary knowledge for the production of a detailed specification, on which alone fair tendering can be based, is probably not forthcoming without professional advice, in the absence of which those firms who only undertake first-class work in a conscientious manner are likely to be heavily penalized by less scrupulous competitors anxious to obtain the contract. Further, there is a natural tendency on the part of the firm selected to make use of designs which it already possesses, which do not necessarily best meet the special requirements of the case, and unless difficulties are to arise, the architect's drawings, and in most cases his approval of many details, will be necessary, as the fittings must conform to his prearranged construction. If the former method is adopted, the whole of the fittings being placed under the architect's care, specialist firms can still, if desired, tender and will do so on adequate particulars and drawings which will ensure fair competition. The committee and staff will have an opportunity of discussing and settling in detail the various requirements previous to any financial acceptance of the work, and this will be carried out under the architect's supervision and in harmony with the other details of the design. Further, it generally happens that a large proportion of these fittings consist of joinery which can be constructed in the shops of a general contractor, given adequate drawings, who may thus be given an opportunity of tendering against specialist firms for such fittings if desired.

The production of such drawings and particulars presupposes the necessary technical knowledge of laboratory requirements. Modern architectural practice is so wide that such knowledge is possessed by advisers in varying degrees, and if necessary some member of the professional staff should be largely freed from his ordinary duties for the purpose of assisting the architect in this work. Few lay committees can realize the great amount of time involved in preparing detailed schemes for fittings.

Finally, the apparatus is almost invariably selected by the professorial staff, and, subject to adequate provision for its appropriate housing in the fittings, can be regarded as an isolated matter, which again emphasizes the desirability of making suitable staff appointments previous to the fruition of any scheme.

Outlay—Architects base their first estimates of cost upon the number of cubic feet which a building, measured externally, contains, placing the price per cu. foot at a figure which their experience and knowledge of local conditions indicate is a fair valuation for competitive tendering.[1] At the present time a substantial building of reasonable magnitude, brick-faced, with limited stone dressings, not devoid of architectural character, but simple in design, including heating, lighting, and drains, can usually be erected on a reasonably level site for about 1s. 9d. a cu. foot, as above defined, excluding site, fittings, and architect's fees.

[1] The cost per cu. foot of buildings described in Chapter VI, of which the author has personal knowledge, will be found in these descriptions.

CHAPTER II

THE REQUIREMENTS OF CHEMISTRY

IN this chapter an attempt will be made to describe the rooms and more important fittings which may be required in a chemical department.

No branch of science makes such heavy demands in the matter of special construction and fittings, owing to the varied and extensive nature of the appliances used and the supply services required. Hence it is particularly desirable that a chemical department be designed with its fittings and not erected to be subsequently fitted by some one who has had no responsibility in connection with the design of the building, as this can only result in increased outlay and loss of efficiency.

List of Rooms—The following rooms may be required in a chemical department for advanced work. In this list the rooms marked (1) are usually the minimum for any separate scheme for chemical teaching, while (1) and (2) would constitute a desirable scheme for a large secondary school. The remaining rooms are seldom found in institutions of less than university standing. In perusing this list, it must be understood that in large schemes, rooms must be often duplicated, thus one large and several small lecture rooms, each with its own preparation room and store, may be necessary. Again, each laboratory may have its own balance room, and several combustion and dark rooms may be wanted, while many research rooms may be devoted to various purposes. On the other hand, certain rooms may be outside the programme of work required, e.g. for metallurgy.

1. General Laboratory
1. Lecture Theatre
1. Preparation Room
1. Store Room
1. Balance Room
2. Advanced Laboratory
2. Dispensary
2. Research Laboratory
2. Dark Room
2. Library

Physical Chemistry Laboratory
Electro-chemical Laboratory
Gas Analysis Room
Sulphuretted Hydrogen Room
Closed Tube Room
Bio-chemical Laboratory
Combustion Room
Museum
Constant Temperature Room
Metallurgical Furnace Room
Metallurgical Laboratory
Acid and Special Store Room
Workshop, Power Room, etc.
Staff Rooms

LOCATION AND RELATION OF ROOMS

Some general remarks on planning have been made in Chapter I, and though the relations of rooms can best be appreciated by studying actual designs, with proper allowance for special circumstances which often involve compromise, a few comments are now added with reference to chemical departments. Administrative rooms should usually be near the principal entrance. The main lecture theatre, which may run through two stories, and possibly be thus approachable from two floors owing to its raised seating, should be well situated for ready approach from outside the building, and the preparation room which serves it should be behind the lecturer and have an entrance direct into the lecture room in addition to one to the corridor, a further connection being often provided between these two rooms by a fume cupboard, opening on both sides, in the wall between them. In a small scheme it may be desirable that the preparation room also adjoin the main laboratory, as it will probably have to serve as a dispensary and perhaps also as a store for the general requirements of the students.

A sulphuretted hydrogen room, if provided, is required in conjunction with the general elementary laboratory.

A balance room should adjoin the laboratory for which it is required or be accessible therefrom without the necessity for crossing any stream of traffic, since the work of many days may be ruined by a chance collision in reaching this room for weighing. This room may often be arranged to serve two laboratories by being placed between them. The advanced laboratory should be arranged in conjunction with the combustion room, where lengthy operations dealing with the analysis of organic compounds are carried out ; and to the organic laboratory belongs the closed tube room, if its place is not taken by a bench furnished with the necessary protection in the laboratory itself. An open balcony to this laboratory for certain experiments is often useful.

If a bio-chemical laboratory is provided, it should form a part of the advanced or organic laboratory section, and will probably consist of a room fitted for general advanced work and a separate room for incubations and culture work, which should be disconnected from the former by a ventilated lobby or other means to keep its atmosphere free from chemical fumes which easily destroy microscopic life.[1]

In the physical chemistry laboratory, a great deal of heating and stirring over long periods generally occurs, hence this work is often carried on in the basement where there is usually less combustible material than elsewhere, but this is not essential. Electro-chemistry requires heavy cables for conveying large currents, so it is obviously an economy to locate the room for this work as near as possible to the source of power, which may be the supply mains or private plant, and almost invariably involves a set of accumulators, best housed in a detached building. This laboratory will possess its own switchboard, with probably a very large number of connections to the main switchboard of the building.

Dark rooms must be larger than those usually devoted to photography, and should be near advanced and research laboratories.

A library in a small scheme may be combined with a common room or seldom used reception room, but a separate room is essential in a scheme of any magnitude. This room should be within easy reach of all students, who should be encouraged to use it, and space should be reserved for the ready extension of the initial shelving. In a large composite science building departmental libraries are often preferred to a general central library.

A constant temperature room is used chiefly in connection with crystallizations,[2] and the difficulty of overcoming the natural changes in atmospheric temperature relegates it most conveniently to the basement, since the lower down and less exposed to sun and wind, the less need be the elaboration in its construction. As experiments requiring this room only involve very intermittent attendance, proximity to the laboratories is not essential.

For metallurgy, the furnace room is almost invariably placed at as low a level as possible in order to secure the maximum chimney draught, which has a considerable influence on the temperature obtainable in the furnaces, though up-cast fans can now take the place of tall shafts. The use of coke, ore breakers, and the like, also make a room near ground level desirable, but it should be well lighted and supplied with fresh air. The metallurgical laboratory, naturally, most suitably

[1] See also Chapter IV. [2] See also Biology.

adjoins the furnace room, but if situated on the floor above it should have a stair in connection special to this department.

Stores should provide for the direct delivery of goods with the minimum of handling. Cases are often large and heavy, and an unpacking room, in addition to the actual store room, is very useful. Connection with the preparation rooms or laboratories by a hand lift or other convenient means will save much labour and breakage. Acid and inflammable liquid stores are best arranged with external doors only.

It is now proposed to deal with the fittings required in individual rooms, with some comments on their arrangement.

Arrangement of the General Laboratory—Of all rooms, the main laboratory is the most important, not only as containing the largest number of students, but as the place in which the foundation of their habit of work is laid. The room should be lofty and well lighted, and should be generous in the matter of space, as movement is inevitable. The Board of Education require 30 sq. ft. per head in laboratories in schools coming under their jurisdiction, an area which must be regarded as a minimum and not sufficient for adult students ; indeed, unless the room is planned for the fittings, it will often be found difficult to arrange it satisfactorily on this basis. As a matter of interest, the following areas in sq. feet per head, found by dividing the whole area of the actual laboratory by the number of students it will hold at one time, are given : Berlin Chemical Institute Inorganic Laboratory, 40½ ; Bristol University Inorganic Laboratory, 50 ; Harrow School, 52 ; University College, London, Advanced Inorganic Laboratory, 64½ ; Oxford University General Organic Laboratory, 75. In the Elementary Laboratories, Clifton College, 42½ ; Highgate School, 44½ ; University College of North Wales, 36 ; and Advanced, Beaumont College, 49 sq. ft. per head.

Fig. 2 gives an illustration of a large laboratory for elementary work in the science buildings of University College, Bangor.

The usual fittings of a general laboratory are students' working benches, fume cupboards, combustion and general benches, shelving, blow-pipe table, drying ovens, often connected with a still, and sometimes a demonstration table on a low platform. Since wall space is very necessary for shelves, cupboards, ovens, and apparatus of a public character, the working benches are never placed round the walls in the manner often adopted in private or research rooms. Usually they are made double so that students can work on both sides, which economizes both space and cost of services, and the best arrangement is that of a series of island (isolated) fittings, placed in parallel rows at right angles to the window walls, which should be the long walls of the room. If the laboratory can be lighted from both sides by windows, it is very advantageous, as this gives a good cross light, unimpeded by fittings, down each bench. These benches are often of considerable

FIG. 2.—Elementary Chemistry Laboratory, Bangor University.

length : in a room of moderate width they may extend across it, leaving only a gangway along the wall on each side, but if the room be a very wide one, a third central gangway is also desirable, parallel to the side gangways. The actual bench lengths will be naturally some multiple of the linear dimension allotted to each student : if 3 ft. 6 ins., which should be regarded as the minimum, be adopted,[1] a bench 10 ft. 6 ins. long will hold three students on each side, but even for elementary work

[1] This length is usually accepted as the standard for junior work both in this country and in America.

an allowance of 4 ft. each is very desirable, especially with the style of work often undertaken in modern teaching. If the width of the room is such that a bench would much exceed 14 ft. in length, it is better to substitute two benches, with a central gangway between them, which will much improve working facilities though it costs space and possibly increased outlay in drainage and services. It may be of interest to note that all the working benches in the general (both elementary and advanced) rooms in Fischer's laboratory in Berlin are 10 ft. 5 ins. long.

The gangways between the sides of the benches must be wide enough to provide a free passage between the students. In certain operations, such as blow-pipe work, the student has to lean over the bench and thus extend his legs for convenient balance some distance from the bench, hence 6 ft. between the bench tops is not extravagant, and anything less than 5 ft. will involve occasional interruption of work when transit between the two rows of students is necessary; 4-ft. gangways, however, are common. For passage behind a single row of students, as where a bench faces a wall or a little-used fitting for general purposes, a gangway 4 ft. wide will be sufficient. The width of the longitudinal gangways, parallel to the window walls, will depend upon the use to which the wall and window space is put, and whether there are sinks projecting beyond the ends of benches. A very usual practice is to put fume cupboards in the windows, in which circumstances a good deal of standing in these gangways will occur, and 4 ft. clear of all fittings should be given. For a central longitudinal gangway, 3 ft. clear between projecting sinks or other fittings should be quite sufficient.

An arrangement slightly more economical of space is to place the benches parallel to the long axis of the room, which has the sole advantage of enabling all the students to turn more readily to face the demonstration table, to obtain any general instructions, if this is placed at one end of the room. A demonstration table, however, is often omitted in large laboratories for adults, and, even in schools, is by no means universal; moreover, if the reagent (bottle) shelves on the benches are above the eye line, no general view of the table from where the students stand will be available. With high side windows or top light no serious objection to this arrangement exists as far as lighting is concerned, but this is not the case with low side windows, as the students will have their own shadows or those of the bottle racks, if high, thrown on to their work.

The width of a double bench is usually between 4 ft. and 5 ft. 6 ins., and a greater width is not desirable. If a demonstrator's table is required, this need not, as a rule, be more than 2 ft. to 2 ft. 6 ins. wide, with some 4 ft. between it and the wall. In front of this table, space should be left if possible to enable a class to stand, observe experiments which cannot conveniently be seen at a distance, and, take notes. Wall benches for general apparatus, distillations and combustions are usually about 2 ft. wide. The extent of such benches varies a good deal and depends in some measure upon the area devoted to fume cupboards and the provision of subsidiary rooms. Plans illustrating the arrangements of the fittings enumerated will be found in Chapter VI.

Students' Benches (Design)—The working benches are the most important fitting in a general laboratory, and before they can be designed the fittings must be laid out on the plan. Bench construction depends largely upon whether the students are to have individual drawers and lockers.

In the case of institutions of university rank, where students purchase their own apparatus, lockers are essential. It is possible to provide three lockers and drawers under a working place 3 ft. 6 ins. long, and if 4 ft. be given to each place, even four could be arranged, as the 11 ins. width per locker only thus available would be enough for elementary needs. Thus three or even four different sets of students can be provided with private lockers under their own working places, which location is essential if confusion is to be avoided.

It not infrequently happens that fittings are ordered from some firm of makers or that designs are prepared by the architect without sufficient information as to the scheme of work intended, which indeed may not have been matured. In this case probably one or two lockers are provided under each place, an arrangement which may prove very unsuitable. Though three lockers under each place may supply all the needs of a small school, say for two large forms and two higher forms of half their size, it is probable that even four will not be enough for a large school. In this event it must be decided whether to attempt a further division of the space into what will amount to "pigeon-holes," to let certain groups be lockerless, or allow more than one set of students to use the same locker.

Another matter affecting bench construction is the position and number of the sinks. Undoubtedly the simplest arrangement is to have sinks at the ends of the bench only, but as every worker must have access to a sink without leaving his position, benches for more than two on each side should have sinks in the bench top itself. One sink,

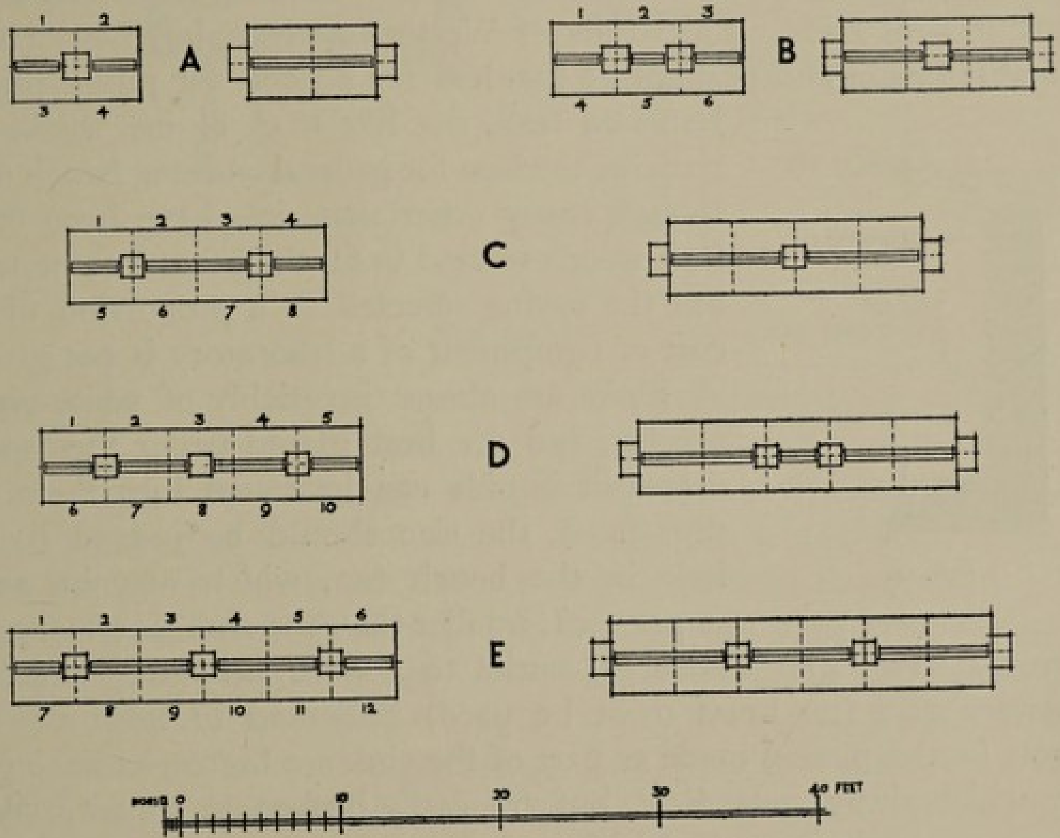


FIG. 3.—Arrangement of Bench Sinks.

however, can serve four students, if their places all adjoin it, hence it follows that the least sinks are necessary when the total number of students on a bench is a multiple of four. The use of end sinks requires one more on any bench than when more central positions are employed. These alternatives will be made clear by a study of the diagrams, Fig. 3, A-E. Subject to the necessities of the case, the less drainage and service pipes in the bench the better.

If the bench length is generous, probably a single row of bottles standing on opal glass, raised an inch above the bench for student's use will be enough, further shelves may be of plate glass about 8 ins. apart and 4 ins. wide. The absence of bottle racks, however, is a great aid to supervision and lightens the general effect of the room, and their only constructional merit is that they form useful supports for running gas, water, and electric services.

Construction of Working Benches—Double benches are generally 4 ft. to 5 ft. wide, and the height is usually 3 ft. above the floor, or slightly less, though in certain American High Schools the height recommended is 3 ft. to 3 ft. 2 ins. For adults of Western nations, however, 3 ft. is a suitable height and perhaps $1\frac{1}{2}$ ins. less for schools for junior pupils. Rangoon teak, not less than $1\frac{1}{4}$ ins. thick, still remains the best for general working bench tops, though many other materials have been tried. Soft woods treated to fill the pores may be used, but the saving effected as a proportion of the cost of equipment of a laboratory is not great.

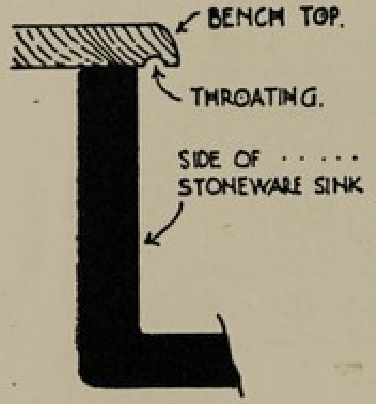
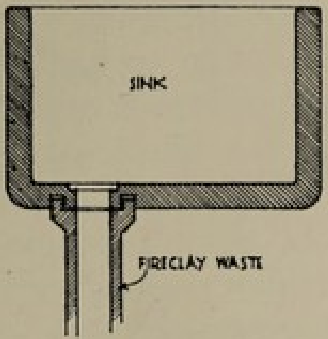


FIG. 4.

Sinks are almost invariably of white-glazed fireclay, and are best placed under the tops so that spilt liquids can be swept into them. If thus fixed, the size should be judged by the hole in the bench top, which may be 20 to 30 per cent. smaller than the sink, as the top will overrun it (Fig. 4). The usual outlet to a ware laboratory sink is a stoneware grid (no brass must be used) cemented in from the top. Spigots (outlet pieces) made as part of the sink are better, as having no joint, which always gets dirty, but are easily broken in transit. Ware wastes can also be cemented in from below (Fig. 5) and are satisfactory if not made to carry the weight of wastes. Grids in waste openings are best made movable, but not too easily so, otherwise solid bodies may find their way into the drains. A perforated, slightly-tapered glazed ware plug (Fig. 6), the top flush with the bottom of the sink, will prove satisfactory. Vulcanite outlets have recently become available, and prove very efficient. They can be used with movable vulcanite standing wastes. The short lengths of waste pipes to bench drains should be straight lengths of untrapped glazed earthenware pipe, suitably supported on the bench framing, and terminated with a shoe discharging in the direction of flow in the drain. Lead, often employed, and sometimes alone amenable to awkward situations, is satisfactory if used at high angles, so that waste liquids cannot find a lodgment. Sometimes an open waste channel in lead or glazed ware is formed down the centre of a double bench, discharging into an end sink in place of sinks in the



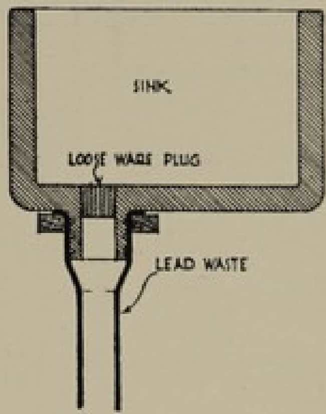


FIG. 5. FIG. 6.
Sink Outlets.

bench itself. On a bench much used for distillations such a channel is preferable to sinks in the bench.

The top of the bench should project over the framing 2 or 3 ins., and if the top rail to the framing is omitted (an arrangement which reduces rigidity for transport) things cannot stick in the drawers. The lockers should have a shelf, but only over part of their area, so that tall apparatus may stand in front. A bottom raised about 4 or 5 ins. above the floor should always be provided, and the door should be arranged to stop against this to assist in excluding dust. Below the door a toe-space recess is often arranged, though if the lockers are again recessed under the drawers, as is often done, this space is hardly necessary. Drawer and locker handles should be of hardwood, or the front may be recessed to form a finger grip. The sides of drawers are sometimes run on beyond the back to reduce the danger of pulling the drawer right out; alternatively a button may be fixed to the back which will, when vertical, catch on the framing below the drawer and prevent removal until it is turned into a horizontal position (Fig. 7). Drawers need not be deeper than 3 to 4 ins., and should

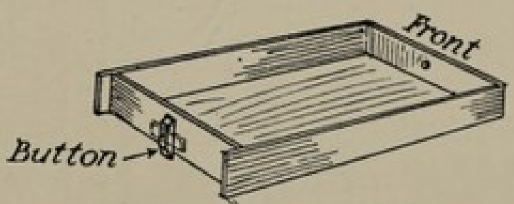


FIG. 7.—Security of Bench Drawers.

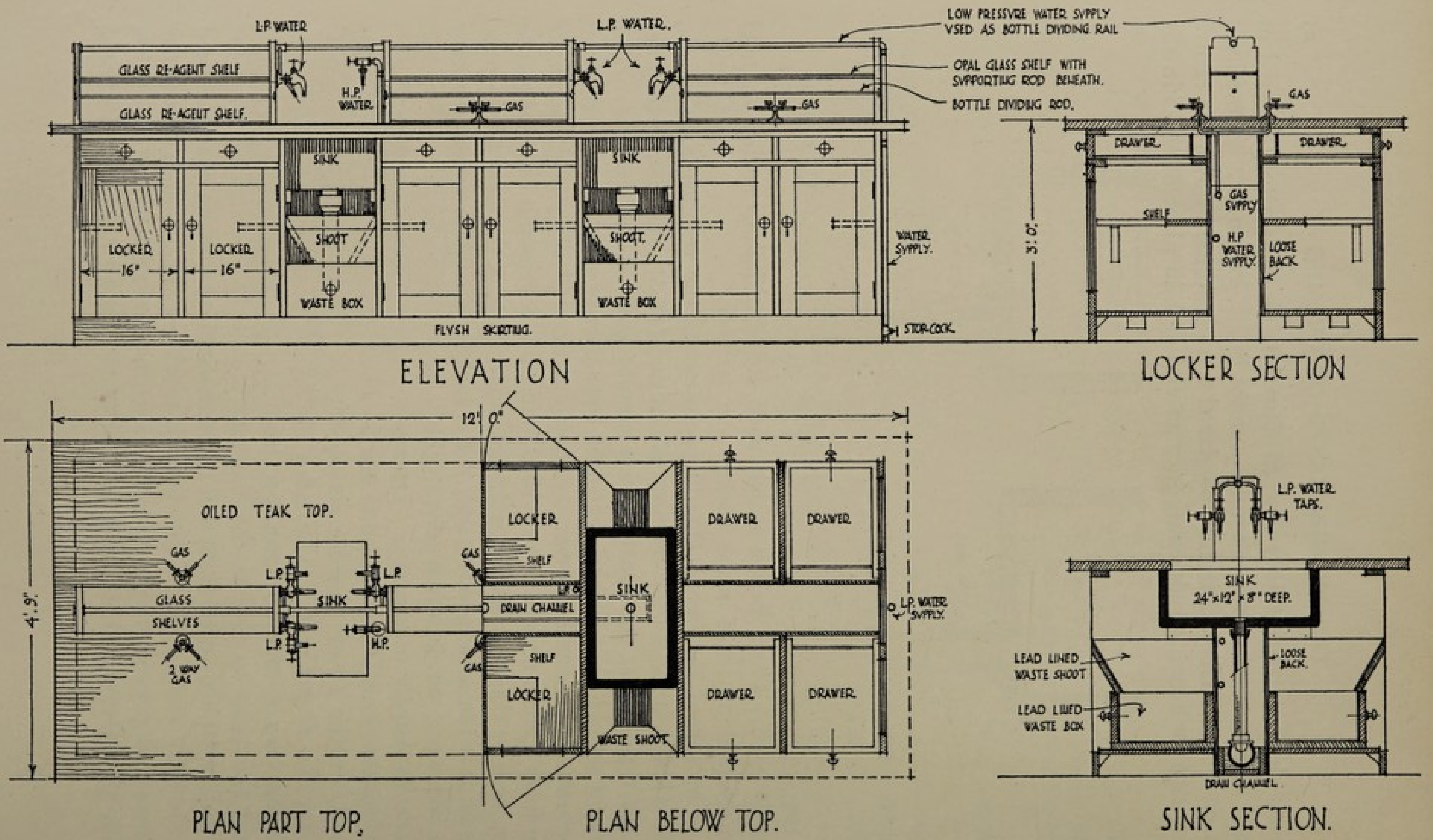


Fig. 8.—Detail of Working Chemical Bench.

have hardwood runners of oak. Locker fronts are often made of pitch pine but may be in yellow deal, and Douglas fir has been largely used in recent fittings, which is very satisfactory provided its shrinkage in seasoning is appreciated. Access to drains in benches must be provided by doors at bench ends, and movable locker backs. Fig. 8 shows a detail of a chemical working bench.

Surface Treatment of Benches—The tops of benches when of wood require frequent treatment for their protection, paraffin wax, beeswax, and similar " fillers," either melted and ironed in or dissolved in suitable organic liquids, are frequently used but should not be so applied that hot bodies produce a mark due to melting of excess of these ingredients. Raw linseed oil applied hot in a thin layer with successive applications only after complete absorption is still one of the best protections known, the oil drying into a resinous and insoluble body in the pores of the wood. This treatment should be repeated at intervals, say each vacation.[1] This subject needs and deserves investigation, probably some treatment under pressure could be found which would render many of the less costly woods available for bench tops. As to the framing, stain and varnish form the best protection.

Fume Cupboards—Fume cupboards, required in all laboratories where noxious gases are produced, consist of a specially ventilated glazed case, with sliding front sash. The most usual and probably best place for these cupboards is in the windows, as good light is essential. Such a situation in a low room dependent upon its side windows might seriously reduce the general illumination, but with a lofty window the cupboard top can terminate at the transom, leaving the upper part of the window unimpeded. In practice it will be found that chemical laboratory windows, near the bench level, can never be opened on account of draughts affecting flames and producing other disturbing causes, hence no detriment results by fixing this lower sash. These cupboards may vary in size a good deal, but should not generally much exceed 2 ft. from back to front for ordinary work, and should be high enough for tall apparatus. They are usually between 3 and 6 ft. in length, and the sash should be able to be thrown up to a height of not less than 2 ft. 6 ins. Suspension may be by cords (the life of which

[1] Aniline black is also a good protector, and is used on ordinary pine for bench tops in some American schools, with a waterproof lead paint finish.

is extended by treatment with vaseline), flexible steel rope, or catgut, with pulleys and weights in the framing like an ordinary window. Sometimes wire rope is used as a single suspension run back to a pulley

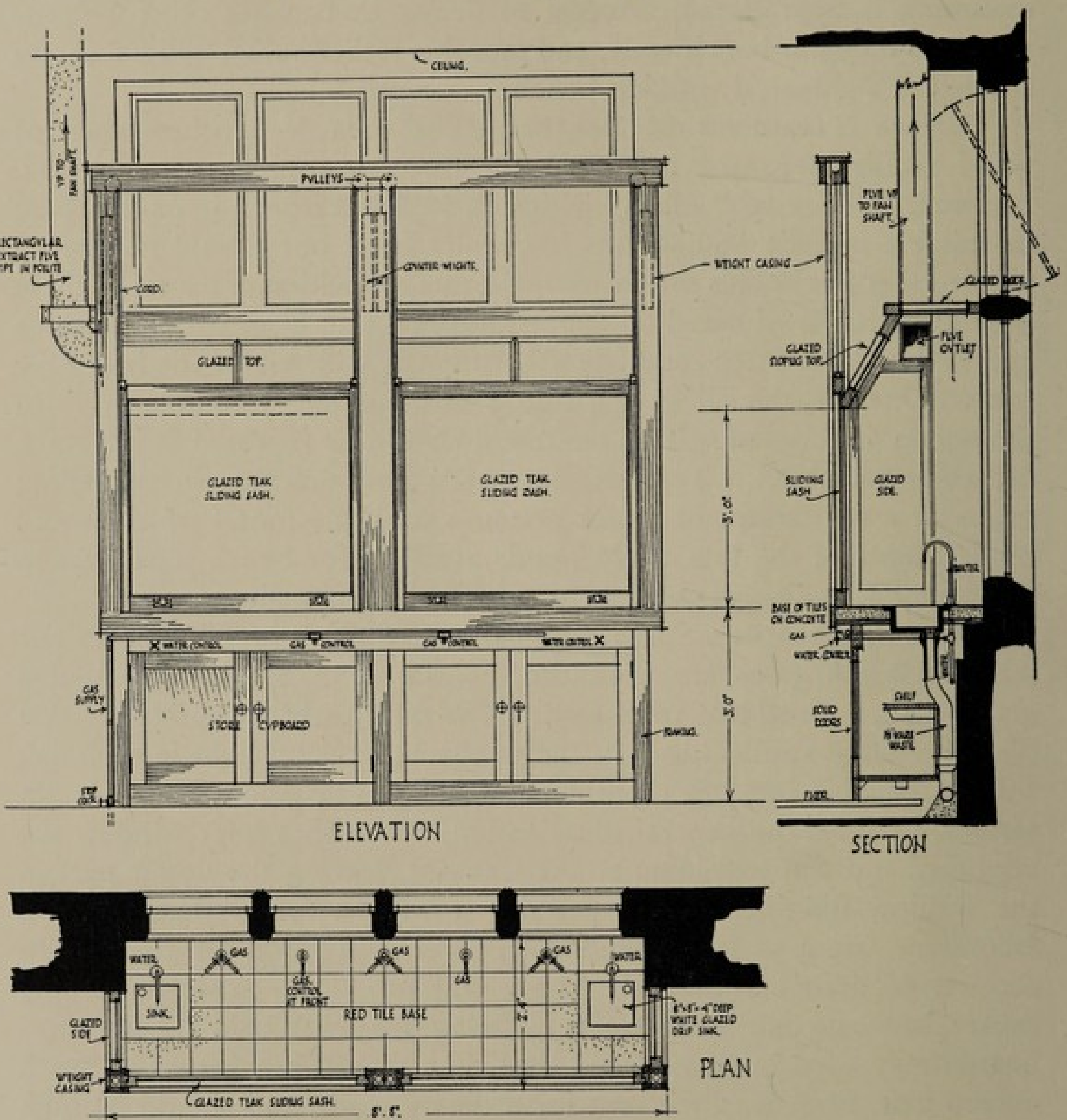


FIG. 9.—Detail of Fume Cupboard.

and weight on the wall behind. Fig. 9 shows details of a fume cupboard of recent type. In this example ventilation is effected by a fan.

To prevent the escape of fumes between the glass and the top horizontal rail of the front framing, the sash may be made so that when closed its top rail is above the frame rail, which is extended to almost touch the glass. Fig. 10 explains this simple means of meeting a very long-standing objection.

Semi-glazed tiles make the best base. A small sink or drain channel is usually required in such cupboards.

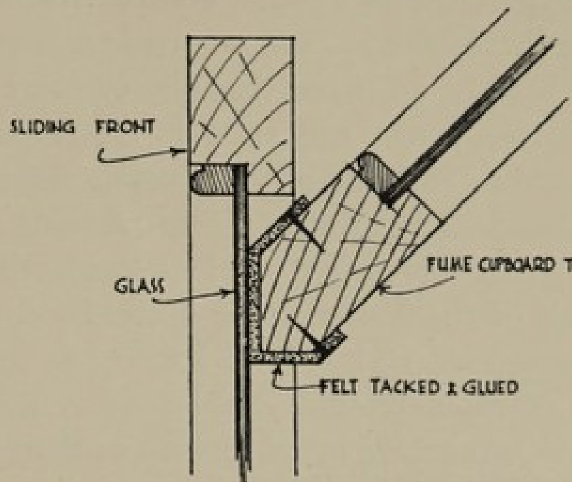


FIG. 10.—Fume Cupboard Meeting Rail.

Evaporation Cupboards—Cupboards of a special type are sometimes used for evaporations. They are constructed like ordinary fume cupboards, but the bottom consists of a copper vessel fed with water so that its water-level remains constant. On this, supported by suitable rings, the vessel containing the liquid to be evaporated is placed. The water is heated by steam or a gas jet. These cupboards are often only 18 ins. square, and want a good draught to remove condensed moisture. They are usually placed in rows of three or four to economize gas and water service. Frequently, however, evaporations are carried out in ordinary fume cupboards, and this is sometimes effected from above by means of a heated sheet of silica.

Side Benches—Several public benches in a laboratory are a great advantage. Under some of these benches, cupboards and shelves will be desirable for storing things in general use. Space may sometimes be found for such benches between fume cupboards in the windows. Every laboratory should have some bench area of incombustible material, commonly fine sandstone, for dealing with bodies too hot to be placed on wood.

Drying Ovens—It is constantly necessary to dry in small vessels solids produced by precipitation, and for this purpose a set of drying ovens—pigeon-holes with doors—round which steam circulates in an outer jacket, are provided, and with these ovens a still, for producing distilled water, is often combined. If there is a steam supply this is used as the source of heat, otherwise gas is employed to boil water in a tank forming the bottom of the range of ovens. In either case the steam is often condensed by finally impinging upon metal surfaces cooled by water, and is collected in a tank of tin-lined copper or in a large stoneware or glass bottle. In these ovens, which are made of copper, the individual compartments vary in size from about 6 ins. to 12 ins. each way, and are made in sets, but in order to dry long apparatus, it is often arranged that one or more vertical tiers have movable trays as bottoms, and can thus be converted into a single high oven. The number and size of these ovens depends on the work proposed. In the Chemical Institute, Berlin, serving the two large organic laboratories holding forty-eight students each, there is a group of twenty-five ovens, half of them measuring 6 ins. by 6 ins. by 7 ins. high inside, and the remainder 13 ins. by 6 ins. by 11 ins. high.

Demonstration Table—If a demonstration table is provided—a provision more usual in schools than in university laboratories—it should be raised 6 ins. or 8 ins. on a platform and resemble a lecture table. Usually a table 10 ft. or 12 ft. long and 2 ft. wide, or even smaller, is sufficient, unless it is to take the place of a lecture table altogether. Gas, water, and a sink are requisite, and some drawers and cupboards.

Fig. 11 shows detail of such a table.

Blow-pipe Table—A blow-pipe is required for glass working and for raising small vessels to a high temperature. In the absence of a compressed air service this is operated by foot bellows and is usually placed on a table 2 ft. to 3 ft. square, about 2 ft. 9 ins. high, with its top covered with asbestos, or sheet-iron or lead, dressed over a fillet at the edge to prevent hot glass fragments falling on to the floor. Bellows are usually fixed to the table framing.

Shelves—A great deal of wall shelving is required in a laboratory, mostly for bottles not wanted on the benches, and if the room is a large one, duplicate sets of such reagents may be necessary. No shelves should be wide enough to allow one bottle to stand behind another, and a surprisingly large proportion of bottles will be found not to exceed 3 ins. in diameter; a Winchester quart (a tall 2-qt. bottle) will stand on a $4\frac{1}{2}$-in. shelf, a large aspirator on one 9 ins. wide. It is not desirable to risk the use of adjustable shelves for this purpose, though alterations are frequent, but ledges or brackets may be fixed with brass screws which will help modifications. Shelves, as a rule, do not need backs, but a wood fillet may be advantageous to prevent delicate apparatus being carelessly thrust against a hard wall surface. Wall shelves are usually

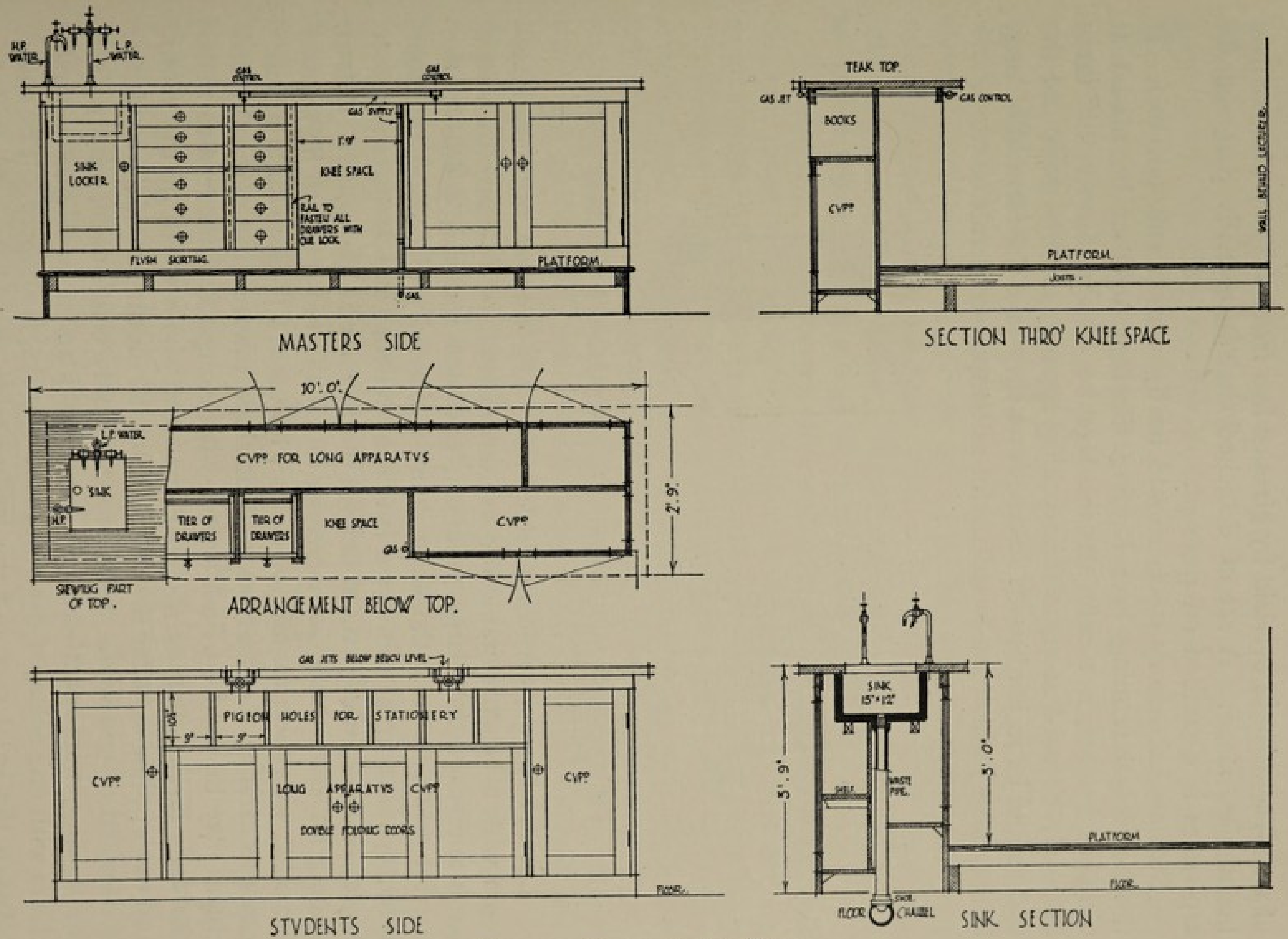


FIG. 11.—Demonstration Table.

of wood, sometimes overlaid by glass or less frequently by tiles, or may be of glass alone. A set of detached shelves specially designed for aspirators is described on page 48.

Stools—Laboratory stools should be light and easily portable. If the horizontal framing bars holding the legs together be placed at different heights, not only can the legs be rather thinner but these bars may be used as steps for reaching apparatus. The bars and the seat should be in hardwood. Sometimes they take the form of oblong, lidless boxes, which are found useful as temporary stands or trays.

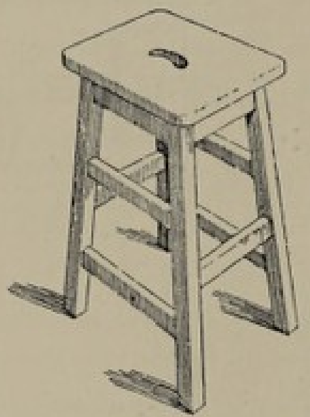


Fig. 12.—Stool with Rails at Different Heights.

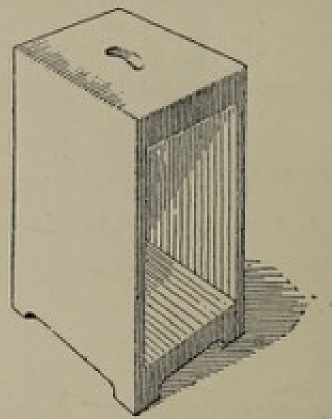


Fig. 13.—Box Form of Stool.

Lecture Rooms—A lecture room may vary from an ordinary class-room with a bench suitable for demonstrations, to a theatre to hold a large audience. For large numbers, entrance and exit doors require careful arrangement; the main doors are usually placed on the floor level, opening upon the space between students and lecturer; direct access to a preparation room behind the lecturer is also usual. Raised staging for seats is almost universal, but if the room has to be cleared for other purposes, cannot, of course, be used. It is possible in such cases to arrange the floor on a slight slope towards the platform, and chairs may be used on such a floor with elongated front legs to make the seats level. Staging should extend the whole width of the room, and the window light for the desks should be on the left of the students, if confined to one wall. Seats are commonly continuous, with a desk for writing, but sometimes the American plan of providing separate chairs with one enlarged flat arm for notebooks, is adopted. The space between the front seat and the lecture table should be 4 ft. to 6 ft., and between the other side of this table and the wall, about the same. Efficient means for hearing, seeing, and writing are the essentials of a good lecture theatre; the first deals with matters beyond the scope of this book, but it may be said that the chief things to avoid for acoustic success are large flat and hard surfaces facing the lecturer, great open space behind or above him, and unnecessary space above the students, though this is less important. The speaker's voice should go direct to the audience with as little disturbance on the way from recesses, deep window and door reveals, and the like, as possible. Splayed angles at the end of the room will prevent seats near the corners being worse than others for hearing, and any ventilation currents should set from the lecturer towards the audience. Raised staging is a great help to hearing as well as seeing, and in a large room assists in preventing echo.

In addition to the lecture table and seating, ample blackboard and diagram space, a fume cupboard near the lecture table, shelves for reagent bottles, and a demonstration lantern and its screen are necessary.

A lecture table may vary from an ordinary elongated table, or bench, supplied with a few drawers, and with gas and water, to an elaborate fitting suitable for every kind of experiment. The table is usually 3 ft. wide and 3 ft. high, and as space is never amiss, its length is generally the width of the room, less suitable passage ways between its ends and the walls. The side facing the students is often merely panelled, but since the full width is not entirely required for drawers and cupboards, it is possible to introduce glazed cupboards for keeping specimens, pigeon-holes for class notebooks and the like, on the students' side.

Fig. 14 shows details of a lecture table suitable for chemical work. On the lecturer's side the whole front is sometimes filled with drawers and cupboards, though, if the table is a long one, an open space or spaces near the centre are often left which are useful for retort stands, rubbish boxes, and anything not requiring better accommodation. The drawers should vary in size, one or two may be only a quarter of an inch deep and divided for rows of lantern or microscope slides,[1] others slightly deeper for storing thermometers, a few small but deep drawers for such things as dusters, and compartments in larger drawers for valuables, such as platinum, will be found useful. Unless the optical lantern is

[1] The former slides are 3¼ ins. square, the latter 3 ins. by 1 in.

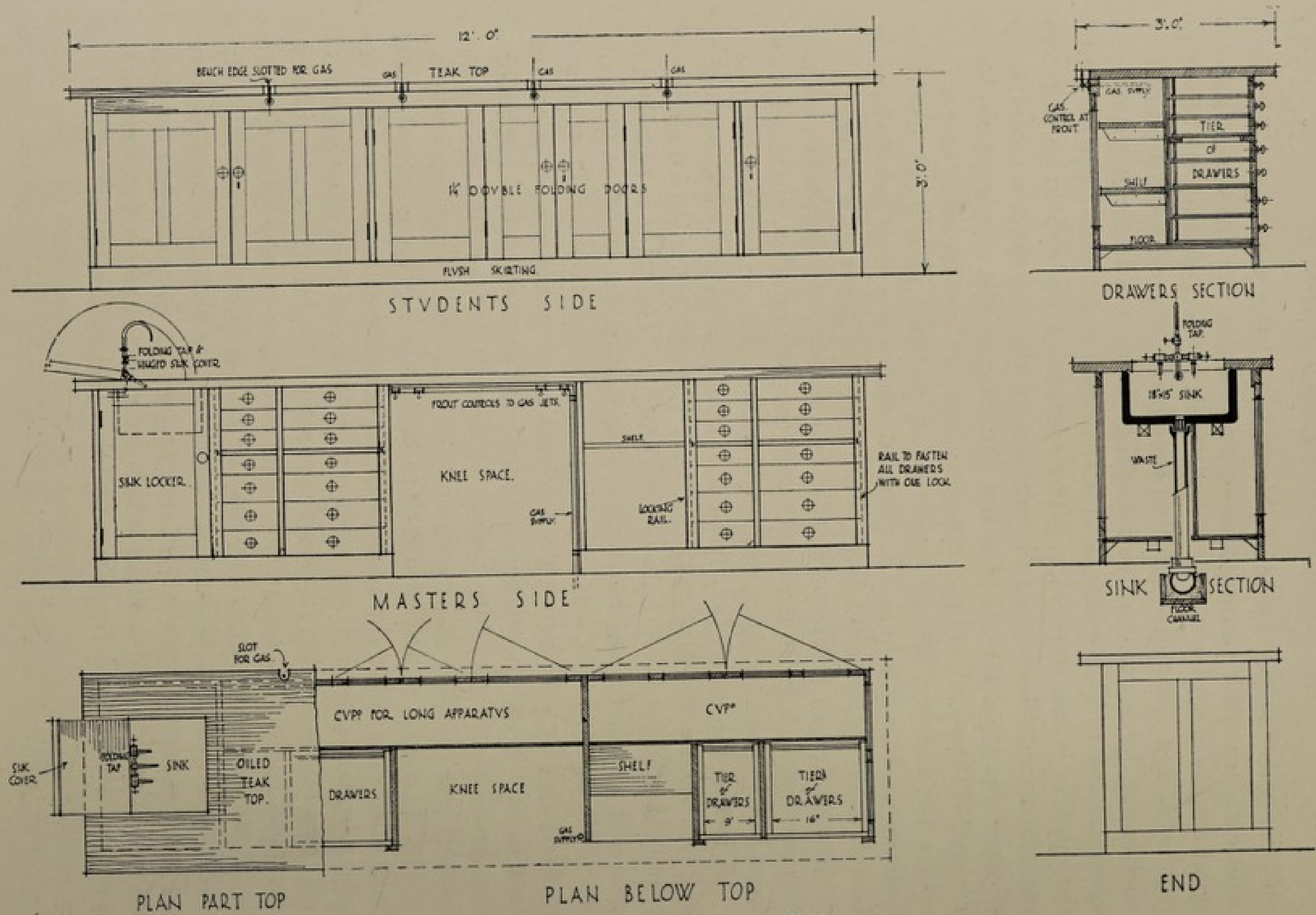


Fig. 14.—Details of Lecture Table.

permanently located otherwise, a cupboard large enough for its reception will be valuable in the lecture table, and 4 ft. will not be too great a length to provide for this purpose, though the requisite width may not exceed a foot. Occasionally glass panels are placed on the students' side as backs to the cupboards to illuminate their contents. It is desirable to have a specific place for a couple of compressed gas cylinders. If small these can stand vertically in one of the open recesses with their fittings and gauges within easy reach and sight of the lecturer; if large they must lie on the floor under the table, and may occupy space of very little value for other purposes. It was formerly the custom to provide a trough in the table with glazed ends for collecting gases over water. Such a trough can only be seen by a limited number, and apparatus on the table may well take its place. A mercury bath—a small special trough for holding mercury instead of water—is another feature found in more elaborate examples which may well be dispensed with in favour of loose apparatus. At least one, and in a long table two, sinks are required, which are generally placed in the table itself, but may be external adjoining its ends. If the table is very long or for any reason carried through to the side walls, flaps should be provided to admit of ready access to the front, and these are especially desirable if the lantern is to be operated, from the space between the table and the audience, by the lecturer. The main part of the table top is usually of teak, but it is an advantage to have a limited area a few feet in length made of some incombustible material, such as tiles on concrete, sandstone or merely fine concrete, for experiments involving much heating. Occasionally a small area is covered with lead for experiments involving strong acids. The services necessary are often extensive; in addition to gas and water, electricity for experimental uses is usual and often involves space for a small switchboard and heavy cables. An efficient down-draught is most necessary unless a fume cupboard in the room is to answer this purpose. On the table, this generally takes the form of a 3-in. or 4-in. earthenware pipe connected to the exhaust system or special flue and terminated on the table by a sunk circular cap (Fig. 15). Occasionally this takes the form of a rectangular area, a foot or more square, provided with

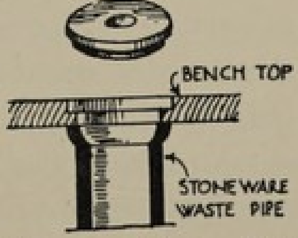


FIG. 15.—Fume Exit to Lecture Table Top.

a wooden grid below a movable cover flush with the table top. The apparatus is placed on this grid, which has a funnel-shaped attachment to the exhaust system. Sometimes a pipe made of well-painted sheet-iron, or better in " asbestos," and bent over at the top is inserted into the draught hole. This pipe terminates with a trumpet-shaped mouth over the vessel emitting fumes. Such an arrangement (used, however, on the students' benches) at Leipzig is shown in Fig. 16.

A very useful protection to supply-nozzles is used at some institutions : a small section of the lecturer's edge of the table over each group

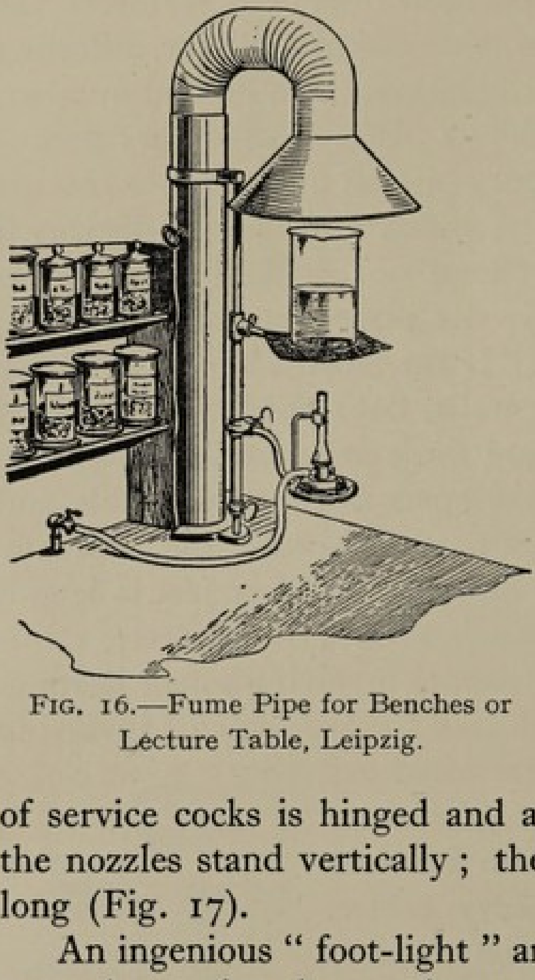


Fig. 16.—Fume Pipe for Benches or Lecture Table, Leipzig.

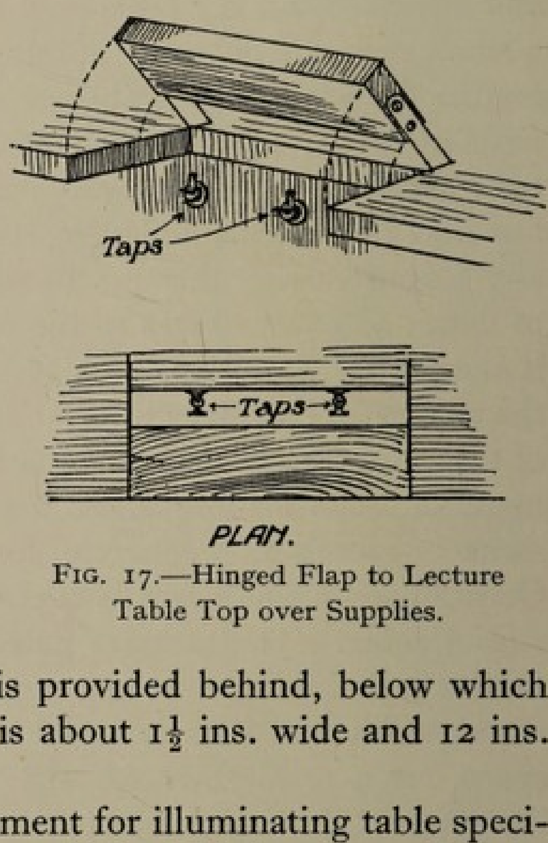


Fig. 17.—Hinged Flap to Lecture Table Top over Supplies.

of service cocks is hinged and a slot is provided behind, below which the nozzles stand vertically ; the slot is about $1\frac{1}{2}$ ins. wide and 12 ins. long (Fig. 17).

An ingenious " foot-light " arrangement for illuminating table specimens is employed on a lecture table at Bristol University. On the students' side the whole length of the top is hinged in sections 3 to 4 ft. long and about 6 ins. wide ; below these lids, in a continuous recess, are electric lamps which can be turned on in pairs. The under surface of the lids is painted white and can be supported by hinged arms at a suitable angle, thus reflecting the light on to the object on the table, while screening direct rays from the audience. Fig. 18 shows this arrangement. This lecture table is of further interest as being entirely movable, and is arranged in four sections on castors, to admit of which the various services are made detachable by the use of suitable unions.

One of the most elaborate lecture tables in existence is that at Fischer's laboratory in Berlin, which is no less than 60 ft. long and runs the whole width of the room. This table is 2 ft. 7½ ins. wide, 5 ft. 5 ins. from the back wall, and 6 ft. 7 ins. from the audience. It has hinged flaps at each end and in the middle; a pneumatic trough about 3 ft. by 18 ins. by 2 ft. deep with glazed ends; a mercury bath 2 ft. 4 ins. by 1 ft. 8 ins. by 8 ins. deep; a sandstone area 3 ft. by 1 ft. 10 ins. for furnace work; two lead-covered areas 3 ft. 8 ins. by 2 ft. 1 in.; two down-draught flues 6 ins. in diameter with slate grids at their mouths; six other 1¼-in. exhaust vents in lead; twelve waste pipes; twenty-four single gas cocks, two for heavy and two more for very heavy work; one exhaust (water) pump; six vacuum cocks; one pair of leads for six amperes, four for twenty, one for twenty-five, and one for 400 amperes for electric furnace work, with appropriate switches and resistances. At Leipzig, supplies of hydrogen, oxygen, nitrogen, and carbon dioxide are arranged to the main lecture theatre table from an adjoining room.

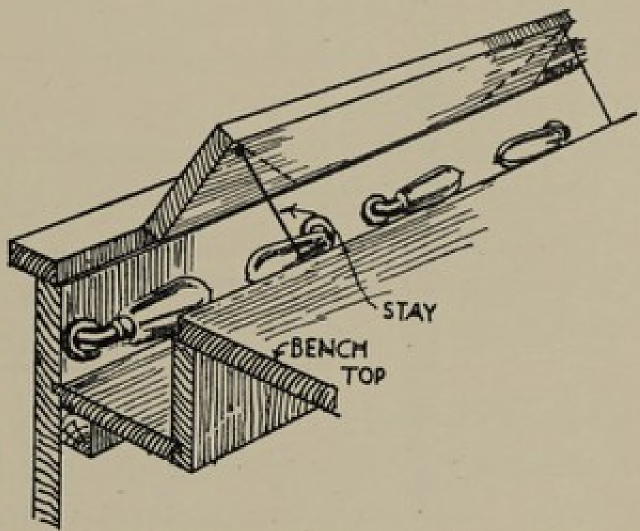


FIG. 18.—"Footlight" Illumination on Lecture Table as used at Bristol University.

Blackboards—Extensive blackboard surface is required in the centre of the wall behind the lecturer, and as sufficient wall area within reach cannot be usually devoted to this alone, boards almost invariably slide. They may be arranged as single sashes with weights; as a pair of sashes, one balanced against the other; as a Kelvin suspension with one weight only, as in Fig. 19; as a continuous prepared canvas on rollers; or as a series of boards one behind the other sliding horizontally. In practice the first method is probably best, but pulleys should always be large and well machined. As a fume cupboard is generally placed to be near the lecturer and in view of the audience in the centre of the wall behind the table, blackboard surfaces in front are for this reason wholly movable, but if no fume cupboard exists, the writing surface may be formed on the wall with a single board sliding over it. The best material for boards is probably black pot glass—the term " pot " meaning that the glass is black all through and not merely surface treated. The working down of surfaces of glass or slate to a proper condition requires care, as if too rough they will be difficult to clean, and use a

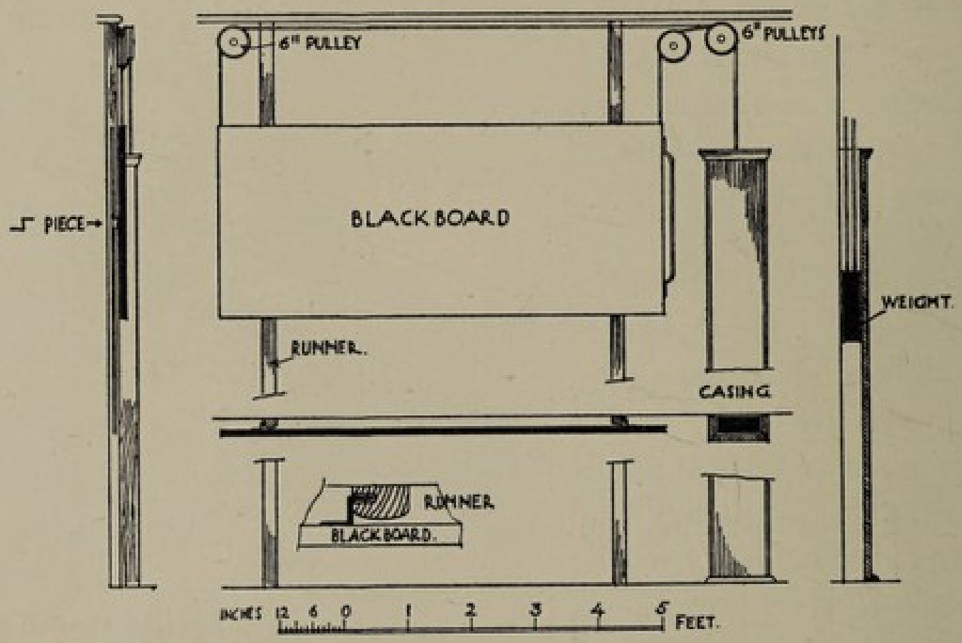


FIG. 19.—Elevation, Plan, and Sections, Kelvin-hung Blackboard.

great quantity of chalk. A narrow trough of wood or sheet-metal to catch chalk dust is desirable below the board.

Diagram Screens—Diagrams may be permanent or temporary. If the room is lofty and a diagram room can be provided above the preparation room behind the lecturer, temporary display could be made by providing suitable doors or slots in this wall through which the diagrams could be pushed, or a couple of vertical rollers might be inserted in the wall at a sufficient distance apart carrying an endless canvas to which the sheets could be fixed in the diagram room and then wound round to face the lecture-room audience. The writer does not know of any such arrangement, but it would utilize a very inaccessible piece of wall area. The usual practice is to have skeleton screens composed of flat laths and tape, which can be lowered and raised by cords and pulleys, for the attachment and display of diagrams; these screens need not necessarily be against walls, but may be suspended from the ceiling somewhat nearer the audience when the accommodation is for sheets which do not require detailed explanation with a pointer.

Lantern—The optical lantern plays such an important rôle in lectures that though strictly a piece of apparatus it must receive mention.[1] The lantern, usually an epidioscope and ordinary lantern combined, is used for prints, slides, and apparatus, and (with a suitable attachment in place of the ordinary objective) for microscope slides, for which last purpose it is generally required in another position nearer the screen.

When the lecture centres round the lantern's exhibition, there is no better place for it than at the level of the centre of the screen well back in the raised staging of the audience, but it is usually wanted intermittently, perhaps only for a few minutes, and may have to be operated by the lecturer himself; hence, for many students' classes, it is placed on the lecture table near one end, to illuminate a screen fixed anglewise in one corner of the room on the lecturer's side, or a special movable table is used for the lantern placed between the lecture table and the students' seating.

Probably the best screen for general purposes is a dead white opaque surface such as a white-washed wall. Aluminium-painted surfaces are better for normal vision, but not so good for oblique vision. Canvas-backed white paper on a frame, or less desirably on a roller, is satisfactory, and white-stretched fabrics are common, but if translucent result in much reflective loss. For short ranges, often very convenient, much distortion may occur with ordinary short focus lenses, which might be corrected by the use of a saucer-shaped screen, allowing the picture to appear on a curved surface. For pictures 4 ft. to 5 ft. in diameter it should be possible to construct such a screen of papier mâché or other light material.

Lecture Room Seating—Though some lecturers prefer to look down on their audiences, sight and hearing is always better when raised tiers are provided, as the voice tends to be thrown up, and warm currents of air from the auditors further tend to accentuate this deflection.

[1] Some remarks on Cinematographs will be found in Chapter IV.

A view of the lecture table top is necessary for all experimental work, and it is chiefly for this reason that staging is used. This should be arranged to allow each row just to see over the heads of those in front, and if so arranged, it will be found that the heights of the tiers are not all the same, those at the back being greater than those in front. The principles governing these heights have been worked out, and to apply them it is necessary to set up a section to scale through the tiers and their seats. Before this can be done, the room must be planned and the following decided : the width back to front of each tier, the height of the seats on the tiers, the distance of the front seat from the lecture table, and the height of the lecture table. A number of vertical lines are then drawn, the width of the tiers apart, but to pass through the centres of the seats, and the height of the lowest seat above the floor, marked off on the vertical nearest the lecture table. If this seat is made an inch or two lower than the rest, this will quite preciably decrease the necessary height of the staging at the back. Above this lowest seat level 2 ft. 9 ins. is marked off vertically to give the level of the sitter's eye, and a further 6 ins. to clear the top of his head, through which point a line is next ruled to the centre of the table top, and back to the vertical line cutting the centre of the seat behind. The level of this seat will be 2 ft. 9 ins. below this point of intersection, and at the decided distance (16 ins. to 18 ins.) below this seat will be the first tier level, above which the desk (often provided as a shelf attached to the back of the seat below) should be 29 ins. to 30 ins. The point of intersection of the line to the table clearing the lowest student's head with the vertical through the second seat, gives the eye of the second tier student, and 6 ins. above this, as before, a line from the lecture table continued back, will, on the next vertical, give the position of the third tier student's eye, and so on.[1] A slight tilt on the seats will much add to comfort by bringing part of the weight of the body on to the thighs, and thus decreasing the weight per unit area ; the backs and desks should also slope slightly, the accepted angle for the latter being about 15 degrees. Fig. 20 shows a section through such seating and the constructional lines necessary for its determination.

Preparation Room—No rules can be laid down for the size of a preparation room. It should be remembered, however, that for

[1] The line touching the edges of seats in section is called an "isacoustic curve."

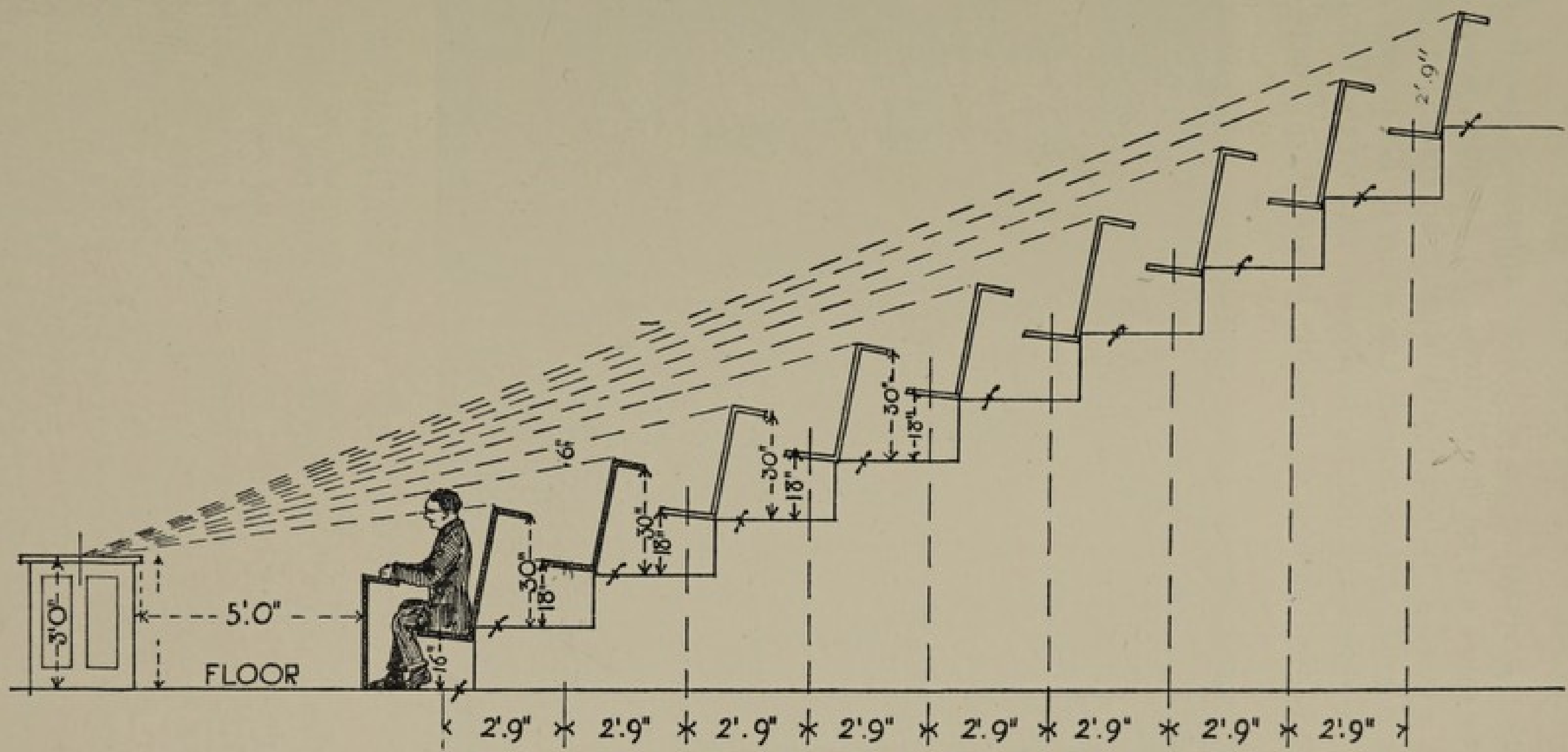


FIG. 20.—Method of Setting Out Raised Seating for a Lecture Theatre.

advanced work much setting up of delicate apparatus may be done here, hence the area must not be too limited. In a school, space for ample shelving and a good wall bench will usually be sufficient, but for advanced work a large central branch has often to be accommodated in addition. Two doors are usually necessary, one to the lecture theatre and the other to the corridor or possibly laboratory. These should be

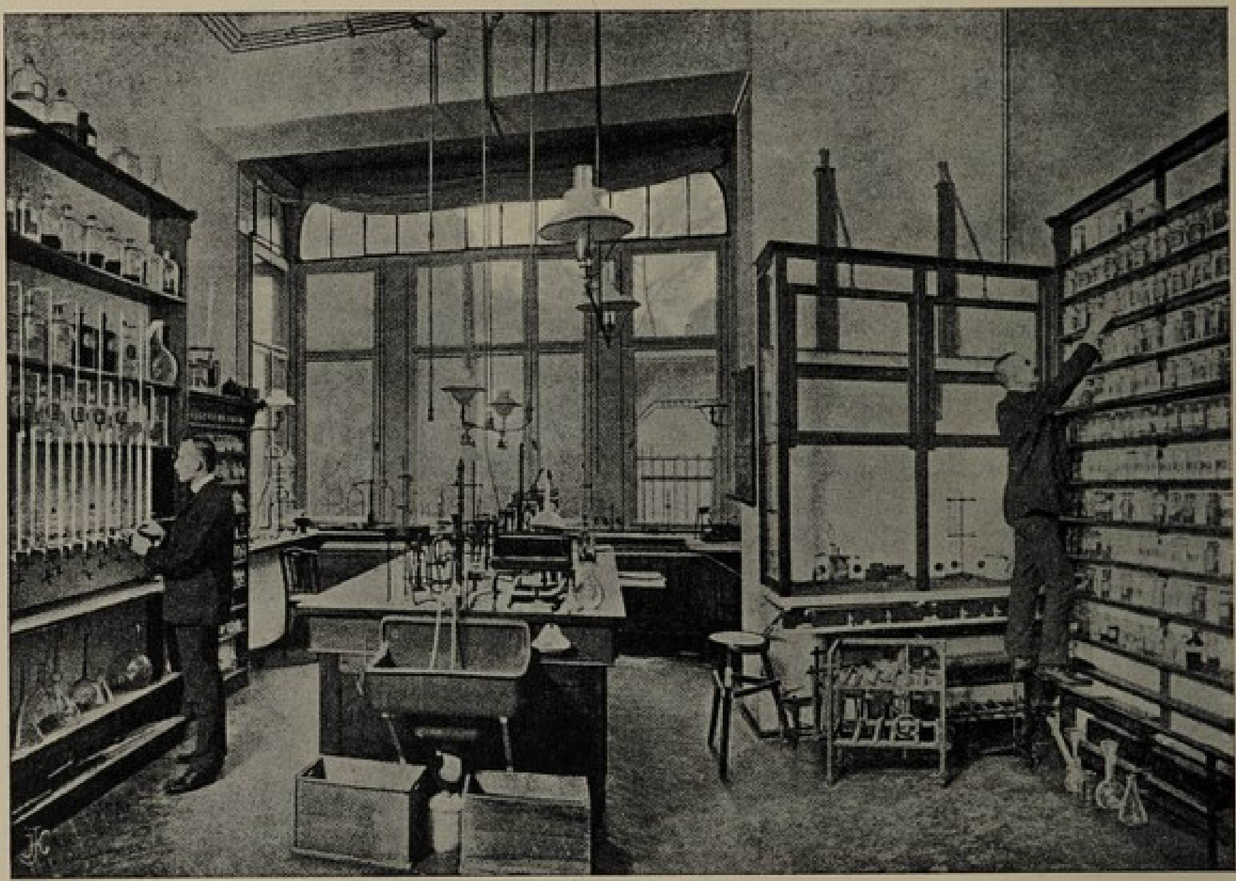


FIG. 21.—Preparation Room, Beckmann's Laboratory, Leipzig.

near one another if possible so that the room does not become a passage. The floor is preferably wood, and so much of the walls are covered by cupboards that if tiles or glazed bricks are used on the walls they are only necessary to a very limited extent. Sometimes this room is used for making up solutions of given strength, when its character will differ somewhat from a room wholly at the disposal of a lecture theatre.

The fittings usually comprise a good centre bench and one or more wall benches fitted below with cupboards, a very large sink with ample services, and a fume cupboard and shelves. The benches do not get the rough usage of a laboratory, but hardwood tops are very desirable. A small area should be of incombustible material, and if no separate blow-pipe table is provided this should be rather lower than the general height, say 2 ft. 9 ins. Drawers and cupboards are required in much larger numbers than in the students' benches, and should vary in size.

The sink is best kept as a separate fitting, large enough to enable a quantity of apparatus to be dealt with at one time. Ample draining boards are of course required, above which, or arranged as a separate rectangular stand, wood grids formed by cross pieces about 1 in. square, intersecting at right angles to form openings about 2 ins. square, will be found valuable as drying racks for glass.

The use of a fume cupboard as a hatch to the lecture room has been referred to. In this position the projection of the cupboard should be into the preparation room.

A good idea of the shelving wanted in a room devoted largely to reagents (that is, chemicals as contrasted with apparatus) is obtainable from Fig. 21, which shows a photograph of the main preparation room in Beckmann's laboratory at Leipzig; the foot rail round the walls is a useful feature, both protecting glass near the floor and forming a ready means of reaching the higher shelves. To raise the floor about 3 ins. at the walls as a platform, 6 to 9 ins. wide, will be found useful for storage enabling the floors to be cleaned without fear of breakage of things in this position.

Store Room—Where only one store is provided the floor is best of asphalt, laid to slope very slightly to an outlet if possible, as although the breakage of a Winchester of strong sulphuric acid or ether is a rare thing, it is an incident to be reckoned with. Whether such a floor is provided or not a box of sand should be installed in a fixed position. Shelves should be wide enough for large bottles or jars, and racks provided for light glass, such as flasks and beakers, some of which may be of considerable size. Porcelain dishes and small materials such as corks, rubber tube and crucibles, require drawers.

Racks for stocks of glass tubes, which may be 6 ft. long, are also required. These may be vertical or horizontal. The former arrangement best shows the lengths, the latter the bore. Possibly a vertical rack in which the tubes stand on hard glass with a mirror below might be contrived to give an indication of length and bore at a glance.

To enable stock to be purchased to advantage in large quantities, storage space should be ample. Sometimes roof space may be used where economy makes the necessary floor space unattainable.

Balance Room—A balance room may have merely a glazed screen between it and the laboratory to aid supervision. A dry still atmosphere and good light, both natural and artificial, are the chief matters of importance. The fittings comprise shelves for the balances, and sometimes cupboards are supplied below for certain special apparatus, though the use of the room for anything not actually required for weighing is to be discouraged. Balance shelves or tables require to be very rigid and are best fixed to substantial walls by brackets. These shelves are usually of slate 1 in. to $1\frac{1}{2}$ ins. thick, but for ordinary purposes substantial wood shelves are very satisfactory. The width need not be more than 15 ins. to 18 ins., hence T irons built into the walls form effective supports. A very rigid form of movable shelf, suitable for balances or general use in a research laboratory, consists of a top of slate or wood attached to brackets of wrought iron. A continuous angle iron is built into the wall and engages with an iron plate attached to the back of the shelf (Fig. 22). The feet of the brackets are covered with felt and merely press against the wall. The pressure of both hands on the edge of a balance shelf should not cause disturbance to a swinging balance, and the brackets must be strong enough to comply with this condition. With solid floors, glazed brick piers are often built at intervals to carry the shelves. Some further comments on vibration and its prevention will be found in the next chapter. It is interesting to note that the late Professor Ramsay's balance, used in many of his classic researches, stood on an ordinary wooden table on a joisted floor. Fig. 23 shows a balance table with cupboards below for books, designed with balance cases for Cheltenham College, used, however, in the laboratory itself.

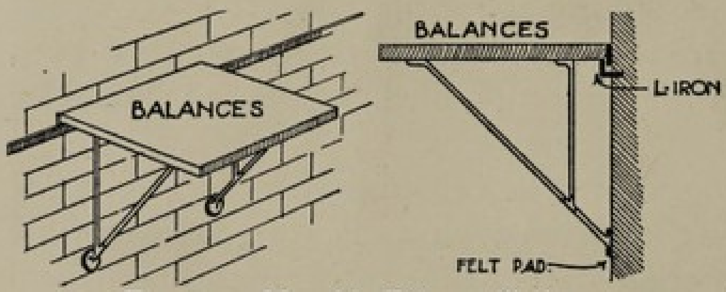


FIG. 22.—Movable Balance Shelves.

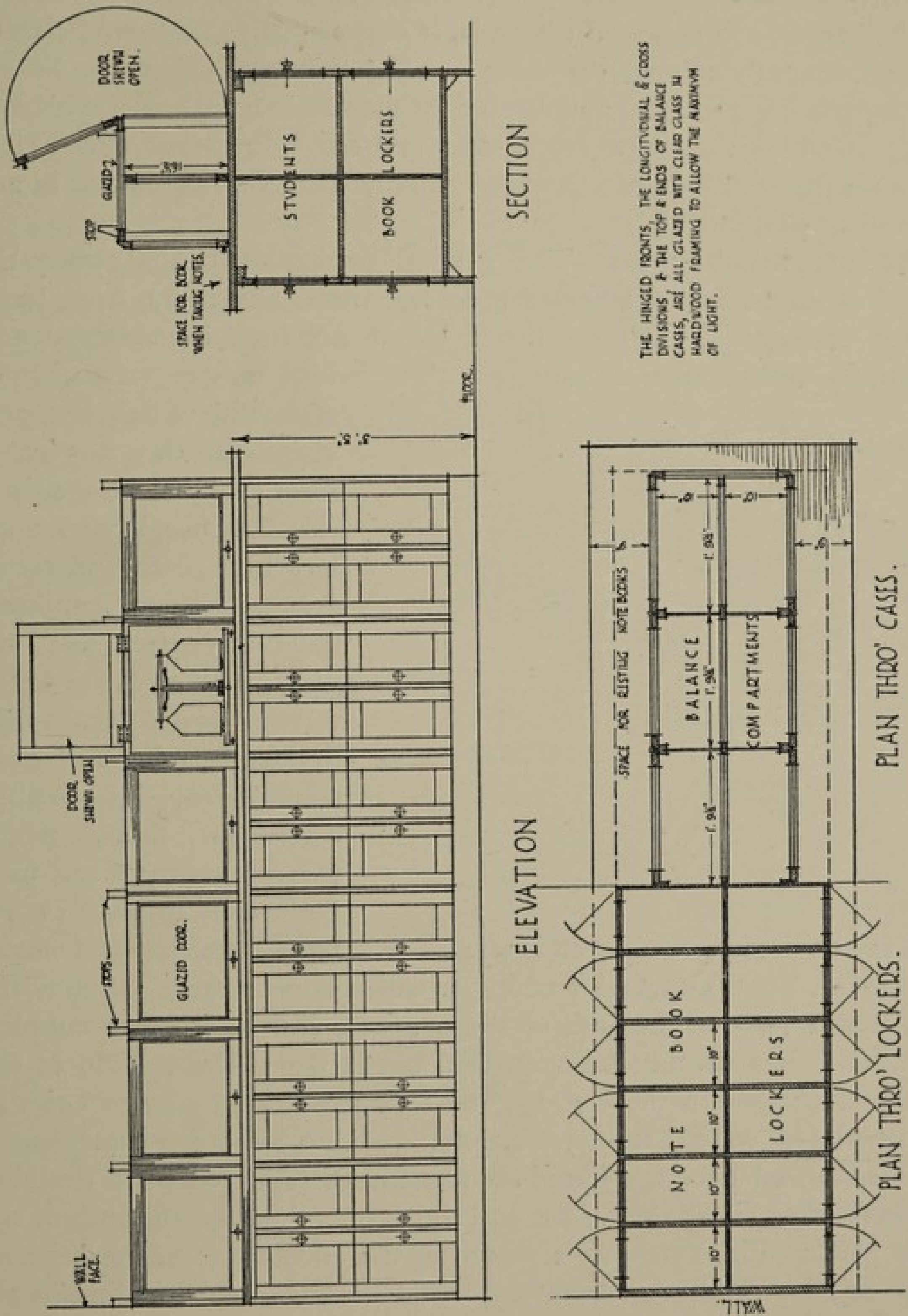


FIG. 23.—Balance Tables.

Each balance requires its individual artificial light, and if electric pendants are fixed at stated intervals, it may happen that more balances are subsequently added, throwing out the lighting. This can be got over by placing a rod at a suitable height the whole length of the balance shelf, on which the lights are hooked and fed from flexes attached to plugs on the wall behind; they can thus be placed immediately in any convenient position.

Advanced Laboratory—The general principles which govern the design of an advanced laboratory do not materially differ from those already enunciated, but more bench length per head is necessary, and sometimes more elaborate services. The width of gangways, height and width of benches, provision in the matter of fume cupboards, oven and side benches, is very similar, but since individual apparatus and cupboard space is greater, less provision is required for public apparatus. The bench length per head should be, if possible, 5 ft. 6 ins., though where this laboratory is not used for much organic or research work the length allowed is often less. More water jets and wastes are wanted, but less actual washing in sinks is necessary. Hence, the latter may well be at the ends of the benches, and extra water supplies be either over a continuous open lead gutter down the middle of the bench, draining into these sinks, or over drip sinks, or waste holes in lead or glazed ware (Fig. 24). Lastly, draining pegs are most useful on an advanced bench. These are sometimes arranged upon draining boards fixed on either side of the end sinks, sometimes on the ends of the bottle racks. Fig. 25 shows a sketch of the end of one of the benches in the late Dr. Perkin's laboratory, Oxford. When spherical flasks are placed to drain on pegs, as illustrated, water will usually remain in the shoulder and for such glass, pegs more widely spaced and set at a very

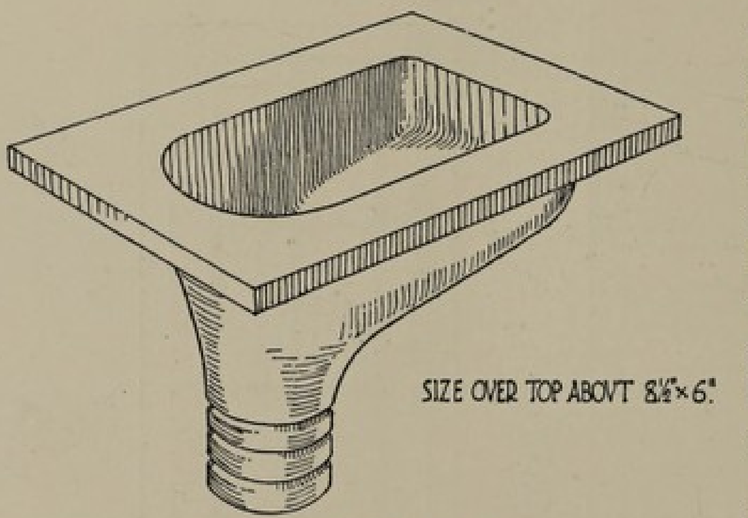


FIG. 24.—Drip Sink.

high angle will be appreciated. Draining pegs are sometimes arranged on the wall in place of reagent shelves. A continuous horizontal wood fillet let into the tiled walls is provided for attaching the pegs, below which is an open lead-covered drain channel, U-shaped, running along the back of the bench.

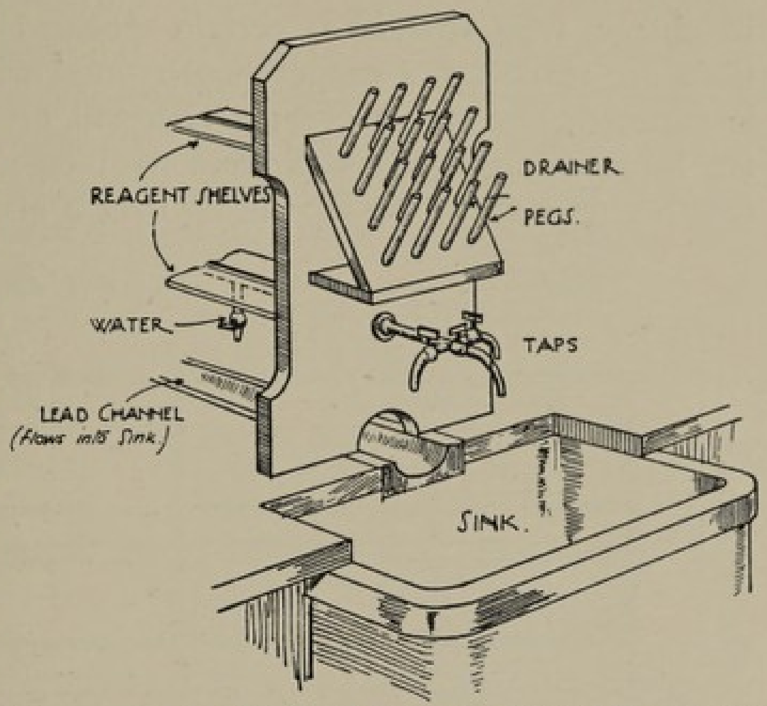


FIG. 25.—End of Students' Bench for General Work in the Organic Chemical Laboratory, Oxford University.

Fig. 26 shows a drainage channel in glazed ware at the end of a tiled side bench.

A shower-rose for the purpose of extinguishing fire on students' clothing, and a specially deep sink for cooling very large flasks, are other adjuncts sometimes found in an advanced laboratory.

Dispensary—In a large building, a room through which all apparatus and chemicals are issued and to which loaned apparatus is returned, is very necessary, as only by some proper system, resembling that of a sales department, can any check be kept upon these materials, which form a large item in annual expenditure. Such a room may be called a dispensary. Materials are drafted into this room from the store rooms, which should be as near as is feasible. Further, many of the stock solutions are often made

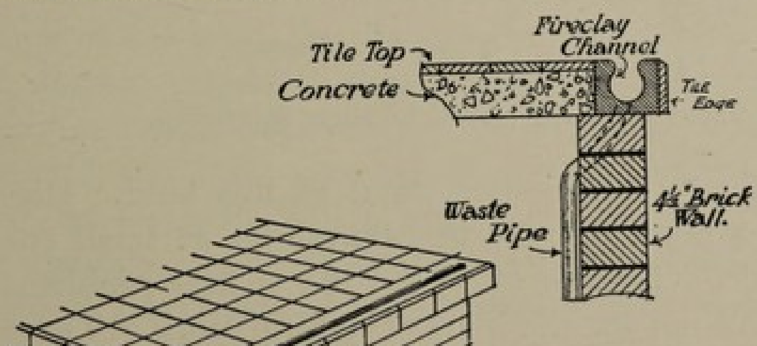


FIG. 26.—Waste Channel to Bench Top, Advanced Chemical Laboratory, Bristol University.

up here for the students' requirements. In addition to shelves, cupboards, and drawers, a fume cupboard is required for filling acid bottles, and a counter and flap for handing out materials by the man in charge, who attends at certain specified hours. Further, if solutions are made up, a proper bench fitted with a sink, water, and gas is required, but in any event a sink will be wanted. Many solutions are kept in large glass aspirators with taps, and these should stand together on a shelf, the taps being over a glazed channel with a waste

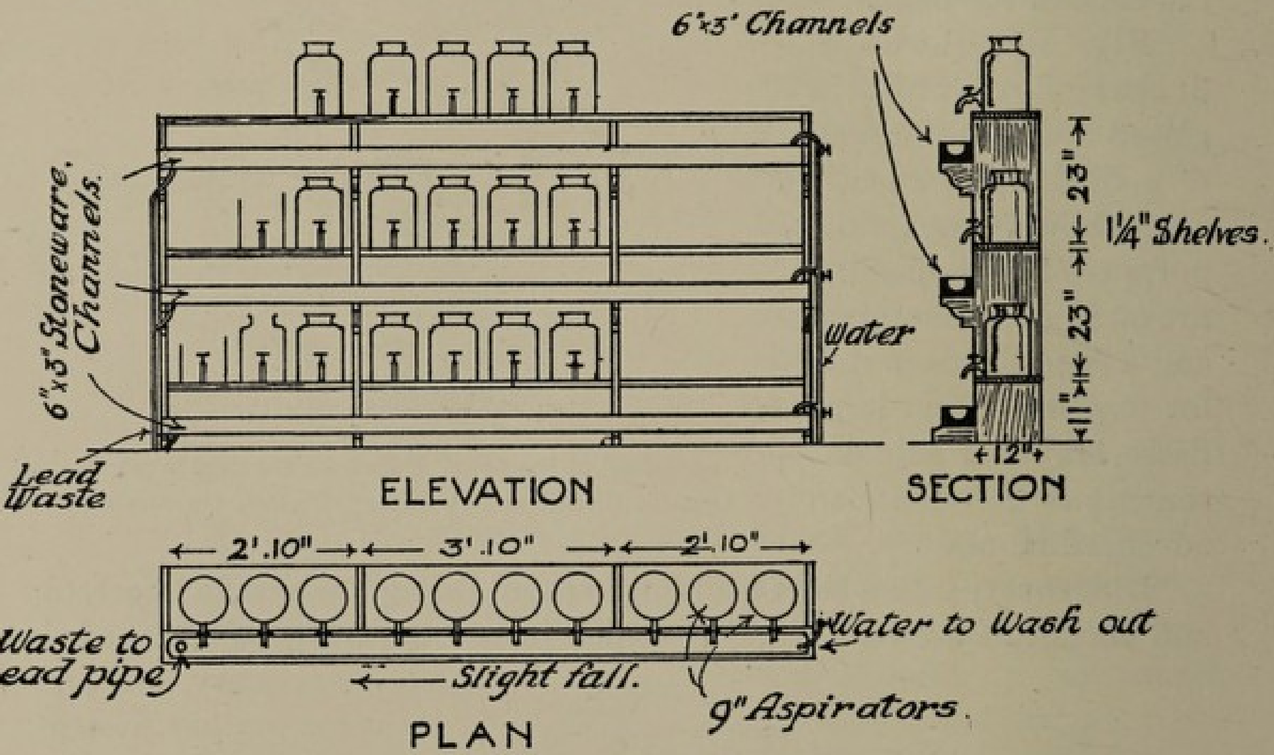


FIG. 27.—Aspirator Stand for Stock and Volumetric Solutions.

pipe attached. Fig. 27 shows a three-tier stand of this kind. Dispensaries sometimes find a place actually in laboratories as small enclosures, but these are chiefly for providing for the special problems set to the junior worker and not for the issue of general stock. These enclosures require shelves, a few cupboards, and drawers, and a small bench with a sink, gas, and water. It is generally desirable to be able to lock up such enclosures.

Research Rooms—Researches differ so much in character that no rules for fittings are possible. Such work may be carried on in a large laboratory fitted like an advanced laboratory, with about twice such laboratory's run of bench allotted to each student, or may be conducted in private rooms devoted only to one or two workers. In the latter case as much free space should be given as possible. A good fume cupboard and combustion bench and a large sink are necessary fixtures, but an ordinary working bench may not be wanted. The scheme which is probably most satisfactory, consists of supplying a teak shelf about 9 ins. wide on one of the walls with drip sinks, wastes, and the service supplies above it. A few plain tables the same height as the shelf are provided, and these are moved up to the wall for the services, and arranged in any form which the worker finds most convenient. Very often a considerable piece of joinery is required to be made for some special research, hence the centre of the room should be as free from fixtures as possible.

Dark Rooms—Dark rooms are required for spectroscopic, polarimeter, and similar work, and also for photography. Dark blinds (discussed in the next chapter) and provision for good ventilation are essential in these rooms. A sink, draining board, and bench are of course necessary for photographic work. The room should have one or two small loose tables, and a small solid table with incombustible top for the spectroscope, the flame of which is sometimes provided with a little hood and draught flue. The walls should be black or of a dull tint, and linoleum forms a suitable floor covering when water is not in frequent use.

Library—The subject of libraries cannot be entered into in a book of this kind, but the growing recognition of libraries as necessities in science buildings may be emphasized. There is much to be said for small departmental libraries as places more readily accessible to the worker and more capable of rapidly satisfying his needs than large general libraries, which involve more formal arrangements in the use of their contents. If the room is large enough, a series of bays flanked by the cases with a table between them make the best arrangement, subjects being classified by bays, but in a small room this is better not attempted. Given enough height a gallery much adds to capacity, and in any event some place for use as a stack room is required in all but the smallest schemes. Where many periodicals are taken table space should be liberal, and separate tables reserved for reference work.

4

These remarks, though placed under chemistry as taken first, are, of course, of general application.

Physical-chemical Laboratory—In recent years very great developments in the field of chemistry where it touches physics have been apparent; work in which physical apparatus largely replaces chemical reagents and glass ware in use in a general laboratory. The fittings include ordinary working benches with but a limited supply of sinks

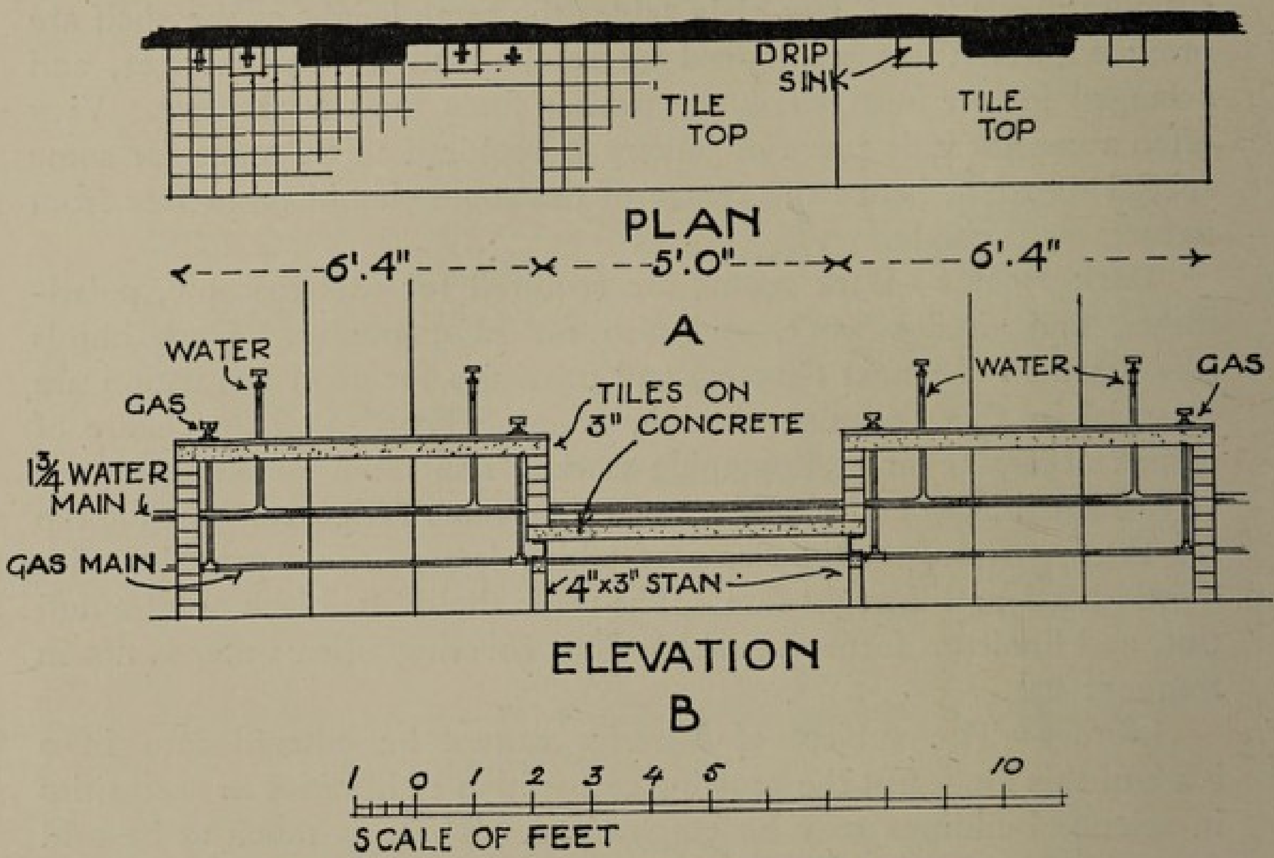


Fig. 28.—Physical Chemistry Laboratory Benches.

and bottle racks, and benches of incombustible material, sometimes arranged for large apparatus at different levels, and liberally supplied with gas and water, which services often have to be kept in use continuously day and night. These may be made of concrete slabs about 3 ins. thick, covered with red tiles, and supported on glazed brick piers or iron supports. Those used at University College, London, are shown in Fig. 28, and are 2 ft. 6 ins. wide, and alternately 3 ft. and 18 ins. high, in lengths of 5 ft. to 6 ft., the lower slabs being supported on steel channels and legs, built into wall and floor. Gas and water are supplied at the higher level. It is usually desirable, as in a research laboratory, to keep as much floor space as possible free for any special work, and students require as much bench space as for research purposes.

A table with a raised bead in front for mercury experiments may be useful.

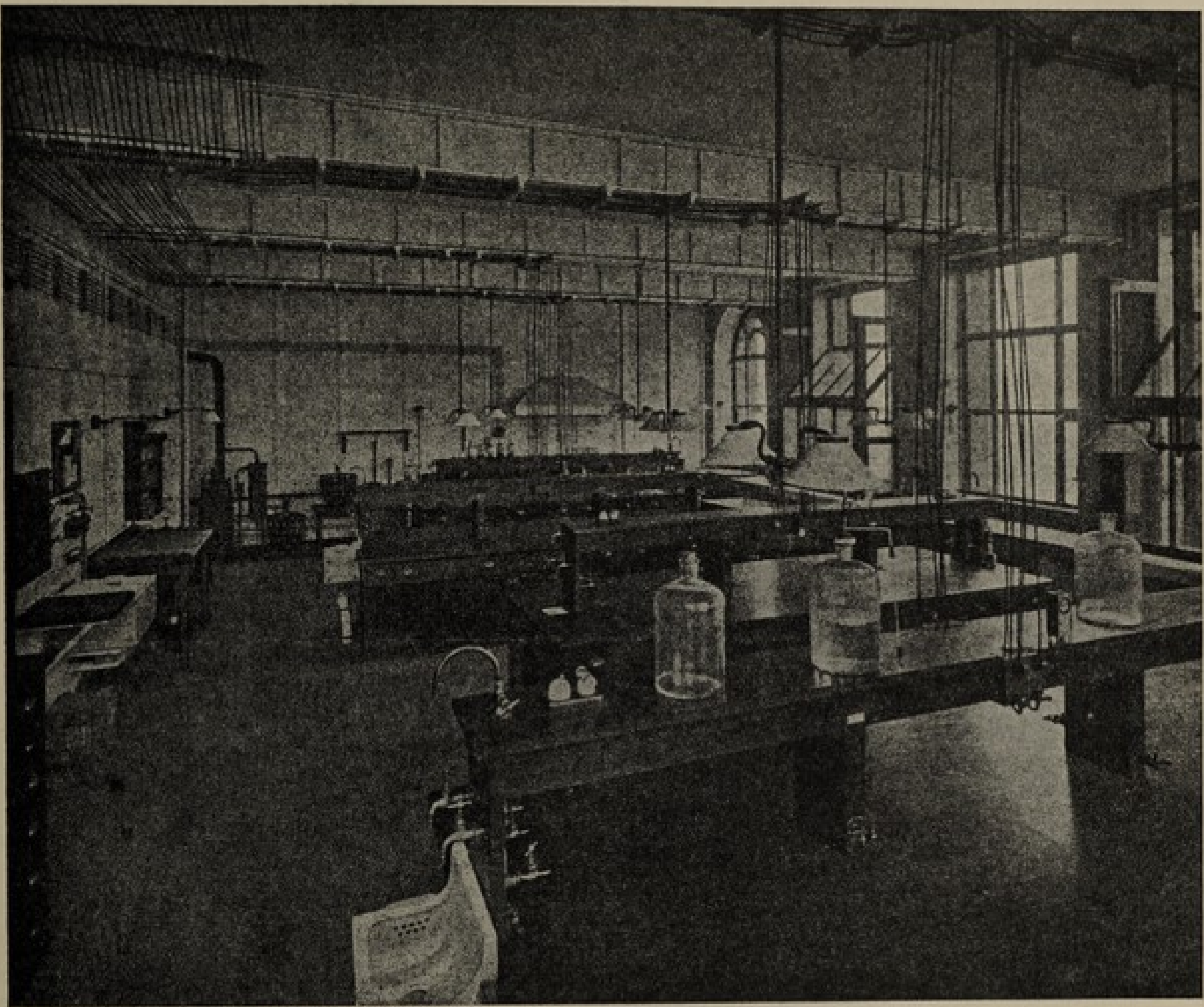


FIG. 29.—Electro-chemical Laboratory, Liverpool University.

Electro-chemical Laboratory—Though electro-chemistry is strictly a branch of physical chemistry, it embraces so large a field that it is generally classed as a distinct subject. The fittings above described are suitable for such a laboratory, but a great deal of electric wiring for experimental purposes (further alluded to in Chapter V) is necessary. Fig. 29 shows a photograph of the general laboratory in the institute devoted to this subject at Liverpool University. The double benches (not that in the foreground) are 12 ft. by 5 ft. and 3 ft. high.

Gas Analysis Room—Gas volumes are so readily affected by temperature that a special room which can be maintained at an even temperature is required for analysis. As mercury is much used, the floor is frequently cement laid to fall to a small catch-pit whence spilt mercury

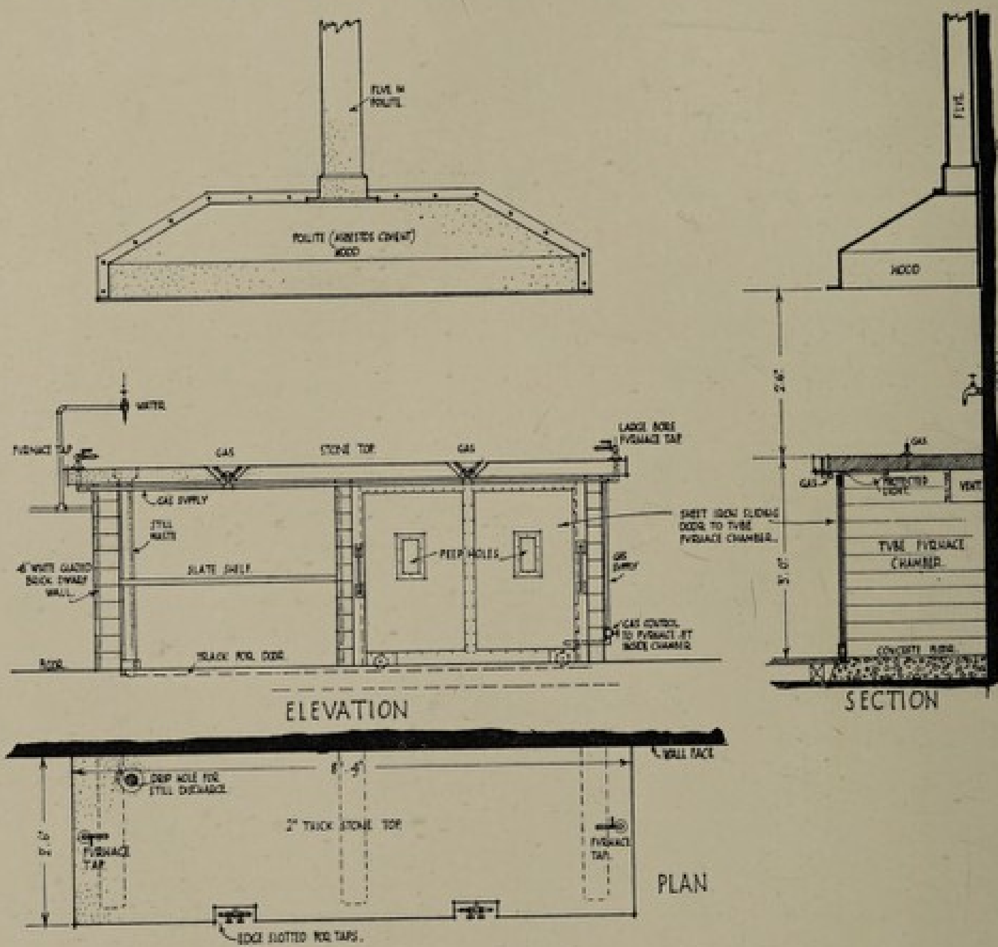


FIG. 30.—Detail of Combustion Bench.

can be recovered. Fittings are few, plain strong benches or tables to hold tall tubes and large glass aspirators are necessary, also a large sink and a few shelves for reagent bottles.

Sulphuretted Hydrogen Room—Where much sulphuretted hydrogen (which is not only evil smelling, but poisonous and inflammable) is used, it is desirable to have a small annexe to the laboratory devoted to it, though in most schemes one or two fume cupboards are merely set apart for it in the laboratory itself. Such an annexe should be as open to the air as protection from wind and weather will permit, and as operations are transient, need not be heated. The room contains one or more fume cupboards approached by suitable gangways, one cupboard being usually devoted to the apparatus for making the gas, which is laid on in glass or lead tubes to various points in the others. The corrosive effects of this gas on metal are so great that every effort must be taken to keep gas and water fittings outside the cupboards, and to reduce metal work in the annexe to a minimum. The floor of this room may be suitably of asphalt. To prevent the constant small evolution of the gas from the water surface, necessarily exposed in the supply apparatus, this surface may be covered with paraffin oil. At Leipzig the gas is made and stored in a regular gasometer in the basement, and laid on to the laboratories, but this arrangement is very unusual.

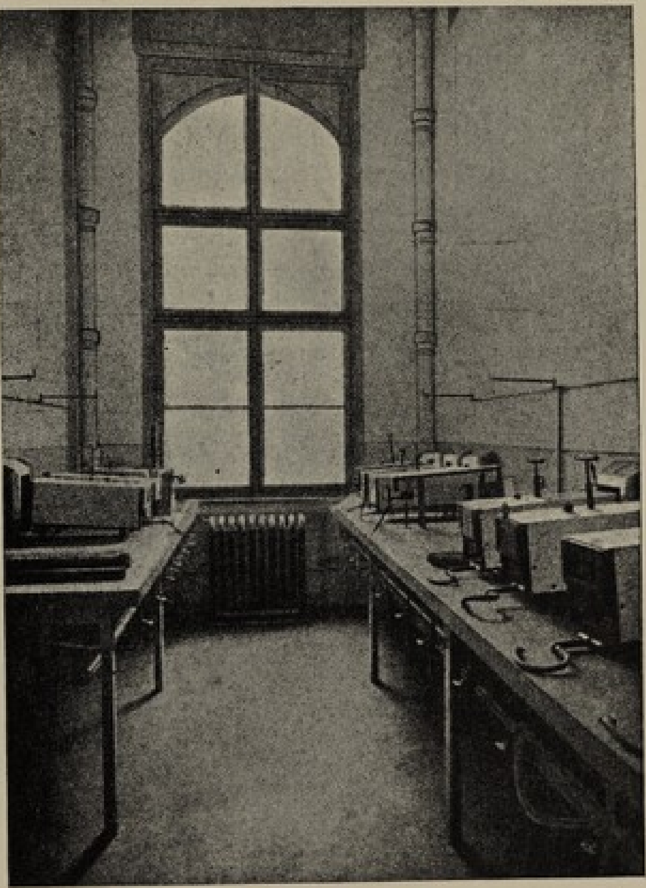


FIG. 31.—Closed Tube Room, Chemical Institute, Berlin.

Closed Tube Room—In a large department a small separate room for organic analysis by decomposition under pressure is desirable owing to liability to explosion. This decomposition is effected in glass tubes some 18 ins. long and 2 ins. in diameter which are heated by gas in small cylindrical portable ovens which stand on a bench. The gas supply necessary is quite small, as these tubes are only heated slightly. This operation may take place in the combustion room or in the organic laboratory itself, provided effectual protection is arranged in the form of a strong iron case or cupboard. Fig. 30 shows a closed tube cupboard with iron doors under a combustion bench arranged for use in a laboratory.

Naturally everything in such a room or area should be of incombustible materials, the benches of stone or concrete and the floor in cement or tiled. Fig. 31 shows this room with a series of the ovens on the benches in Fischer's laboratory in Berlin.

Combustion Room—By a combustion room is generally understood a room set apart for organic analysis, where a given weight of a compound is burnt under carefully regulated conditions and its products are measured by volume if gaseous, or if not are weighed subsequently in the balance room. Other work, such as melting in furnaces, blowpipe operations and the like, though requiring very similar fittings, is best done in a separate room, because organic combustions require great care and concentrated attention extending over some time. The arrangement for organic work consists of benches of concrete with tiled tops, as previously described, or these may be of fine sandstone or even cement-faced concrete. The tops may be carried on brick piers or strong iron brackets. The floor of the room should be cement, tiles, or other incombustible material. Over each bench, which requires an ample gas supply, is a hood connected with a flue to remove combustion products from the furnaces. These hoods are best made of "asbestos," reinforced by iron as necessary, which obviates all exposed metal work. Near the bench attached to a water supply and preferably placed in a sink, aspirators—large glass or metal bottles—are provided for attachment to the combustion furnace. The benches are usually against the walls to facilitate draught and water arrangements. A special sink with a well, a few inches square and perhaps 2 ft. deep, in one corner for adjusting the level of water in long vertical tubes, for the eudiometric determination of nitrogen is desirable, and this should be in a good light.

In Fischer's Berlin laboratory the benches are 7 ft. 10 ins. long, 21 ins. wide, and 3 ft. 1½ ins. high. The arrangements in Beckmann's laboratory at Leipzig are shown in Fig. 32.

Constant Temperature Room—For constant temperature work in a chemical department it is often considered sufficient to provide in the basement in the interior of the building, or on an aspect subject to little change of temperature, a room 8 or 10 ft. square, with double walls with a hollow space between them and a thick non-conducting door, or two doors so that one can be closed before the second is opened.

Such a room is valuable for crystallizations and the like. When, however, incubations are required the temperature must not only be constant but capable of control at will, which is a less simple matter. This is arranged by providing some source of heat capable of regulation; sometimes this is supplied by hot-water pipes with a gas-heated boiler, but electricity is more usually employed in modern installations. These

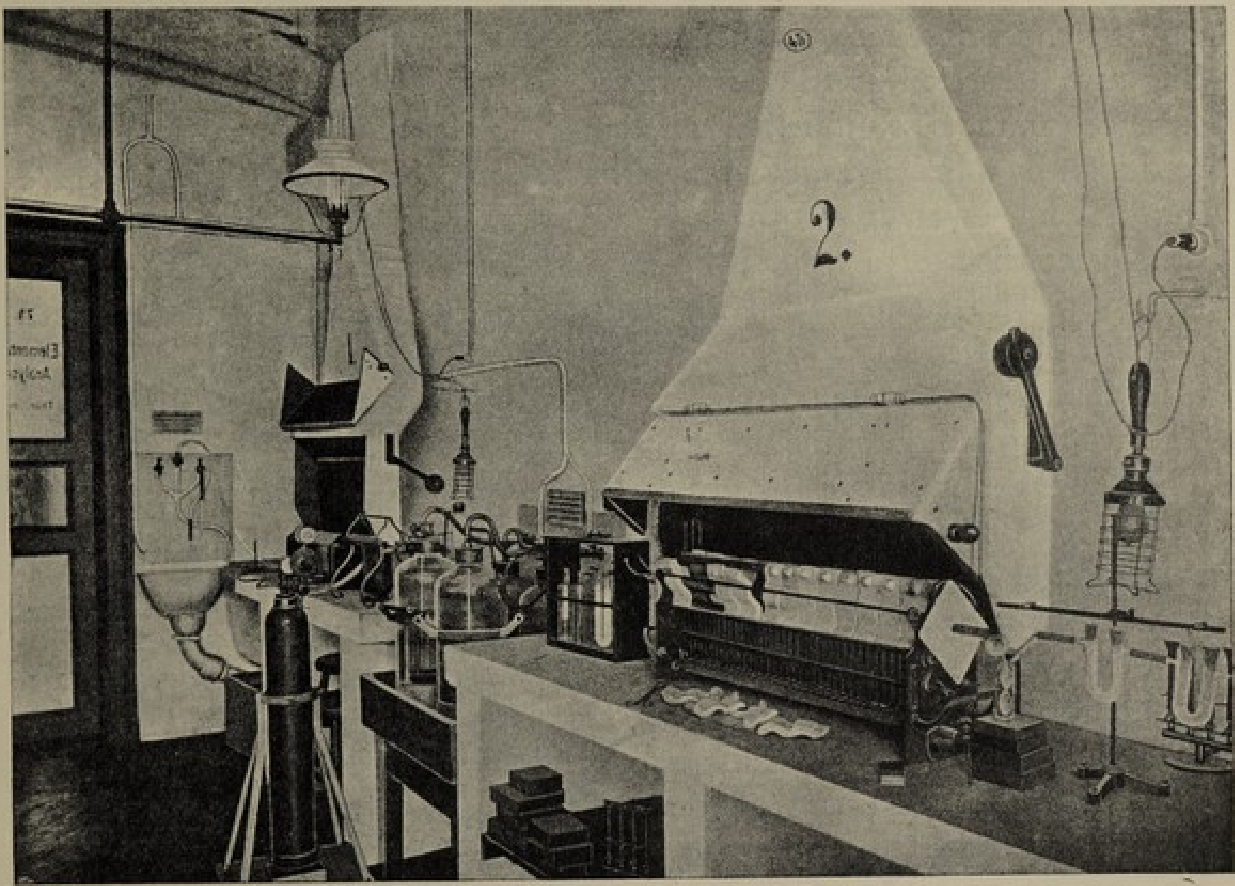


FIG. 32.—Combustion Bench, Leipzig.

requirements are mostly associated with biology, and further details will be found on pages 97-8.

Metallurgy[1]—The accommodation will comprise at least a furnace room, laboratory, and separate balance room, and, of course, a complete suite of rooms, as for other branches of chemical work, may be necessary in certain instances. In the furnace room metals are melted in furnaces operated by coke, gas, or electric power, and the fittings

[1] This subject is not necessarily represented, even in a department of considerable magnitude.

should be of an incombustible nature. Two main classes of furnaces are required, known as " wind " and " muffle " furnaces ; the former are generally operated by coke burning under the natural draught of a tall chimney, hence the desirability of placing this room at the bottom of the building of ordinary height to obtain an efficient length of flue. Very high temperatures have to be attained in these furnaces, and perhaps 50 ft. may be taken as an average length of vertical flue necessary,[1] but if a short flue is inevitable, the difficulty can be overcome by installing an upcast fan at the base of the shaft. The usual type of wind furnace cannot be supplied by an apparatus maker, but must be erected to design by a builder, and so few illustrations are available that a working drawing of such a furnace is shown in Fig. 33. A wind furnace usually consists of a 9-in. by 9-in. opening, surrounded by 9 ins. of brickwork and standing 2 ft. 9 ins. high. At a depth of about 1 ft. 4 ins. a set of heavy wrought-iron movable bars (club-headed to keep them distanced) are supported by two wrought-iron bars built in below. The whole of the interior must be in firebrick with thin fireclay joints. The flue is at the side or back of the furnace at the top. In the example shown the flue had to be carried horizontally cut into the wall to an existing flue in another part of the room, but this would be unnecessary if flue and furnace were designed together. The furnace has a cast-iron top (wrought iron is unsuitable, as it warps), perforated for the full opening (9 ins. by 9 ins.) which is covered by two loose fireclay slabs of different size bound with iron straps, and these are handled with tongs. At the floor level is a furnace door with damper by which the draught can be regulated. A damper is also provided in the flue (see section EE). The elongation of the table top shown in the elevation is merely for the purpose of carrying the muffle furnace, which is heated by gas and also requires a flue, generally arranged with an opening in the wall. To this a small hood is attached to receive the gases from an open wrought-iron flue pipe about 3 ft. long, placed on the top of the muffle.

Where several wind furnaces are wanted they are all connected to one main chimney shaft, placed as centrally as possible, by branch flues sloping up at an angle which should be not less than 30 degrees even for those most distant from the shaft. Dampers in each flue are very

[1] The wind furnace flue at Birmingham University is some 45 ft. in height.

desirable to give means for equalizing the draught when several furnaces are in use together.

The modern applications of electricity have introduced very powerful and rapid electric furnaces which can be used for melting operations

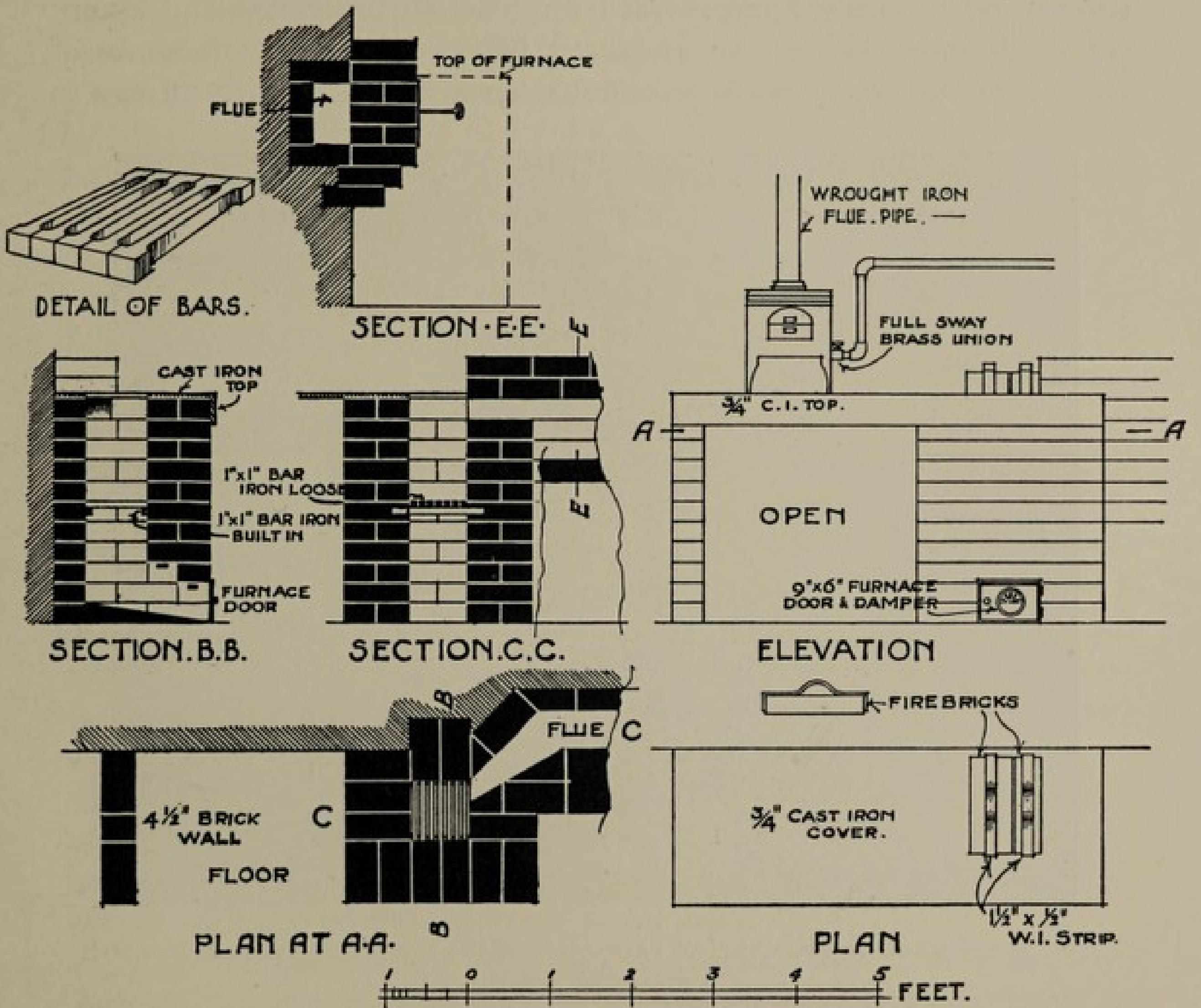


FIG. 33.—Metallurgical Furnace Details.

without the necessity for fuel or flues. These furnaces are sometimes operated by D.C., heat being produced by the direct resistance of some infusible partial conductor. The more efficient but much more expensive types are operated by A.C. Hence when electric power is readily available the types of furnace described may be unnecessary. Fig. 34 shows part of a metallurgical furnace room in the new research laboratories of the Non-Ferrous Metals Research Association, London, opened in June, 1931. The electric furnace in the foreground consumes 25 kilowatts, and can melt 120 lbs. of copper. That on the left with a hood over is gas-operated and melts 100 lbs. of copper. A runway on the ceiling is provided for handling crucibles, and a very powerful ventilation extract system is installed to deal with fumes of zinc oxide and finely divided combustion products. Other fittings in

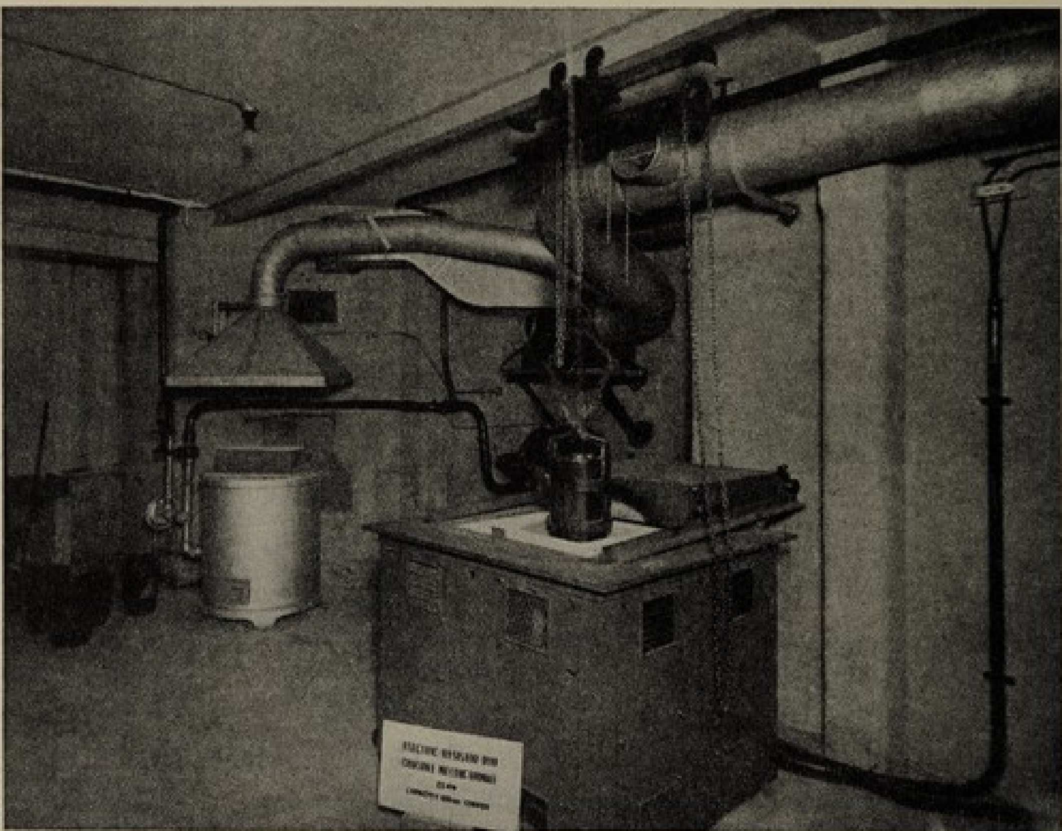


FIG. 34.—Part of the Metallurgical Laboratory of the Non-Ferrous Metals Research Association, London.

the furnace room are one or two strong tables or benches for cutting metal and using mortars, and for a small milling machine and perhaps one or more pieces of tree trunk about 2 ft. 6 ins. long and with an iron band at the top for use as blocks for hammering and the like. Bins or retaining boards for coke and possibly also for ores, used in experimental work, will also be required.

The necessity for a laboratory special to metallurgy will depend largely on the magnitude of the department and its opportunities of utilizing other laboratories which the institution may possess. Much important work has recently been done on the microstructure of metals, and for this microscope benches and photographic facilities are necessary. Etching with acids and other chemicals is also required. The working benches are of ordinary construction, those for microscope work being lower (see Chapter IV). A fume cupboard is required, and a bench of incombustible material, as described for physical chemistry (p. 50), will sometimes prove valuable. If balance cases have to be designed, particulars should be ascertained, since one or more assay balances are often of much greater size than those in use for ordinary work.

Acid and Special Stores—In large institutions a special room for acids is desirable, with a solid floor covered with asphalt and laid to fall to a special drain or catch-pit, not connected with the general drainage system, as a provision in case of breakage. Strong acids are diluted with water in this room, and carboys—6-gallon glass vessels in wicker or iron cases—supported on an iron frame on which they can be safely tilted, are emptied into smaller bottles. Plenty of strong shelving to hold Winchester quart bottles, which are about 14 ins. high and 4½ ins. in diameter, a place for funnels and similar apparatus, and a sink and water supply are necessary. Where any quantity of ether, alcohol, benzene, and like inflammable liquids are used, a special store, devoid of combustible materials, and with an iron door external to the building, is desirable. The windows of such a store should have iron shutters operated externally, and a shower-rose with both internal and external tap should be supplied in the ceiling. The floor may be in cement or asphalt, and should be laid to fall as for acids.

A special place under control, such as a cupboard in a wall with slate shelves and an iron door, is sometimes used in store rooms for keeping phosphorus, sodium, and other dangerous chemicals, while a small locked cupboard of ordinary type may be desirable for certain violent poisons, such as alkaloids.

CHAPTER III

THE REQUIREMENTS OF PHYSICS

THE fittings of a physics laboratory are less elaborate than those of a chemical laboratory, but the apparatus required is more so. While the branches of physics are more easily defined than those of chemistry, the actual separation of the work in this subject under specific rooms is difficult, because the general similarity of the fittings is greater than in the case of chemistry. The branches of physics are, as stated, mechanics, heat, optics, acoustics, and magnetism and electricity.

In the case of a small scheme with different subjects in one building, the physics department generally occupies the ground floor, but as such a department of any magnitude must involve several floors, this cannot be regarded as essential. The fumes and smells suggest an upper floor for chemistry, but the drainage and stock requirements make a ground floor decidedly simpler, and for average work in a well-constructed building there is little reason against the reversal of the usual floors for these subjects if this appears advantageous.

Vibration—One of the first considerations of the designer of a physical department is probably the question of vibration, and as much misconception appears to exist on this subject, it may be dealt with generally here. For advanced work in certain departments of physics, freedom from vibration is so essential that the whole construction of the building and even its site may be modified by this necessity, and an example will be found in Chapter VI illustrative of the great amount of care expended upon this problem. In the same manner the magnetic disturbances caused by electric currents used in commercial undertakings quite external to the building may in certain delicate researches have a most detrimental influence, but having said this, it may be added that for the work undertaken by the average student, even of university standing, no elaborate precautions are required. A well-built structure in ordinary surroundings will provide upon its main walls, and particularly near the intersection of cross walls, sufficient stability for ordinary mirror galvanometer work if these instruments are supported on masonry corbles, and needless expense is often incurred by carrying down to considerable depths, isolated brick piers through perhaps more than one story for this purpose. Further, now that it is possible to record exceedingly small currents on an ammeter of ordinary type, mirror galvanometers have a more restricted use. If such piers are decided upon, and this decision must of course rest with the teaching staff, every effort should be made to remove or combat any surrounding causes of vibration which exist; the installation of moving machinery may easily negative very elaborate efforts to produce quiescence, and in this connection anything in the nature of an internal combustion engine is much more detrimental than a rotary machine. Where movement beyond control exists near the building, as for example, in the case of an island site surrounded by heavy traffic, or near moving machinery, the inevitable vibration must be absorbed by a bed of confined sand or similar device. A very severe test for vibration is the steadiness of a beam of light reflected from a mercury surface, and this forms a simple means of recording the relative effect of possible disturbing causes on a site or in an existing building proposed to be used for physical experiments, but a great deal of delicate physical work can be done where a perfectly still mercury surface is not obtainable.

List of Rooms—As explained above, it is difficult to give a satisfactory list of rooms for physics, but this may be attempted; and on the lines of the last chapter, those marked (1) may be regarded as the minimum and with those marked (2) will form a desirable scheme for a large secondary school, with any necessary duplications.

1. General Laboratory	Balance Room
1. Lecture Room	Mechanics' Laboratory
1. Preparation Room	Heat Laboratory
2. Workshop	Electrical Laboratory
2. Optical Room	High Tension Laboratory
2. Advanced Laboratory	Transformer Room
2. Store Room	Switch-board Room
2. Library	Accumulator Room
2. Photographic Room	Unpacking Room, Instrument Room
2. Research Laboratory	Staff Rooms

Uses and Relation of Rooms—If more than one laboratory exist, a general laboratory will be usually devoted to mensuration, elementary mechanics, and heat, but quite possibly the whole range of subjects for a first-year course will be conducted therein. A good deal of small apparatus, in addition to larger pieces suitable for glazed cupboards, is required, and means for darkening the room are necessary.

The lecture room resembles in its design and relations to the laboratory that described for chemistry.

The preparation room, conveniently placed between the above in a small scheme, requires considerable space for the often bulky apparatus wanted for demonstration, and though a fume cupboard is not necessary, connection with the lecture room through a similar medium is desirable. This may take the form of a hot cupboard for electric apparatus.

Store rooms for physics should be arranged for the safe keeping of much delicate apparatus which may be damaged by damp and dust. These rooms, therefore, demand a somewhat better situation and certainly better fittings than those for chemistry, but the consumption of stock is much smaller.

Balance rooms, which should adjoin the laboratories, are not so necessary in a physical as in a chemical department, and for elementary work are often dispensed with, space in the laboratory being found for balances. When provided, these rooms resemble those for chemistry.

Workshop repairs to physical instruments are frequent, and a capable assistant can often make a great deal of apparatus. Such a shop need not usually be large, but should be in close touch with the laboratories.

Optical rooms were formerly held necessary even in very small schemes, but optics is best studied in the general laboratory provided with efficient blinds. For certain photometric experiments, however, a special room is very desirable, owing to the fixed apparatus required. When provided, this room should be long and narrow, and usually adjoins a laboratory, often with no separate approach.

Advanced laboratories do not materially differ from elementary rooms in their fittings, and are also used for a large range of work, but more space per head is necessary, and usually more extensive supply services.

To turn to the individual branches of physics, mechanics in its applied stages involves the study of machine principles on a working scale, and sometimes tests on materials. Occasionally, special foundations for heavy loads, sinkings in floors for belt races, or engine beds and makers' bed-plates have to be dealt with in this department. Electrical work forms so important a part of physics that special rooms are often devoted to it; indeed, where commercial electric machines are installed two or more rooms are essential, as running tests on motors with various loads and the like are not suitable for a room in which delicate experiments are in progress. The room for the former purpose resembles a workshop, and for the latter is merely an advanced laboratory, and if this can be near the lecture room some advantages in connection with movement of delicate apparatus will often be obtained. Switchboards are desirably placed in special rooms in schemes of any size, in order to be under suitable control; here also rotary or stationary transformers may find a home. To reduce the cost of wiring, the main board should be near the accumulator room, if provided.

The General Laboratory—Owing to the absence of corrosive fumes and the small amount of water required in a physical laboratory the provision in the matter of special surfaces is not so important as it is for chemical work. A large part of the wall surface is usually covered by shelves and cupboards, and the walls may therefore be merely plastered. The floor is usually of wood blocks, but if care is taken in the matter of the occasional use of alkaline solutions there is no reason why a really good linoleum should not be used, and in a new building this could be laid on cement, not only saving the expense of boarding, but removing any possible trouble due to the decay of such boards under this covering. An oblong room, well lighted from both sides if possible, is most desirable for a physical as for a chemical laboratory.

Fittings—The fittings usually comprise working benches, cupboards for apparatus, one or more large sinks, drawers of various sizes, balance shelves, and sometimes wall and ceiling fixtures for attaching apparatus. If no demonstration table is required, at least a blackboard should be placed in some conspicuous position. Cupboards and balances are generally placed on walls, and the demonstration table (if any) at one end of the room. Working benches should be in the middle of the room and are preferably ordinary, strongly-built tables, approachable on all sides, designed for two or four students. In many laboratories, however, continuous long tables are found and are in favour. They are more economical in space, but facility for getting to apparatus from all sides has many advantages. In the case of long tables 4 ft. or at least 3 ft. 6 ins., as for chemistry, should be given to each student, and if work is done on both sides, that is, they are double benches, their width should be 4 ft. Rather more than half this width is necessary for single benches. The necessary gangways are influenced somewhat by the style of bench adopted. If single tables with passage ways between their ends are used, the space between one table and the next may be rather less than if continuous benches are adopted, since in the former case the same necessity for the demonstrator to pass behind the students will not exist. 2 ft. 6 ins. to 5 ft. 6 ins. may be taken as the limits, the former for a gangway not containing students' places or down which little traffic passes, the latter for a long pair of benches with students back to back.

The Board of Education (England) gives 30 sq. ft. per head as the allowance over the whole room for a physical, as for a chemical laboratory, but it will be found rather difficult to arrange an adequately spaced and fitted room on this basis if small tables are used.

Working Benches—Turning now to the details of construction of the fittings, benches are usually 3 ft. high for adults, but may be less for juniors; an inch or two, however, makes a great difference, and few will care to work standing at a table less than 2 ft. 10 ins. high. The tops are usually of teak, but less costly woods such as pitch-pine make very serviceable tops and decrease the weight, an advantage if the tables are to be much moved. Seniors are seldom, and juniors hardly ever, given lockers and individual apparatus as for chemistry, and as advanced work often involves erected apparatus which must remain over a long period, lockers for physics possess less utility. It is therefore best not to fill in the space below the tables with cupboards for storage, unless limited laboratory accommodation makes this imperative, in which case the doors to such cupboards should be placed on the side or end not occupied by the students, to admit of ready access while a class is at work. Sometimes a drawer alone is arranged below the top for each student, but very little use is generally made of it, and a good nest of drawers in one or more places in fixed fittings is often preferable. The writer's view is that as many of the working tables as possible should be movable. They should have $1\frac{1}{4}$-in. teak or pitch-pine or $1\frac{1}{2}$-in. soft wood tops, legs $3\frac{1}{2}$ ins. square, which may be tapered at the bottom and should not be much more than 4 ft. apart ; the framing should be strong, and if held by dragon pieces at the corners (Fig. 35) the tables will not be racked when moved, which is often otherwise the case.

If likely to be submitted to unauthorised movement the legs may be screwed to the floor by buttons. A bottom rail and cross braces are further necessary in tables of large size which are not fixtures, but unless arranged with one longitudinal centre rail attached to two end rails, as in Fig. 35, they have the disadvantage of preventing stools being placed out of the way under the tables when not in use, and when gangways cannot be on a generous scale this is important. If movement is desired the gas and other services must, of course, be arranged to admit of these being supplied from ceiling or floor or from wall connections.

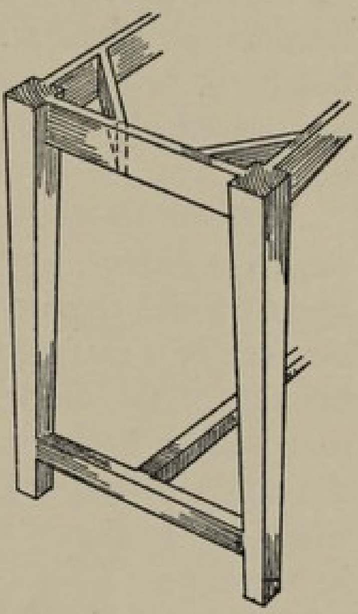


FIG. 35.—Framing to Physical Laboratory Tables.

Toe space should be usually provided where cupboards are placed under working benches, but the top should overhang the framing by some 4 ins. on at least one working side to admit of clamps being secured for holding apparatus. A groove round the top is often provided to catch spilt mercury, but it is probably better to omit this and perform experiments involving mercury in a loose shallow wood tray supplied to each student as required.

Suspension rails of wood or metal down the centre of double benches, and 3 or 4 ft. above them, are sometimes used for attaching apparatus, mostly in connection with mechanics. Probably the balance of opinion in this country is against these rails, though means for suspension on a more limited scale against some wall of the laboratory is often desirable. If it is felt that the space below the tables is too valuable to be wasted altogether, then it is best to place the benches with cupboard fixtures nearest the walls and retain the movable tables in a group so that on occasions a clear space of reasonable area may still be obtainable if wanted.

Apparatus Cupboards—Physical apparatus varies in size from things quite minute to others very bulky. Long tubes, rolled diagrams, and the like, should be provided for. Apparatus cupboards should be 15 to 20 ins. deep and have backs and glazed doors; the bottom shelves should be several inches above the floor to avoid breakage and dust. Doors are best hinged, but in confined situations may slide, in which case running tracks should be used to facilitate movement. A good deal of dust may be excluded by rebating the framing or putting a stop all round, provided the cases are carefully made. A number of small drawers are necessary for holding delicate apparatus, either with cupboards or in a separate fitting. Fig. 36 shows a cupboard, the lower part of which serves also as a bench without interference from the doors above.

Ladders to High Cupboards—In the case of high cupboards which require a ladder, a good flat space, say 6 ins. wide, must be arranged, against which the top of the ladder (usually provided with a padded bar) can rest, or a metal rod may be fixed horizontally to the case upon which the top of the ladder can be hooked. Very light ladders capable of sustaining a heavy man are made by embedding on the under-side of the styles (sides) a $\frac{1}{4}$-in. steel wire rope firmly secured at both ends, when any tendency to bend is resisted by the tension thus developed in the rope.

Cupboards in ill-lighted situations should be painted white inside. Where apparatus is wanted in two adjoining rooms it might occasionally be advantageous to make the cupboards part of the dividing wall, with shelves running through and glazed doors on both sides. This would aid illumination, cleaning, and transference, and would enable a deep cupboard to be effectively employed.

Sinks—One large glazed-ware sink, say 5 or 6 sq. ft. in area, in a central position will serve an elementary laboratory, but it should have several water taps, say two at ordinary height and two about 24 ins. above the sink bottom to admit tall apparatus. A good-sized draining board, part of which may be covered with lead for vessels containing acids, should be provided. The top of the sink should be about 2 ft. 6 ins. above the floor. Sinks should not be placed on the working benches, which require as large an unencumbered surface as possible.

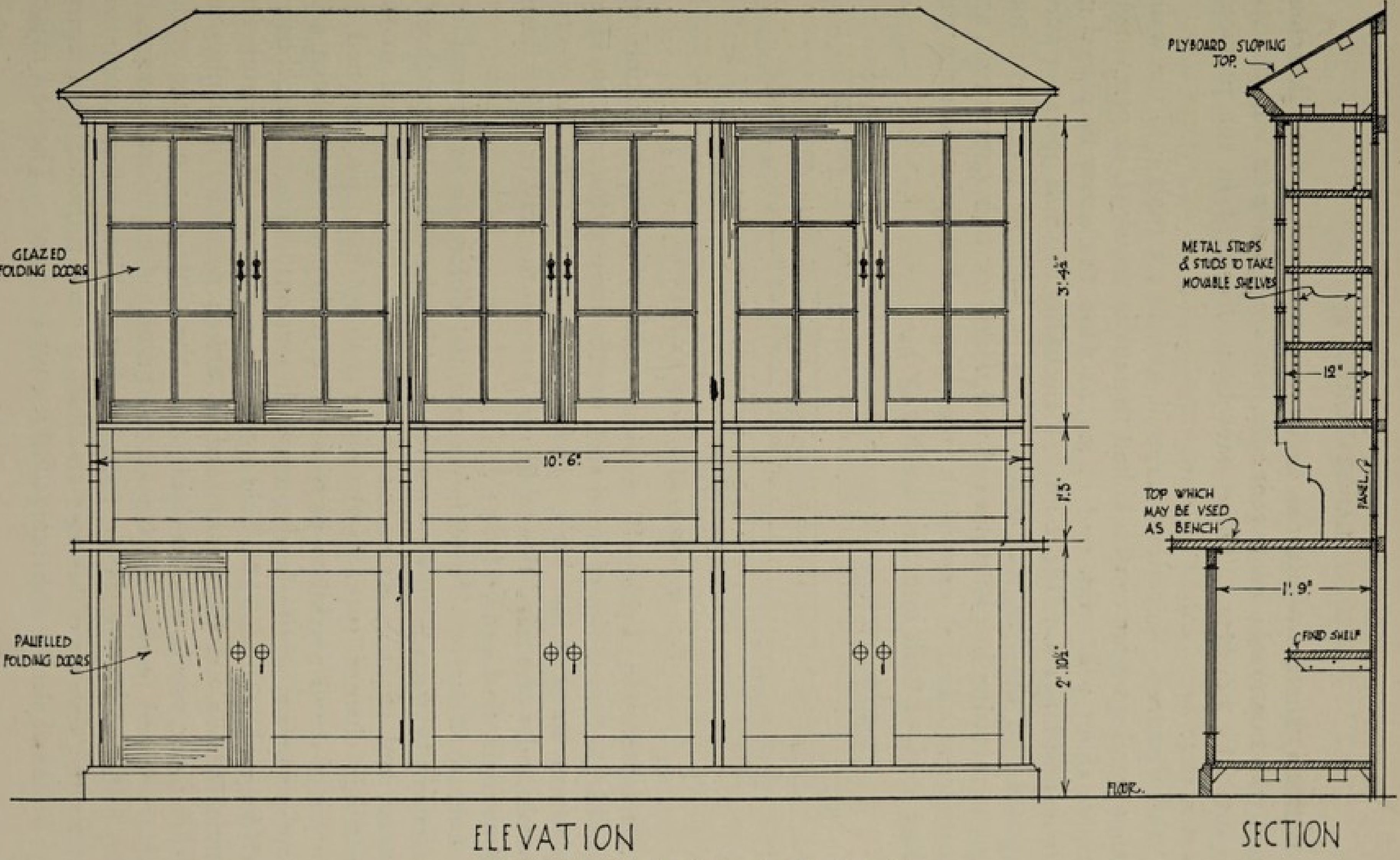


FIG. 36.—Physics Apparatus Cupboard.

Balance Shelves—Balances sometimes stand on a fixed detached bench with cupboards below generally, but are usually on wall shelves supported by brackets. These have been discussed in the previous chapter, page 44.

Wall Fixtures—Sometimes screwed sockets are built into the walls so that wood uprights can be bolted thereto as required, or permanent uprights about 3 ins. wide and 1½ ins. to 2 ins. thick may be placed in suitable positions round the room. Their utility depends upon the work proposed and the free wall space which is available. Wrought-iron clips, terminating in plates pierced with holes for fixing apparatus, are sometimes attached at intervals to the flanges of the steel joists at the ceiling level, or built into ceilings (Fig. 37).

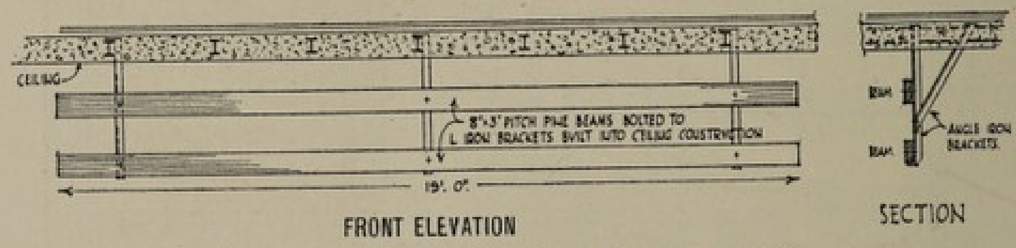


Fig. 37.—Suspension Rails for Mechanics.

Demonstration Table—If provided, tables for demonstration are made like lecture tables of small size, usually have a sink, and stand on a platform about 8 ins. high. It is convenient to place the electric controls under or behind this table, and here on the wall the blackboard will naturally find a place (p. 31).

Lecture Theatre—There is no essential difference in general arrangement between lecture rooms required by the different branches of science, and as these arrangements have been fully discussed in the preceding chapter (pp. 33-7), remarks here may be confined to matters of detail special to physics. Everything which has been said about acoustics, seating and general dimensions, lantern, blackboard, and diagram requirements, hold good for any room for experimental demonstrations. A fume cupboard is seldom necessary in a physical lecture room, nor is a down-draught on the table, but in place of the former, behind the moving blackboards, a glazed cupboard opening to both lecture and preparation room, and resembling a fume cupboard but for the absence of services and flue, is often provided for keeping dry, frictional electric apparatus until required for use. The best means of keeping a dry atmosphere in such a cupboard is by warming the air, most conveniently effected by lamps or other form of electric radiator placed below the cupboard in an incombustible enclosure, the cupboard having a false bottom of perforated slate, enamelled iron, or " asbestos." Alternatively, instead of this cupboard, a hot plate may be provided on the lecture table. This may be designed as a permanent part of its surface with an electric radiator below.

Combustions and similar operations involving much radiation on the table top are not so frequent in physical as in chemical experiments, hence an area of incombustible material is less necessary. Again, the use of water is more restricted, and a single sink and smaller number of supply cocks and drips will be sufficient. Gas also is rather less in demand. On the other hand, the electric supply services are much greater and more varied.

Dark Blinds—Means for darkening rooms are required by every branch of science, but chiefly in the domain of physics. Ordinary union blinds are not sufficiently opaque for many purposes, and specially treated black cloth is necessary. As blinds are often wanted for a short interval only, rapidity of action is necessary, and occasionally they are operated by small electro-motors, as in the Bio-chemical Laboratory, Oxford. For operation by hand, spring rollers are very desirable, and these should have a check to prevent the spring over-running. A wood casing, in which the edges can run, is also required to exclude light ; this should be deep and wide enough to take the blind lath, without fear of its jamming or coming out. It should be painted a dead black internally to absorb any light which may pass round it. The principle of the zip fasteners has recently been applied to blind edges, admitting of the use of a small brass strip on the window linings in place of wood casing. These blinds are usually fixed at the top of the windows, with rollers, in wood cases screwed to the window linings, to exclude any light above them, but they may be fixed at the bottom, with a pulley at the top, over which the cord is drawn. They may also be placed horizontally in the centre, arranged in two sections, one to pull up and the other down. This, of course, involves a considerable bar across the window. Blinds may also be arranged with rollers top and bottom to overlap in the middle. The slight space thus secured between the pair proves valuable in admitting air with open windows, which often result in single blinds being blown out of their casings. If windows are very wide, two blinds divided by a central vertical casing are desirable, as a tendency for wide blinds to come out of their side casings always exists. Skylights need special care if requiring blinds which are usually horizontal and drawn across several strong wires to prevent them from sagging. Heavy black curtains hung on rails and pulleys to overlap across the window centre are sometimes used, the back vertical edges may be fixed to the window casing. Such curtains would seem most suitable for very wide windows. From the above remarks it will be evident that this blind work should be executed by a firm with experience in laboratory

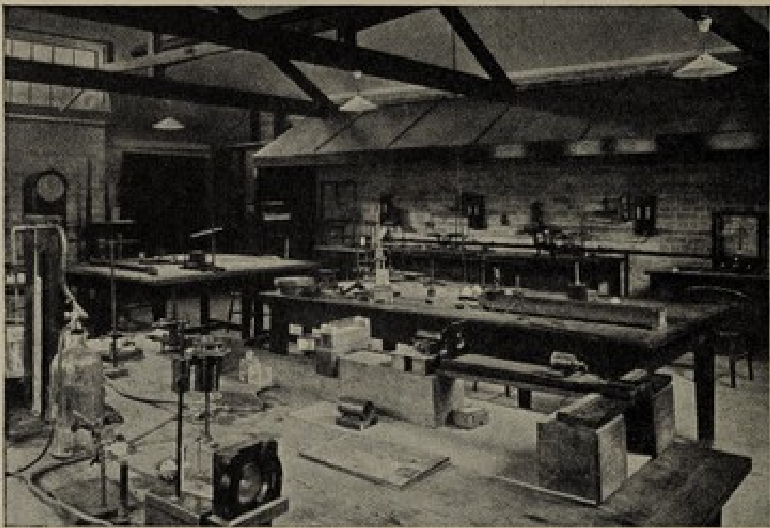


FIG. 38.—Curtained Enclosure for Optics, University College, Bangor.

requirements. Fig. 38 gives an illustration of one of the laboratories at University College, Bangor. The hood supports a black curtain which can be drawn along its whole length to darken the interior for optical work.

Preparation Room—Cupboards and good table space are the essentials for a preparation room: a sink is also necessary, though it may be smaller than for chemical uses. If no special place for dealing with diagrams exists, a large rather low table with shallow drawers will be found valuable. The cupboard space necessary will depend on such provision elsewhere, but there is always certain apparatus confined to lecture use, and this should find a home here. A fume cupboard is hardly necessary.

Balance Room—The description of a balance room used in a chemical department holds for physics, but cupboards under the shelves, sometimes found for chemistry, are not required for physical work. As already stated, in a small scheme a balance room is not a necessity.

Workshop—A workshop, though it be only a room 10 ft. square, is a great asset, and should be fitted with a carpenter's bench and rack for tools, a light metal turning lathe, small table drill, a side bench for general

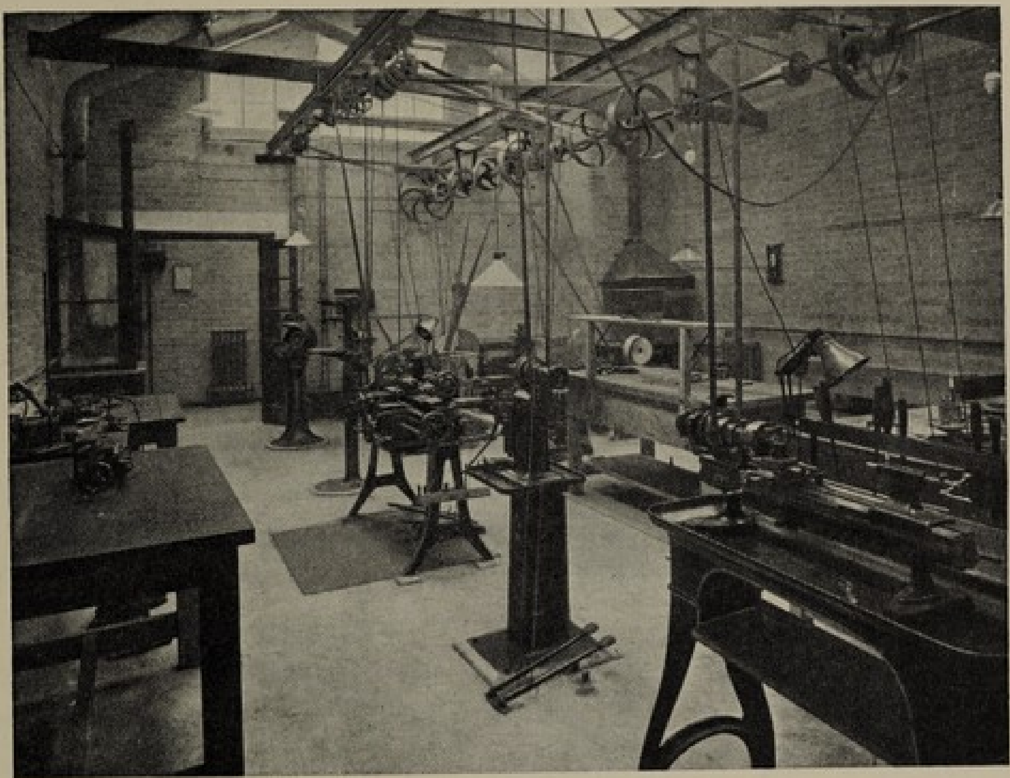


Fig. 39.—Physics Workshop, University College, Bangor.

storage, and a small combustion bench with hood and flue, provided with a good gas supply. Gas is required for a small muffle furnace for annealing, for heating soldering irons and for a blow-pipe (usefully installed here if not in the preparation room). A wood-block floor is desirable to reduce damage to tools which may be dropped.

Fig. 39 shows the workshop of the Physics Department of University College, Bangor, equipped with screw cutting and ordinary lathes, drill, milling machine, circular saw, hack saw, polisher and grindstone, motor driven from overhead shafting. In addition to repairs much apparatus is made in this shop, a plan of which will be found in Chapter VI.

Optical Room—An optical room is necessarily small, since one large enough for numbers would cause interference by numerous lights. Usually designed for two or three workers, its chief feature is an optical bench consisting of a pair of wood or metal rails with a scale attached, upon which apparatus slides. These rails are usually part of the apparatus, and supports in the form of a strong shelf about 15 ins. wide, or merely brackets at intervals, are alone generally required as fixtures. Length is the great asset of this room, and 20 ft. will be appreciated if obtainable. A firm wall bracket or pier, as described under "Advanced Laboratory," is often placed here for a galvanometer. The walls of this room are generally dead black. At the Chelsea Polytechnic, London, where this is an internal basement room, a special flue is provided open to the sky to admit of the use of a beam of natural light. This also serves to ventilate the room, which is very necessary, work in the dark having an oppressive effect much relieved by a current of fresh air.

Advanced Laboratory—The fittings of this room do not greatly differ from those already described for a general laboratory, but more space per head is necessary, and as work requiring entire freedom from vibration is more requisite here, in addition to wall brackets, one or more masonry or brick piers with slate tops may be required. Brackets are best made of hard stone, 2 to 3 ins. thick, and with a projection 9 to 12 ins. square, built in to solid walls $4\frac{1}{2}$ ins. slightly above bench-top level. Piers may be 2 to 3 ft. square and hollow internally, carried down to solid ground through the floor which they clear by a fraction of an inch, terminating in "footings" (brick projecting courses) and concrete. The nature of this termination will depend upon whether the ground is free from vibration or not. If it is, the concrete rests directly upon it, but if not, upon a bed of sand confined by a wall of concrete or brick, such sand bed being 1 to 2 ft. thick. Fig. 40 illustrates the base of the piers used at the Physical Laboratory of Urbana University, Illinois, which is described in Chapter VI, and upon which

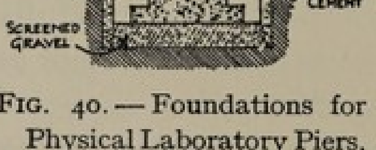


FIG. 40.—Foundations for Physical Laboratory Piers, Urbana University of Illinois.

a very special amount of care was bestowed. Some general comments on the subject of vibration have been made on pages 60-1.

Accumulator Room—In most physics departments a special room is necessary for accumulators which are often required to supply very heavy currents. This room should have an asphalt floor laid to fall to a drain so that the room may be hosed out. It should contain no metal fittings (apart from those of cells) as the atmosphere is often charged with sulphuric acid spray. Fixed glass louvres set directly into the masonry of the windows obviate wood or metal frames and insure permanent ventilation; the door may be covered internally with ruberoid sheeting. To aid ventilation a fan is sometimes installed. Strong wood framing is generally used to support the glass cells which may be in two or three tiers. The number and size of these cells varies considerably with the scheme of work. Fig. 41 gives an illustration of the battery room in the Physics Department of University College, North Wales, which contains 75 cells, giving 330 ampere hours.

FIG. 41.—Battery Room, Physics Department, University College, Bangor.

Photographic Room—Photographic work requires a special room with two doors separated by a lobby, and a window with suitable orange-tinted screens and dark blinds is desirable. Though complete darkness is not essential for lecture purposes or usually for optical work, where sensitive plates have to be exposed the conditions are naturally of a very stringent character. For night work an electric lamp in series with a resistance, or two lamps, one of a voltage higher than for the general lighting, will be found useful to admit of a dimmed or normal light as desired. These lamps are either of tinted glass or are enclosed by coloured screens. An external warning light to show that the room is in use is desirable. The walls of this room may be tinted orange.

The above comments apply to the usual plate-developing room, but where much photographic work is done a suite of rooms, e.g. studio and printing rooms, may be wanted.

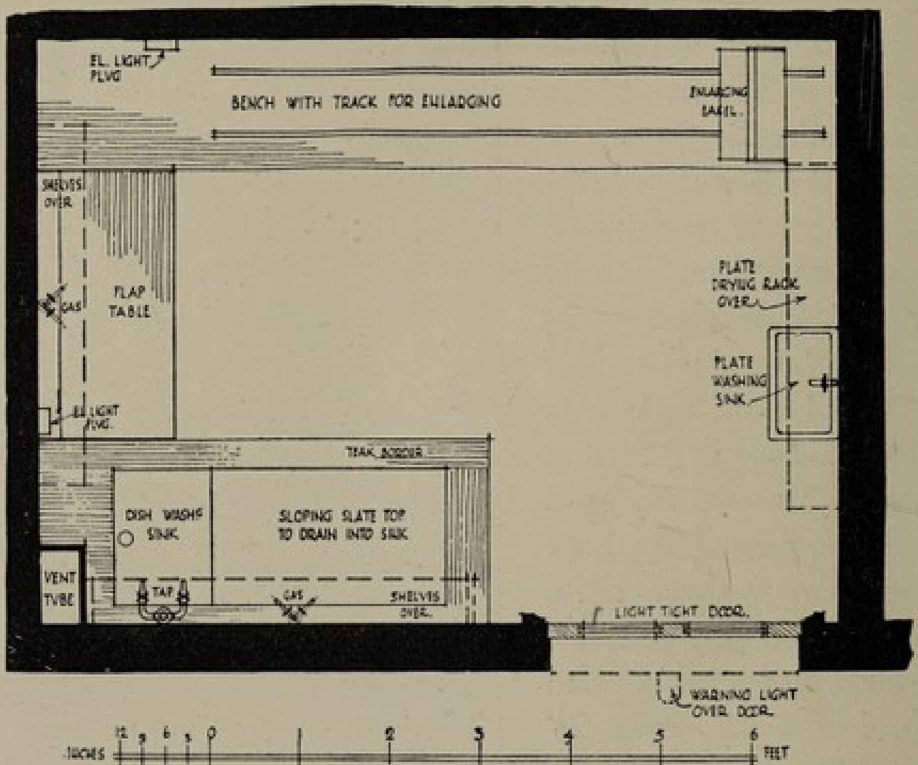


FIG. 42.—Plan of Photographic Dark Room.

Mechanics Laboratory—In a mechanical laboratory a comparatively small amount of work is done seated at specific tables, hence a bench for each worker is hardly necessary. Much of the apparatus is disposed round the walls of the room, very little space upon which can be devoted to benches or cupboards. A solid floor is more necessary for this than other departments, but as a rule special foundations are not required. A few tables at which notes can be made should be provided, but these should be movable, and as much free space as possible retained, though some machines will necessarily be fixtures in the central area of the laboratory. For the determination of what is known as

Young's modulus—which in a physical laboratory usually takes the form of measurement of the stretching of wires with various weights—a great length of vertical wire is necessary. If, therefore, it can be arranged that a space running through two or several stories is devoted to this experiment, it will be a great advantage. Nothing more than the area of a chimney flue is necessary, and may sometimes be obtained conveniently on a staircase wall adjoining the laboratory. Access at the top is required (though not for the students), but no intermediate openings.

Heat Laboratory—A special room is sometimes provided for experiments on heat. The chief difference between this and a general laboratory lies in the provision of a steam supply and a larger number of water supplies and wastes to admit of the use of running water required to circulate through apparatus. Benches are preferably of incombustible material, semi-glazed tiles on concrete are suitable, and these benches, for convenience in arranging supplies and wastes, are sometimes placed round the walls. Another arrangement is to supply steam, water, and gas to a narrow wall shelf adjoining movable benches, at suitable intervals at right angles to the walls. This admits of better lighting and supervision and of more flexibility.

Electrical Laboratory—The concentration of electrical work in one laboratory has the advantage of reducing the outlay in heavy electric cables usually regarded as necessary in modern investigations. Such a room should naturally find a place as near the accumulator room as is practicable, and, unless a special switchboard room is provided for the building elsewhere, the board is one of the main laboratory fittings. Something will be said in Chapter V about the general cable and board arrangements. The fittings otherwise bear a close resemblance to those of an advanced laboratory. A great deal of mirror galvanometer work will be done in this room, hence ample provision should be made for these instruments on wall brackets, and if the lamps and scales required can be placed elsewhere than on the students' benches much saving of room will result. At the Chelsea Polytechnic, London, the galvanometers are on one side of the room about 3 ft. apart, on a slate shelf. Attached to the under side of the shelf is an arm of oak about 1¼ ins. square and 2 ft. 3 ins. long, which can move in a horizontal plane and thus be swung out of the way. This arm, which is about 2 ft. above the bench, carries at its free end a semi-transparent scale and below it a small electric lamp and lens which illuminates the scale by reflection. Wires are run as required from the galvanometer to fixed terminals on the shelf. The tables are all movable. If tests on running plant are proposed, a special laboratory having the character of a workshop should be provided for this purpose. Fig. 43 shows such a room in a department of Liverpool University.

It will be found advantageous to leave one or two holes in internal walls connecting laboratories to admit of cables or temporary pipes

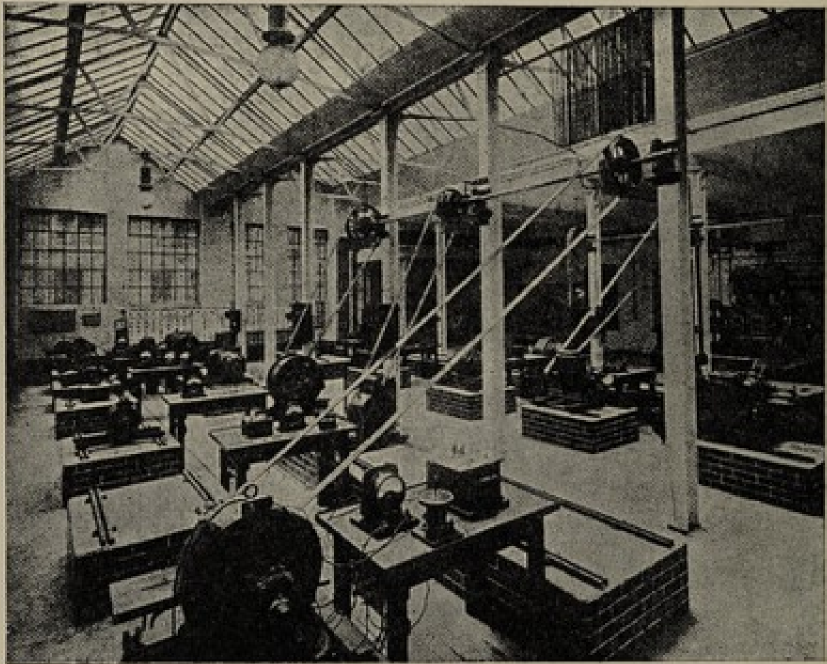


FIG. 43.—Dynamo Room, Applied Electrical Laboratory, Liverpool University.

being carried through when required without cutting the walls. Such holes need not exceed 3 ins. in diameter.

Research Rooms—For research, plenty of free space is desirable, hence tables should be movable, and gas, water, and electric services confined to narrow wall benches or shelves as far as possible. If research in certain branches of physics can be confined to specific rooms, some economy may result in the provision of services of which electric supply is the most important; water and gas are also of course necessary. No generalizations can be made on fittings except to say that initially the fewer probably the better.

Store Rooms—In a small scheme stores are not as prominent in physics as they are in chemistry, but for a large scheme a room for unpacking in addition to an actual store room may be requisite, and if this accommodation is provided on more than one floor, connection by a hand lift will be useful. The fittings should consist of glazed cupboards, a few drawers, and a table or bench. When the height of stories is considerable galleries or mezzanine floors may be contrived to economize space.

Instrument Room—A room may be required for the safe keeping of valuable instruments and possibly also in which certain of them which cannot conveniently be moved can be actually used. Very good storage conditions, coupled with limited working bench facilities, are here indicated. Apart from electric supply, services should hardly be necessary, and are probably best avoided.

CHAPTER IV

THE REQUIREMENTS OF BIOLOGY AND GEOLOGY

BIOLOGY includes the study of all forms of life under the divisions Botany and Zoology. These sciences, particularly the latter, have in recent years greatly developed, and such zoological subjects as anatomy, physiology, pathology, bio-chemistry and pharmacology are now regarded as separate sciences.

A great amount of overlapping, however, will generally be found, many of these subjects extending into the domain of the others according to the trend of work decided upon by the organizing investigators. This makes the task of the designer particularly difficult and the necessity for a proper understanding the more imperative. It seems, indeed, doubtful whether scientists will ever define individually the material needs of these developing subjects sufficiently to enable the designer to forecast them, and as views of successive heads of departments will be found by no means coincident, he should plan his equipment on lines as broad as funds will allow.

The study of man is, apart from certain physiological experiments, usually confined to the work of medical schools, and if anatomical work is required on human bodies the planning and equipment of an institution are materially affected. Such requirements are outside the scope of this book. The descriptions in this chapter therefore refer solely to laboratory work on plants and animals.

Under " Geology " some reference will be made to physiography and mineralogy.

In comparing the requirements of these subjects with those of chemistry and physics, it may be stated broadly that their classificatory nature renders museum equipment a matter of great importance, often involving considerable outlay, but that otherwise, apart from special inroads into the subjects of the previous chapters, the fittings, and in the case of botany, zoology in the restricted sense, and geology, the services necessary, are simpler in character. Special attention is necessary in the matter of lighting owing to the prominence of microscopic study.

Individual apparatus required is often little, which carries with it a considerable reduction in the necessity for movement on the part of the students.

Botany

Recent developments in Botany are largely associated with plant physiology and pathology. The requirements for these subjects differ materially from those for morphology, with which botany was formerly chiefly concerned, and demand laboratories more akin to those for physics and chemistry.

The following rooms may be comprised in a botanical department :—

Elementary Laboratory	Pathology Laboratory
Lecture Room	Research Laboratory
Preparation Room	Chemical Laboratory
Museum	Mounting Room
Greenhouse	Incubator and Sterilizing Room
Advanced Laboratory	Library
Herbarium	Dark Room
Workshop	Store Rooms
Physiology Laboratory	Potting Shed
Mycology Laboratory	Staff Rooms

Elementary Laboratory—A steady light for microscope work is essential in a botanical laboratory, hence a north to east aspect is desirable, though if only used at specific times of day this condition may be modified. Unless the room is high and not of great width, top light is necessary to give sufficient central illumination. For this reason among others the subjects of this chapter are generally given a top floor in a composite scheme. The fittings of the laboratory are simple, and may consist of plain continuous benches 2 ft. to 2 ft. 6 ins. wide, devoid of drawers and lockers, 2 ft. 9 ins. being the minimum bench length for each student. The height is usually 2 ft. 9 ins. to 2 ft. 10 ins., but occasionally as little as 2 ft. 6 ins. This height decision is of some importance and must be considered in relation to the stools or chairs proposed. The bench top may be deal or hard wood. A covering of linoleum makes an easily cleaned bench surface, but is not universally approved. If the bench is not against a wall a ledge 2 or 3 ins. high at the back is desirable to prevent apparatus being pushed off. Sometimes a plate of opal glass about 6 ins. square is let into the bench near the front to assist in the examination of minute specimens or those requiring a white background. Sinks in the benches are not necessary, neither is gas for heating, but both should be provided in one or two accessible parts of the room. Special lights are required for microscope work about which some remarks will be found in Chapter V. For microscopes nests of cupboards about 9 ins. long, 6 ins. deep and 16 ins. high are required, unless the instruments are in their own portable cases, which may stand on shelves. This provision is sometimes made on the walls and sometimes by a limited amount of filling

FIG. 44.—Elementary Laboratory, Botanical School, Cambridge University.

in with cupboards under the working benches. Linoleum forms a very suitable floor covering. Fig. 44 shows the Elementary Laboratory at Cambridge University, the plan of which is given in Chapter VI.

Lecture and Preparation Room—The general description of a lecture room given on pages 32-7 applies to botany, except that the services may be much reduced, and a fume cupboard, down-draught, and electric supply (except for the lantern and lighting) may be dispensed with. The apparatus employed is also less than for most other subjects, hence few cupboards and drawers below the tables are wanted.

The preparation room will be largely concerned with diagrams, and in a small scheme will probably serve also as a mounting and store room. A large low table on which diagrams can be spread, with drawers for their reception below, together with shelves and a sink, are its chief fittings.

Museum—A public museum is often arranged chiefly with a view to the display of its contents in order to engage the interest of the casual visitor, and although such display may have advantages in arousing a serious interest sufficient to induce a wish to study, in educational institutions display should be subservient to teaching facilities. In a large collection a part may be specially allocated to students' work, while still leaving the main collections at disposal for general exhibition. The curator can alone formulate the requirements in the matter of fittings, but whatever his system of classification it will be found that the size of specimens will occasionally interfere with it and demand special cases or stands. Nothing is better for uninterrupted study than a series of bays formed by high cases at right angles to the window walls, between which a table case with a sloping glazed top is often placed, or an ordinary table with chairs in such bays as contain students' collections. If the room is wide enough central cases conveniently devoted to larger specimens may be placed parallel to the window walls down the centre of the room. From the above remarks it will be seen that a long gallery, lighted on both sides, makes a most suitable room for collections. The floor may be finished in any material conducive to silence. General diffused artificial lighting may be adopted, but some individual lights should be provided for students' use in addition. Glass shelves in the cases are advantageous in lessening obstruction to light by fittings, and for botany dead-black backgrounds are often advocated for the majority of specimens, though, of course, absorbing much light otherwise reflected. The materials for and elaboration of the cases will be usually governed by the funds available, but it is better to have a few well-made cases than a large number of inferior ones for collections of any value, because the entrance of dust not only entails labour but permanently spoils many specimens. Oak or mahogany are usually employed, advocates for these woods being fairly equally divided. The latter is less likely to warp, but the attrition of moving parts, such as drawer sides, produces after a time a fine red dust which is a disadvantage. Cheaper soft woods may also be used where economy is desirable. Drawers, which are seldom more than about 3 ins. deep, are sometimes covered by glass in a frame which can only be removed when the drawer is pulled right out, an operation controlled by some special key or mechanism. That used at Charterhouse School, which consists of a hook which engages in a slot in the drawer runner, preventing removal without the application of two special bent lifters, is shown in Fig. 45. Another arrangement, used in the Cambridge Geological Museum, is illustrated in Fig. 46.

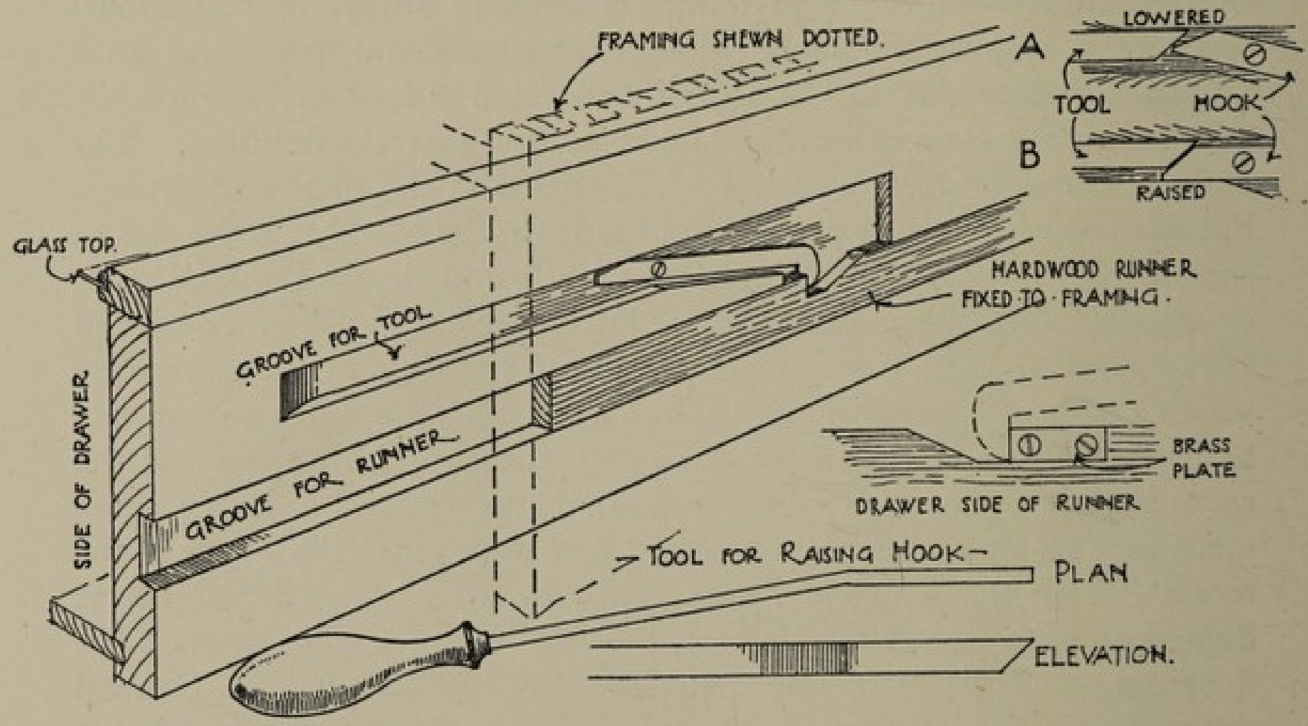


FIG. 45.—Method of Controlling Removal of Drawers in Use at Charterhouse School Museum.

The exclusion of dust is much helped by forming a raised bead on frames and a corresponding groove on doors or lids which close against them, shown in Fig. 47. The great importance of the dust exclusion has led to many devices, and since its entrance is due chiefly to differences of air pressure causing a current at times to flow into the cases, openings are sometimes made which are filled with cotton wool or other porous material to catch the dust while admitting free air access. Such arrangements, of course, require renewal of the absorbent material from time to time. When compressed air is available it might be worth while to consider supplying cleaned air to certain cases, to prevent the entrance of dust-laden air.

Cases should not be too deep, but the dimensions decided upon will be governed by the size of, and detail displayed by, the specimens, and an attempt should always be made to bring some of the specimens

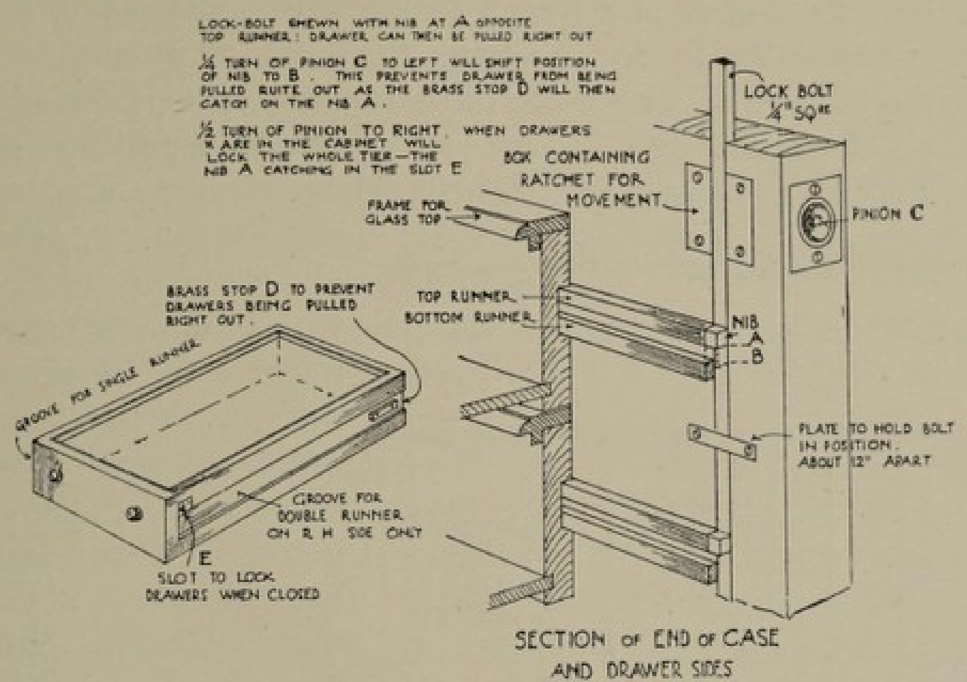


Fig. 46.—Method of Controlling Removal of Drawers, arranged by Messrs. Prime of Cambridge.

which contain much detail sufficiently near the glass to admit of examination by a hand lens without removal, which will often obviate opening the cases for students' work. In table cases the glass must be thick enough to stand the pressure of an arm leaning upon it.

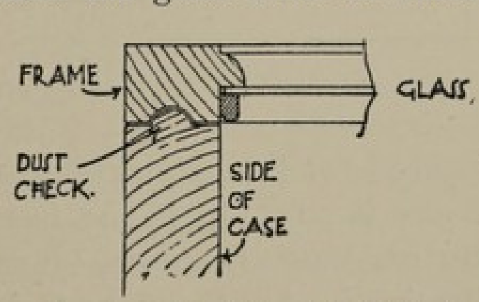


Fig. 47.—Dust Check to Lids of Museum Cases.

Greenhouse — Even where garden ground is available, the roof of the building is often a very convenient place for a greenhouse, and a flat open area in addition should be provided for other work in which exposure to sun and air is desirable. Though sun is required for many purposes, for others it must be excluded; hence if the work warrants it, two houses may be provided. In the botany school at Cambridge, the house for sunless work is sunk in the building a story below the roof, external access being provided to it off a small flat on the top floor of the building (see Chapter VI). The ordinary requirements in the matter of heating and water must be supplied, and naturally the impervious floor must be laid to a fall and drained. Sometimes a series of houses are required maintained at different temperatures. If heat is supplied from the central plant for the buildings, the provision of subsidiary heat to meet the possible closing down of such plant must be considered.

Fig. 48 shows the McGill University Botany Department Greenhouses, Montreal. This is a series of buildings some 75 ft. square, and consists of a laboratory about 75 by 18 ft. fitted with benches for wood and metal work for plant physiology, pathology, and genetics, a small part being set aside for stores and potting. This building is substantial, with stone walls. On its south side are three greenhouses about 58 by 18 ft., that in the centre being wider in part. The two outside houses have side benches, and central cement floors for experimental work on movable tables. The wider part of the central house is used for the display of plants arranged in natural groupings. This house is 20 ft. high, and has two depressed central beds. The section further south has a pool formed in cement for aquatic plants. Steam heating is used throughout the houses, which supply not only the needs of botanical students but also those in other branches of biology in adjoining departments.

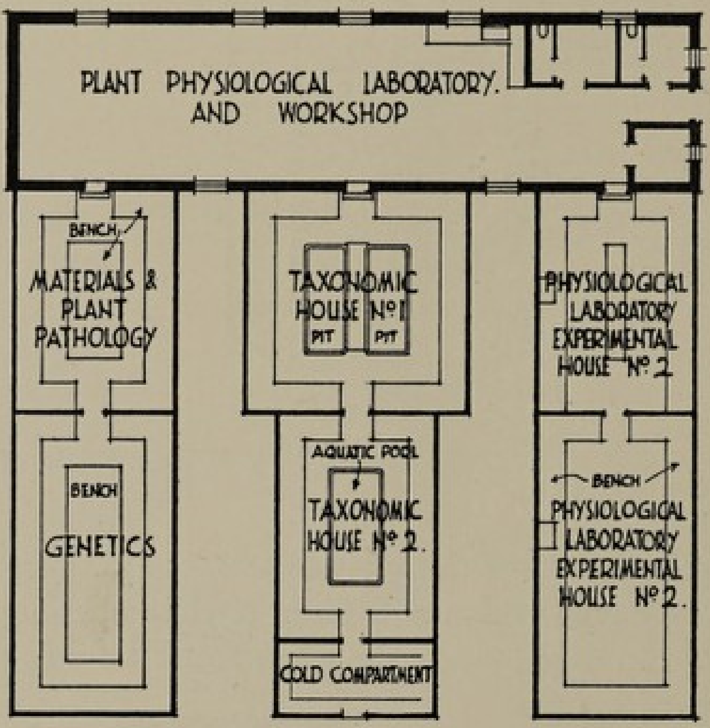


FIG. 48.—McGill University Botany Greenhouses.

Advanced Laboratory—An advanced laboratory will probably be used chiefly for morphology—work on plant structure—but in the absence of other rooms for advanced work, plant physiology and chemistry may also be studied here. For morphology the fittings will not differ greatly from those of an elementary room, but microtomes for cutting sections will involve a rather more liberal supply of water and gas on some of the benches, in connection with the making of slides. The higher microscope powers used will necessitate more attention to efficient lighting, both natural and artificial. In connection with the former, windows should never be divided into small squares when transmitting light for microscope work, as the image of the bars will appear in the picture and may be found difficult to avoid. If physiological and chemical botany are projected, the room should be fitted more like a physical or chemical laboratory.

Herbarium—A herbarium, unlike a museum, is never arranged for display; it forms an immense plant dictionary in kind, the dried specimens being usually mounted on cards and kept in folders of about foolscap size, though some are necessarily larger. These are housed in nests of pigeon-holes a foot or so high, in which the folders lie flat one upon the other. The exclusion of dust from these specimens is most important, and as the doors are hardly large enough for beads, as described on page 83, they should be rebated and fitted very accurately. With a large collection, the arrangement of the cases to form bays, with a window in each, may be followed, and a table, or at least a continuous desk on which the specimens can be studied, should be provided beside them. The natural lighting should be ample, but sunlight should be excluded, if not by the design of the building, at least by the provision of blinds, to prevent damage to the collections when exposed.

Workshop—A general repair shop is necessary in any large scheme and should provide for small joinery work, and for glass blowing, such as can be done on an ordinary blow-pipe table. If much physiological work is done, arrangements for light metal work, as already detailed on page 71, will also be advantageous.

Soil Analysis—The analysis of soils is a chemical matter, but obviously concerns botanical problems. Apart from the drying and incineration of soils, which require a good gas supply but are otherwise matters for apparatus, the main fixture is likely to be a special fume cupboard supplied with Kjeldahl flasks in which extractions take place in boiling acids. These flasks should discharge their acid vapours into a special pipe with a series of holes graduated in size. This pipe resembles a glazed drain pipe, and is attached at one end to the cupboard flue.

As a strong draught is necessary this flue should possess an exhaust fan. Fig. 49 shows such a pipe in a fume cupboard. This room usually requires also an ordinary working chemical bench, large sink and

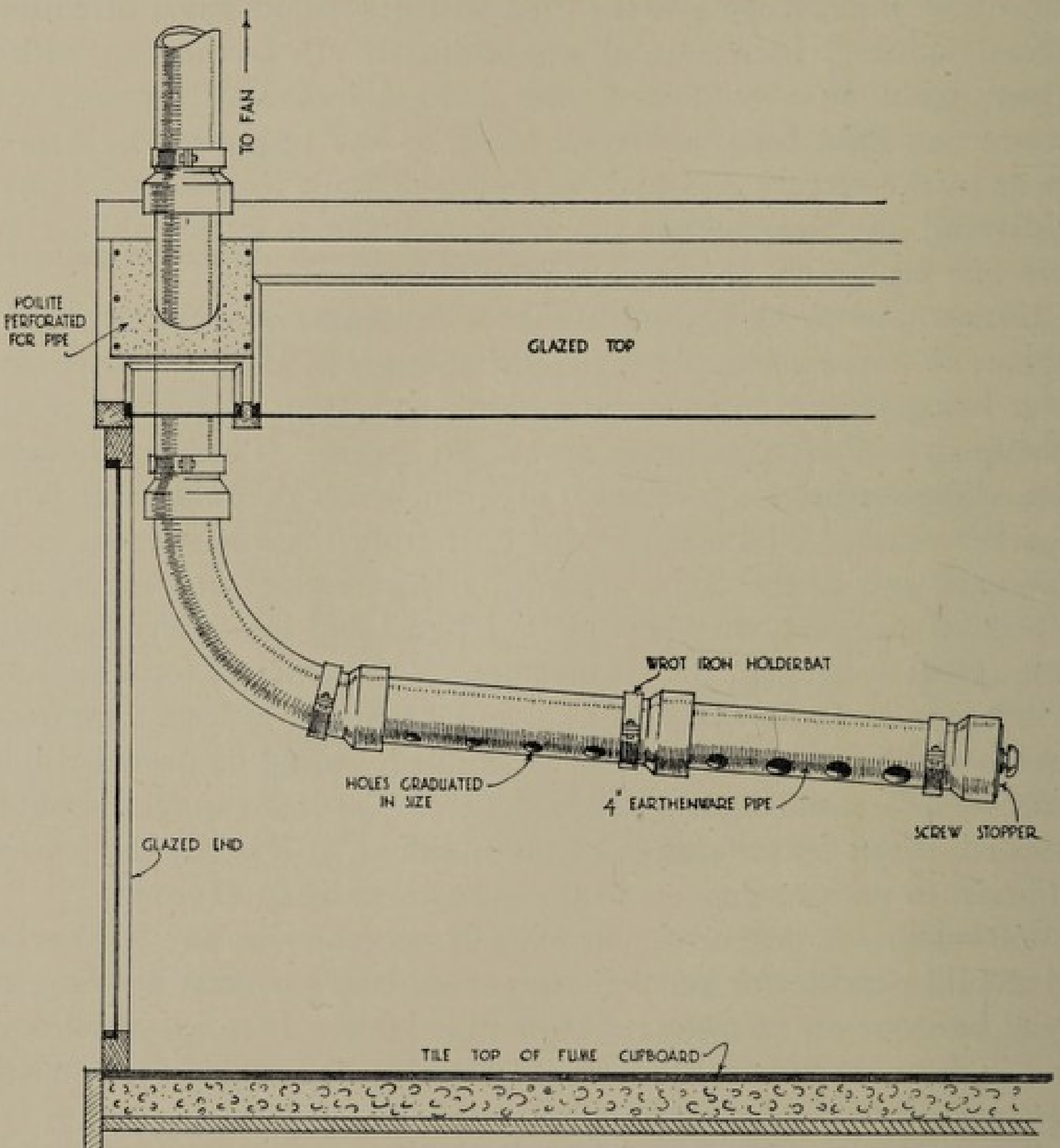


FIG. 49.—Kjeldahl Fume Cupboard.

shelving. If soil samples are to be kept here strong bins will be necessary in which such samples can be stored.

Research Laboratories—Special fittings for laboratories for botanical research are chiefly associated with physiological and chemical work. For the former, two water services to give both low and high pressure from roof tanks and the public mains respectively will be found useful.

In addition to ordinary benches, a table with a raised edge for mercury experiments, and a bench with an incombustible top supplied with gas, will also be necessary, while power leads for running small motors and the like should be provided. Sometimes a little forcing house, such as could stand on an ordinary table, is required in the laboratory itself for physiological research. Chemical botany demands the equipment of an ordinary chemical laboratory, but the extent and variety of glass apparatus and reagents is usually less than for general chemistry. Accommodation for balances must also be included. As work on living plants is conducted in these rooms they should be near the greenhouse.

Minor Rooms—Dark rooms are required in a botanical department; these may be necessary for photographic purposes, but are also required, in connection with physiological research, for optical work. For mounting specimens a room is sometimes specially provided, and should possess plenty of table space and a gas and water supply. For incubation and sterilization, incombustible benches are required for ovens, and for heating under pressure, which is conducted in a large cylindrical vessel on a bench, which should only be raised slightly above the floor.[1] Flues and hoods are desirable over such apparatus. Storage is not so necessary for botany as for some other subjects, but should be considered in the light of the trend of the department's work.

A potting shed, usually an outbuilding, is required for storing soil and flower-pots. Fittings may consist of a strong rough bench under a window for potting, with waste boxes, possibly with external hopper openings for spent soil, bins for fresh soil and shelves for pots and tools.

Zoological Subjects

Under this heading will be discussed zoology, physiology, pathology, bio-chemistry, and pharmacology, also bacteriology and histology, which enter into these subjects. The laboratory requirements of these sciences have so much in common, and so little crystallized opinion upon differentiation is obtainable, that it seems hardly practicable to deal with them separately from the point of view of this book. Hence the author has contented himself with an attempt to state shortly for the benefit of the

[1] See also pages 98-9, Incubator Rooms and Autoclaves.

layman what these sciences embrace and then to treat their needs as a whole.

Zoology, strictly speaking, covers the whole field under discussion, but the term is now accepted as embracing the study of animals from which experiments on higher living vertebrates are excluded. What is now known as "experimental zoology" is really physiology applied to animals as contrasted with human physiology. This science is therefore much concerned with anatomy, man excepted, and a great deal of its studies are of a classificatory character. Museum collections thus rank as of great importance, a large proportion of such collections being animal skeletons. Animal dissection, usually involving nothing larger than a rabbit, again forms a large part of a zoological course. Research, however, may be concerned occasionally with large animals. Histological work demands considerable facilities for the use of the microscope. Calls upon physical and chemical science are small. Supply services are inconsiderable, though a good deal more in the matter of water supply and drainage is required than for botany.

Physiology—Under physiology, body functions are studied, muscle and nerve action, respiration, blood circulation, digestion, nutrition, metabolism, and the special senses. The requirements of physiology involve the applications of physics and, in a lesser degree, chemistry; this means that many rooms resemble those of a physical more than a zoological laboratory. Histological work often remains more important than any other, but kymograph work demands a good deal of space, and from a chemical standpoint, analyses, particularly gas analyses relative to blood tests, are often made. Operations, again, usually confined to small animals, demand a suite of small rooms on the lines of a hospital theatre. Supply services for physiology and the remaining subjects of the zoological group are considerable, and may include gas, water, electric power, compressed air, vacuum, and refrigeration. The physical or chemical trend of the subject will be a guide as to the extent of the first three services and refrigeration is necessary for all.

Pathology is the study of disarranged functions due to disease—specific, parasitic, bacteriological. Naturally pathology is much concerned with operative surgery and microscope work is extensive. Bacteriology is largely associated, of course, with pathology, and owing to the effect of chemical fumes on certain bacteria the chemical arrangements of the department require consideration. To avoid sepsis, pathological work, more especially in the operating theatre suite, demands conditions similar to those found in a hospital. Quarters for living animals may be very considerable.

Bio-chemistry is chemistry applied to life processes, and demands the facilities of a chemical department, but a good deal of biological work proper is necessary. Special facilities for dealing with live matter and for studying changes produced in animals involve arrangements essentially different from those of an ordinary chemical department. Bio-chemistry should be in close touch with physiology. Animal quarters are again necessary.

Pharmacology—The old materia medica days of pharmacology have given way to a wider conception, and this science now deals with the reaction of living matter to chemical changes in its environment. It thus connects the other branches of biology. Its requirements are necessarily mainly chemical, though again showing a biological influence. Even here a supply of animals for experimental purposes is necessary, though on a smaller scale than for pathology.

List of Rooms for Zoological Subjects

The following list of rooms possibly required implies, of course, merely a selection for any one subject.

It is not proposed to describe the rooms in this lengthy list in detail, except in cases in which the fittings are of some special nature which have not been covered by previous descriptions. As far as the laboratories are concerned a general description of fittings for biological work must suffice, leaving the reader to attach the physical or chemical additions as necessary from information given in earlier chapters.

Vertebrate Zoology Laboratory
Invertebrate Zoology Laboratory
Mammalian Experiments Laboratory
Histology Laboratory
Bacteriological Laboratory
Pathological Laboratory
Physiological Chemistry Laboratory
Biochemical Laboratory
Physical Chemistry Laboratory

Dark Room
Constant Temperature Room
Incubator Room
Titration Room
Plating Room
Photographic Room
Centrifuge Room
Refrigerator Room
Autoclave Room

Pharmacological Laboratory
Metabolism Laboratory
Kymograph Room
String Galvanometer Room
Kjeldahl Analysis Room
Blood Analysis Room
Museum
Lecture Room
Preparation Room
Aquarium
Insectarium
Electric Measurements Room
Balance Room
Workshop
Electrocardiograph Room
Extraction Room
Combustion Room
X-Ray Room
Microphotographic Room
Section Cutting Room
Instrument Room
Dissecting Stock Room
Washing-up Room
Mounting Room
Diagram Room
Projector Room
Store Rooms
Research Rooms
Library
Staff Rooms
Operating Suite
- Theatre
- Anæsthetic Room
- Sterilizing Room
- Recovery Room

Animal Suite
- Food Kitchen
- Food Store
- Animal Pens
- Isolation Room
- P.M. Room

Destructor

Laboratories—The microscope plays such an important part in the work of these subjects that benches suitable for those instruments form a feature in most laboratories, and in many cases such benches and perhaps a few strong tables will be all that is necessary. Such benches have been discussed under Botany. Animal dissection, however, involves the use of a good deal of water, hence more sinks are necessary, one between two students for such work being a great convenience. For the disposal of waste matter the provision of a slop sink of the ordinary domestic type with flushing cistern will be found very useful. This must of course be connected to the soil drains. The bench length per student should be greater, as notebooks and books of reference used during dissections are more subject to damage than in botany, and 5 ft. will be appreciated if obtainable. Locker requirements will vary with the subject and the status of the student; for elementary work individual apparatus is little apart from chemical work. The adoption of a movable unit locker beneath but independent of the bench-top has much to commend it, admitting of some elasticity in arrangement and allowing good knee-hole space alongside. Such lockers can have a special compartment designed for a microscope, often either the property of the student or in his specific care for a considerable period (Fig. 50 shows such a locker arrangement). Lighting, both natural and artificial, is of course of paramount importance. Some remarks on the latter subject will be found in Chapter V. A point sometimes overlooked in arranging natural lighting is that for the study of liquids the microscope stage must remain horizontal and requires the reflection of unobstructed sky area in this position.

Histological work occupies a subsidiary position in bio-chemistry and pharmacology, and the laboratories for these subjects, or at least

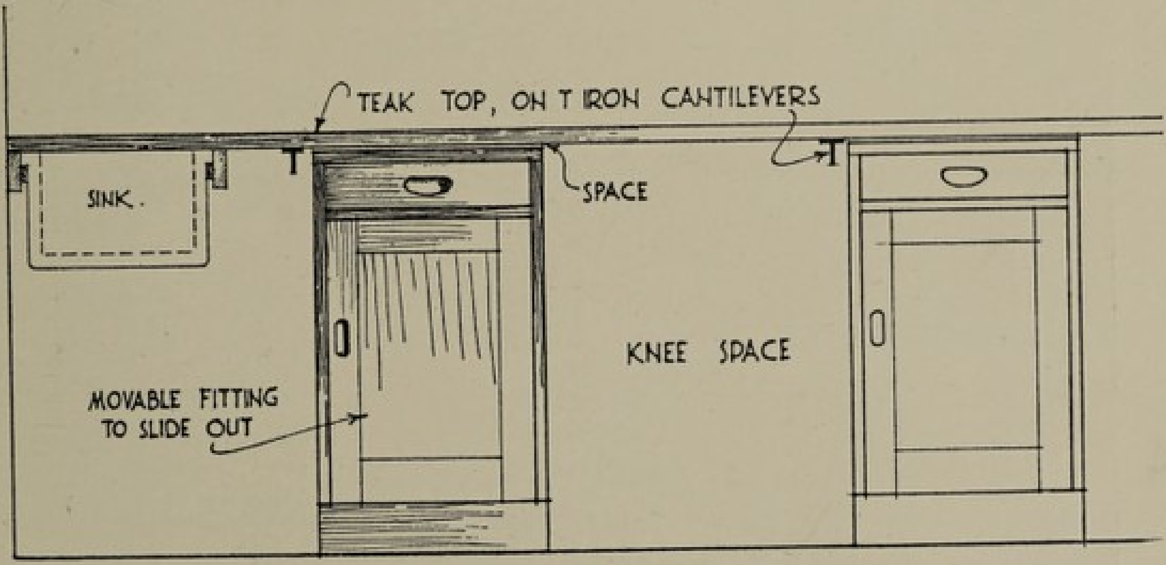


FIG. 50.—Biology Lockers.

most of them, resemble in their fittings ordinary chemical laboratories very closely.

Fig. 51 shows a laboratory for general zoological work.

Kymograph Room—This may be termed a laboratory, but merits separate description; it is devoted chiefly to recording drums which are covered by a thin film of lamp black. These are made to rotate on a vertical axis, and records of pulsations are registered on them by a needle in much the same manner as on a barograph. Sometimes these drums are operated by clockwork, when the tables supporting them can be isolated and movable; but clockwork kymographs of any accuracy are very expensive, and more usually they are driven by a motor from a long horizontal shaft. This involves a long fixed bench 2 to 3 ft. wide, and usually 2 ft. 9 ins. high, students working on one side with the shafting on the other, generally just above the bench, but sometimes below it or again sometimes near the ceiling with appropriate belting to pulleys. The minimum bench length per student is 2 ft. 9 ins., and more is desirable.

Means for smoking the drums, necessary for each experiment, is

FIG. 51.—Laboratory for General Zoological Work.

required. This is done by a smoky flame under a hood which ventilates into a flue. Fig. 52 gives an illustration of such a room with double benches.

String Galvanometer Room—The only fittings required in this room are a number of piers or shelves free from vibration upon which galvanometers can be placed. To secure these conditions such a room is often on a basement floor, and as the work requires a darkened room the location as regards daylight is not important. Owing to the number of loose electric wires usually suspended between apparatus a reasonable height in the room is desirable. Probably a number of enamelled hooks in the ceiling to aid the slinging of these wires will be appreciated.

Blood Analysis—This is mostly concerned with the detection and estimation of gases in blood, and reference may be made to gas analysis under Chemistry, page 52.

Museum—A zoological museum will be largely concerned with skeletons set up in glass cases which vary greatly in size. Some remarks

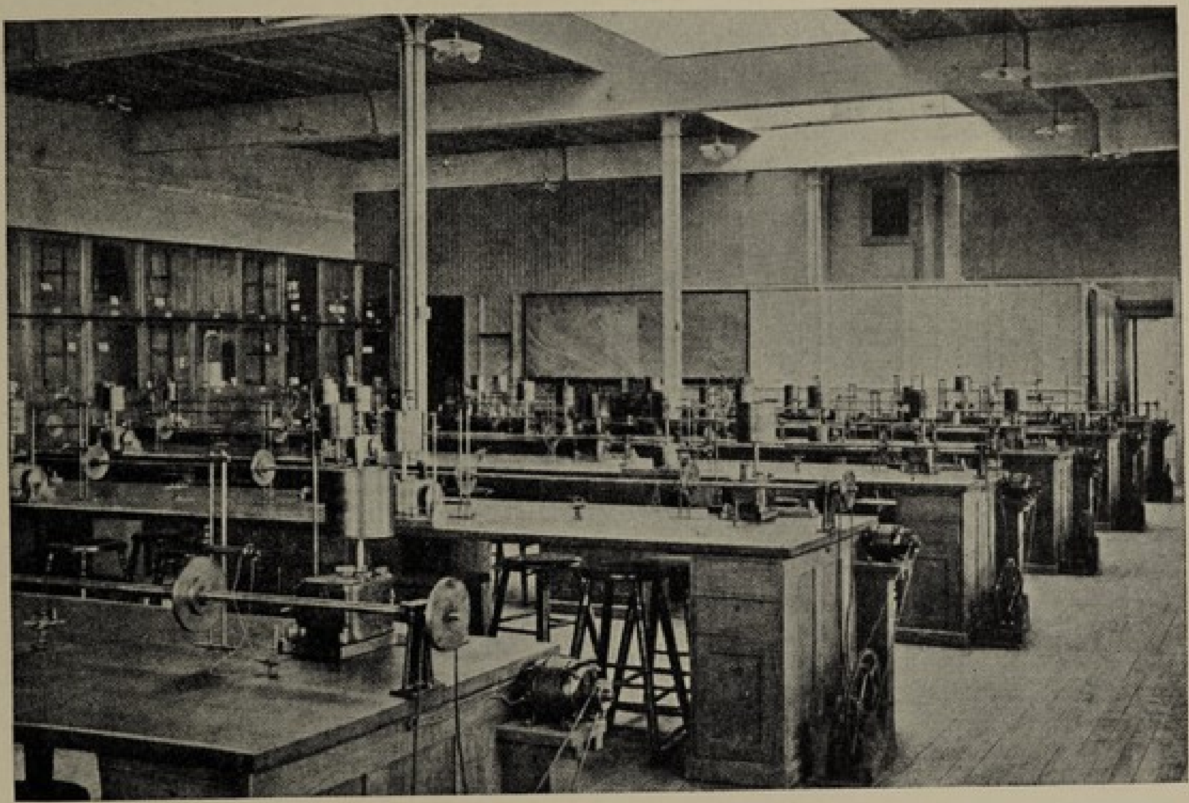


FIG. 52.—Kymograph Laboratory.

on this subject have been made under Botany, pages 81-3. High wall cases are usual, the centre of the room being occupied by detached cases glazed on all sides, which may occasionally be as large as 10 ft. each way. Such large glass fittings merit not only structural considerations, but very definite agreements as to responsibility during transit and erection. The museum may also be concerned with animal life history and environment, demanding cases with opaque and substantial backgrounds. Fig. 53 shows the Zoological Museum at University College, Bangor.

A pathological museum, on the other hand, will be almost exclusively devoted to specimens in glass jars preserved in formaldehyde, glycerine or other liquid, which are best arranged on glass shelves, supported by strong metal stands. Given thick plate glass, the metal supports can be largely confined to one vertical plane holding cantilever brackets which enables the jars to be readily seen and removed, and introduces a desirable air of lightness into a room usually well filled and possessing avenues of limited width.

Small blinds or curtains may be necessary to prevent damage to certain specimens by sunlight. The use of much formaldehyde de-

FIG. 53.—Zoological Museum, University College, Bangor.

mands the provision of a separate well-ventilated room to prevent injury to the museum assistant.

Some table space should be provided for students' use, and a limited amount of drawer and locker space may be needed for special specimens or students' collections to be handled for minute study.

Good lighting is of course an essential of any museum, and if natural top light is not obtainable the room should be high to prevent its contents seriously obstructing light from side windows.

Lecture and Preparation Rooms.—For general lecture purposes a theatre such as would be suitable for physics or chemistry is desirable for zoological subjects, though the elaboration of drawers, cupboards, and services to the lecture table described under these subjects are unnecessary for zoology proper, and for other branches vacuum and compressed air services may take the place of high-power electric leads.

For physiology direct current, and also alternating if available, should be provided, and a fixed galvanometer and screen are necessary. Sometimes a tank is arranged on the top of the table with one or more glass sides, for live specimens in water. The fittings of the preparation room will be governed by the character of the lecture room. Considerable space for diagrams is also necessary; these may be kept flat in drawers, may be rolled like maps, or suspended by hooks attached to a metal strip along the top of the diagram, from a central horizontal rod, in a series of cupboards about 5 ft. deep and 6 ft. 6 ins. high, with sliding doors. The diagram surface is placed at right angles to the doors, and although fifty may easily be housed in every 3 ft. length of cupboard, the subject can quite readily be seen by pushing adjoining diagrams aside.

Aquarium—The development of small amphibious creatures and their preservation alive for future use requires small tanks with water supply and often some aerating device to keep the water fresh. Two rooms may indeed be desirable, one to act as a store which may be in the basement, the other as a working room for observations. The latter will require tanks which may take the form of large shallow sinks of glazed stoneware, or wood lined with sheet metal, or large bell-shaped glass jars may be preferred.

At the Imperial College, South Kensington, the water is kept in slow constant movement by the stirring action of glass plates attached to a lever worked by an intermittent syphon. If a compressed air service is available air may be forced into the water through a rose opening. At Cambridge it has been found possible to keep marine animals in filtered sea-water for three months without renewing the supply. The tanks used in the laboratories at Cambridge for the purpose of storage are formed as a continuous row against the wall of the room, and are built in concrete with round bottoms and hinged ventilated wooden covers. Fig. 54 shows a section through these tanks which have vertical divisions of concrete about 3 ft. apart, and a small connecting pipe at the bottom of each, so that the whole system may be flushed out into a drain on the external wall by means of a water supply at the other end. A connecting opening is also provided near the top of the divisions as an emergency overflow.

Professor Downs, of Alberta University, has experimented with various forms of tank for keeping frogs, and finds their lives best preserved when a running stream of deep cold water, coupled with a mud bank, kept moist, is provided. His tanks are of concrete, 9 ft. by 5 ft. 6 ins., and have a concrete shelf.

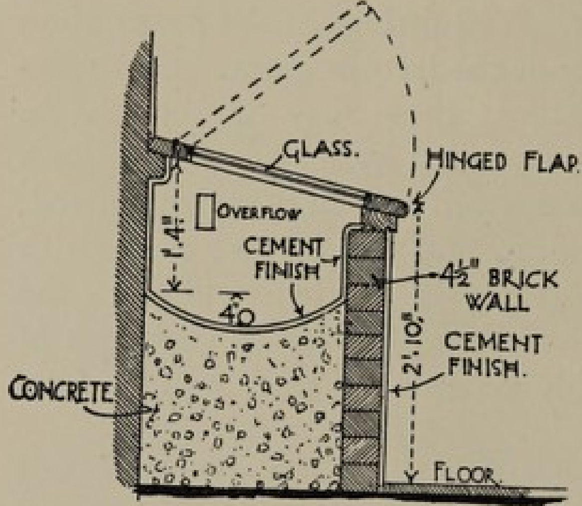


FIG. 54.—Amphibia Tanks for Stock, Cambridge University School of Physiology.

Insectarium — Insects require a room containing compartments separated by gauze of metal or fabric generally arranged on stands or shelves at table height. For flies little more is necessary, but many insects require plant life which involves greenhouse conditions. A rain-water supply should be arranged for this room from roof tanks or other means. If tanks in this situation cannot be provided, such water may be pumped to a small tank in the room. Sometimes when a compressed air service exists this may be utilized for raising the water. An access lobby to admit of double doors is sometimes thought necessary for an insect room. Temperature regulation may be important, and if more than one temperature is required of course complete separation of the compartments is necessary.

Electrocardiograph Room—There will be no fixed fittings here deserving comment. Electric current at about 12 volts will probably be necessary, and as variations are detrimental to experiments, this current is usually D.C. from a set of accumulators. These, however, may be part of the apparatus equipment.

Extraction Room—Sometimes it is necessary to make extracts from a large bulk of material, perhaps more particularly in bio-chemistry and pharmacology. The fittings in this room are a matter of apparatus, such as grinding and mixing mills. These may be of some weight, hence a solid floor finished in cement or hard asphalt is desirable and the question of sound proofing may arise. Electric power needs may be preciable.

X-Ray Room—This should be fairly lofty, both to admit of the safe disposition of high-tension wires and give good air space. Means of darkening the room and good ventilation are important. Relegated in old days to basements, X-ray rooms now merit a good position and plenty of window space. To prevent the danger of sterilization which may make its effect felt in time in surrounding rooms, protection to walls, ceilings, and floors (if rooms are below) is necessary. Formerly lead was used for this purpose, but a thick coat of plaster, consisting of barium sulphate and portland cement, is now usually employed, sometimes mixed with sand, though if the sulphate (barytes) is graded sand may be dispensed with. The thickness of this wall coating necessarily increases with the voltage employed, and must usually be more than that of ordinary plaster.[1]

Constant Temperature Room—This term is very ill-defined. It may apply to a working room of some size with benches and sinks which is kept at an approximate temperature, usually higher than normal, by means of hot pipes or other ordinary means of heating with or without special wall and door insulation. It may refer to a small storage room carefully insulated, kept at a fixed temperature by thermostatic regulation. Again, it may denote a room for physiological experiments involving an elaborate humidifying plant and extract ventilation. Little need be said upon the first type mentioned; usually it has no window and relies on electric light when some means of introducing fresh air is necessary. If a window is provided it must be a double window to prevent heat losses.

The second type usually consists of a windowless room 7 or 8 ft. square and some 8 ft. high, suitably built, say, with 9-in. brick walls with a lining 4 ins. thick of compressed granulated cork slabs. The ceiling is similarly lined, and this and the walls may be plastered as a finish. The floor may be finished with similar insulation, and if of joists these should be filled in with some non-conductor, such as slag wool. The door must be some 6 ins. thick, composed of two wood frames with cork slabs between them. It is generally bevelled to shut

[1] *R.I.B.A. Journal*, 12th July, 1930, p. 646.

on bevelled jambs to the frame, and is closed by a massive lever handle which can be operated on both sides. Doors, frames, and fittings for these rooms can be purchased complete from cold-storage equipment makers. A small, simple type of adjustable opening in the ceiling is necessary for ventilation. Outside the room proper and similarly insulated, and with a similar door, is a lobby or air-lock, generally the width of the room and about 3 ft. deep. Here the controls for the temperature are usually placed. Electric heating lends itself to accurate regulation, and is widely used, generally with some patent form of thermostat, small electric radiators being placed on the walls above the floor. Round the walls open shelves—as would be used in a linen cupboard—about 3 ft. high are placed for the reception of cultures and the like. These rooms are usually required to be kept at 37° C. (98·4° F.), but sometimes other temperatures are necessary, e.g. 22° C., for which alternative rooms must be provided. Electric light is required in the room, and pilot lights are often placed on the central panel.

The third type of room is more rarely found, and its equipment requires highly specialized advice. Here both temperature and humidity require to be capable of variation and exact regulation, the former possibly through some 70° F. and the latter between perhaps 20 per cent. and saturation for a given temperature. Air is first heated by passage through metal tubes heated by steam or other means, and passed into a conditioning chamber, where it is humidified by a water spray operated by a pump and motor. It is then passed to another chamber, where it is heated to the required temperature, and by a fan passed into the experimental room in which the physiological tests to be made on persons or animals are to take place. Arrangement must be made for air extraction from this room for return to the plant, and a refrigerating plant (see Chapter V) will be necessary for cooling the air and condensing the moisture. Very thick cork insulation and lagging are necessary for the rooms and pipe ducts, to prevent interference by external temperature conditions. Condenser cooling water required is considerable. Such a plant for operating a good-sized experimental room may require 1000 gallons of water an hour, usually of course pumped to a cistern for re-use, and 10 to 20 horse-power for the various motors will be necessary.

Incubator Room—This is a constant temperature room of the second type, but incubators complete with thermostats are often placed in laboratories as pieces of apparatus which may be sufficient for work on a small scale.

Titration Room—Here volumetric analysis is conducted by the use of solutions of standard strength kept in large bottles (aspirators) on shelves and feeding burettes—long graduated tubes—whence measured amounts are run into liquids under test (Fig. 21, p. 42). A long rather narrow room, given a good window, with a narrow bench each side and strong shelves over is suitable. A sink and water supply are necessary. It is a great convenience to be able to fill the aspirators from vessels below, and if a compressed air service exists, this reduced to a pressure of about 2 lbs. should be supplied to this room.

Plating Room—Plating consists of the preparation of cultures of bacteria in media placed on flat impervious surfaces such as sheets of glass. The room should be surfaced like an operating theatre with terrazzo (fine mosaic) or plastered enamelled walls with rounded angles at junctions. Fittings should be few, wall benches for work should be clear of walls and supported on brackets. A sink and water supply are required, and gas may be necessary for warming and drying vessels. Periodical sterilization of this room by formaline spray or like means necessitates the reduction of metal fittings to a minimum.

Centrifuge Room—A centrifuge is a piece of apparatus in which a motor-driven drum rotates on a vertical axis at a very high speed for the purpose of separating deposits in attached glass vessels. If large, these machines are sometimes placed in a pit to meet the rare eventuality of disruption, but they are frequently used in the laboratory itself or in one of its service rooms. A solid floor with cement or asphalt surface is desirable. Centrifuges differ greatly in size and hence in power requirements.

Refrigerator Room—This is an insulated room with special door, and fitted with shelving similar to a constant temperature room of the second type described on page 97. This subject is dealt with in Chapter V.

Autoclave Room—Autoclaves are large jacketed drums either vertical or in large sizes horizontal, for heating under pressure for sterilization or other purposes. Heat may be supplied by gas, electricity, or steam. They may be placed with other plant such as centrifuges or in service rooms if a special room is not called for. The floor of the room is usually of cement. If gas is used for heating, autoclaves should stand in a recess supplied with a flue or under a ventilated hood. Means for cleaning easily, as by placing this room near a washing-up room for apparatus, is desirable.

Mounting Room—The setting up of specimens, particularly in connection with museums, may demand much space. The character of such a room will vary from that of a preparation room to a workshop, according to the magnitude of the operations necessary. A very large low table will be an asset, and can be used below for storing diagrams where a separate room is not provided.

Projector Room—Illustrations of movement form an important feature of biological teaching. In public institutions structural regulations made by public authorities have to be complied with for cinematographs, to protect both the audience and operator in the event of fire. The projector lantern must be placed in a separate fire-resisting enclosure, giving external means of escape for the operator. The projector is placed either in a compartment behind and above the audience, or behind and on about the level of the lecturer, in which latter case the picture is seen by transmission through a translucent screen involving some loss of light, and though often more convenient and more readily associated with other service rooms, the front position is more usual for large displays. Growth in the use of " non-flam " films will simplify the arrangements necessary, but at present these films are not so lasting as the ordinary type and hence are not in universal use.[1]

Operating Suite—Though experimental work on animals involving surgery is often performed in the laboratories, its extent, in physiology and pathology particularly, often renders an operating theatre and accessory rooms necessary. The design of the theatre will depend upon whether the institution is devoted only to research or embraces teaching. In the latter case the operating table must be partly surrounded by steeply raised staging with seats and standing space.

A section through such staging in a small room is shown in Fig. 55.

If students are not to be provided for, the theatre may of course be smaller, but must give room for a table of reasonable size, sink, hand-

[1] British Association, "Educational and Documentary Films," 6 pages. 1930, Spottiswoode.

basin, shelves, and trolley for instruments, and if no other rooms are provided space must be found for sterilization, preparation and recovery. Sinks and basins may be conveniently placed in a bay to the theatre as in modern hospital practice.

Sterilizers are desirably put in a separate small room adjoining, but not part of, the theatre.

An anæsthetic room may be small—sufficient for the movement of two people and the operating trolley. A recovery room is necessary, in which animals may be left until sufficiently normal for removal to their pens. The planning of these rooms may follow that for similar requirements for human patients, but generally on a smaller scale, as it is very seldom that the larger animals come within the work of the theatre.

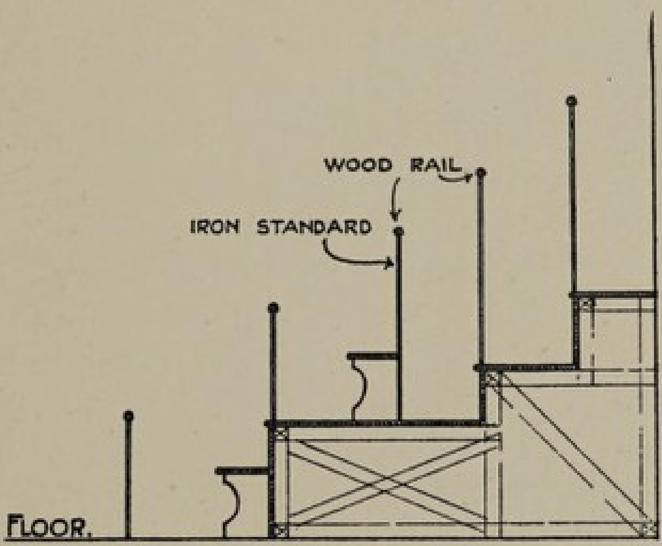


FIG. 55.—Section Through Operating Theatre Seating.

Terrazzo makes the best floor, and should have rounded angles to junctions with walls and rounded corners. Fine terrazzo also makes an excellent wall surface, though white tiles are common, and painted plaster may well serve above dado height. Doors and windows should be devoid of mouldings. In order to enable the various services required on the operating table to be brought up without crossing the floor or preventing access to the table on all sides, these may be carried in or below the floor, and brought up through the centre of a short isolated pillar placed close to the table's usual position. This pillar may be finished in terrazzo with rounded floor corners. This arrangement enables the floor to be hosed down by avoiding holes for pipes. Good natural lighting from the north is necessary to the theatre, though the modern tendency is to operate more and more by artificial light even in daylight.

The necessity for keeping up the theatre temperature at times when the central heating plant is out of use should not be overlooked.

Given a steam supply for experimental purposes this may be effected by steam-heated radiators, either solely or in the summer months only. An alternative is to link the theatre for warming with the domestic supply boiler, preferably through the medium of a calorifier. The means adopted for heating sterilizers will be governed by local conditions. If steam is always available this is convenient and economical. Usually electricity proves very costly for heating the larger plant, and the renewal of heating elements is not an infrequent necessity. Gas requires a flue for combustion products, but is readily controlled. Frequently gas forms the best heater for the larger water containers and electricity for the instrument sterilizers. Examples of the provision for operations will be found among the plans in Chapter VI.

Animal Suite—Quarters for animals, some normal, others under observation as the result of experiment, are needed, and the stock kept may be quite considerable involving a separate building. Examples of recent animal houses will be found in Chapter VI. Sometimes large animals, such as sheep and cows, have to be arranged for, in which case regular stabling and fodder quarters must be supplied with stalls, say, 12 by 12 ft. to 8 by 8 ft. and 10 ft. high. More usually requirements are confined to small animals, such as rabbits, guinea pigs, small dogs, and rats.

Where land is available it is highly desirable to give these animals generous space for runs, and to let their surroundings approximate as closely as possible to natural conditions.

Where a separate building and space for runs is not possible, a flat roof may often be used for cages in tiers facing a corridor with a sunny aspect furnished with a series of movable doors so that this may be thrown open to the animals in suitable weather. Reasonable window area should be given, and gauze screens to admit air while excluding flies may be desirable, e.g. in the P.M. room. A room is required for food storage, which must be kept dry, and another for weighing out and mixing, as a food kitchen. Isolation quarters may be necessary, and a P.M. room is not an infrequent addition to the suite which, if large, may comprise attendants' living quarters. Means for disposing of dead animals must be provided; usually this is effected by a special incinerator conveniently placed with the heating plant to this suite. The practice of sending dead animals down a lift to be destroyed in the central boilers should be avoided if possible.

The construction of the cages merits thought. Obviously space is economized by forming groups of cages of a given size. Sometimes these are of concrete cement faced with drainage arranged to a channel in front, but such cages are seldom impervious to liquids. Another and probably better scheme is to arrange the cages in tiers on metal stands with movable bottoms which can be taken away, cleaned, and

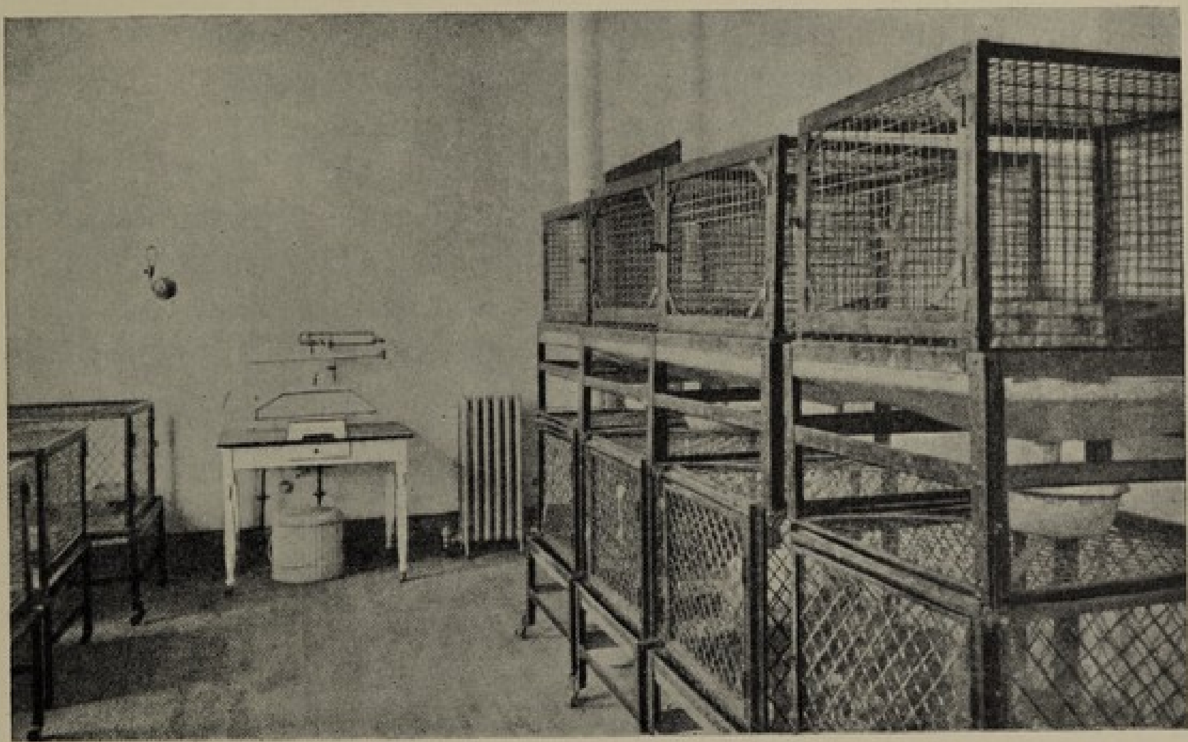


FIG. 56.—Animal Cages for Metabolism Experiments.

sterilized. These bottoms are galvanized iron trays with sides high enough to prevent food and bedding being pushed out by the animals, the rest of the cage being of stout galvanized wire.

Sometimes a large number of small animals are kept together on the floors of the rooms. In such cases pens may be made of impervious sheets with angle bolts at each corner. This enables them to be readily taken to pieces for cleaning and storage. Stout galvanized iron sheets have been used, but ply-board with the internal or both faces in metal would be lighter.

Special types of cages are also necessary for animals under experiment, the bottoms sloping to an outlet connected to some receptacle in which excreta can be collected and subsequently weighed or examined, as illustrated in Fig. 56.

Sometimes small animal cages are slung in groups from the ceilings which admits of the ready cleaning of floors and prevents attacks by rats.

Geology

Apart from museum accommodation, special equipment for the teaching of geology is usually confined to institutions of university standing. Physiography, however, which forms a link between geography and geology is—or should be—largely taught in schools. Apart from museum demands, the requirements of geology in the matter of special fittings are not great. The subject falls into three branches: stratigraphy—the study of the formation and occurrence of rock strata involving much map work; palæontology—the study of fossils; and petrology—the study of rocks both from a mineral and chemical standpoint. This last branch will include the study of minerals themselves, unless a separate mineralogical department is provided. A geological department may comprise the following rooms:—

- Physiography Laboratory
- General Geological Laboratory
- Lecture Theatre
- Museum(s)
- Map-drawing Room
- Advanced Laboratory (Petrology)
- Advanced Laboratory (Palæontology)
- Chemical Laboratory
- Rock-cutting Room
- Research Rooms
- Dark Rooms
- Unpacking and Mounting Room
- Store Room
- Library
- Staff Rooms

Physiography Room—The practical illustrations of natural phenomena in the domain of physical geography and dynamic geology make a most interesting study which lends itself to simple exposition. Hence this work generally forms a part of a junior school course and is often half laboratory half classroom instruction. The effects of rain and rivers in the production of surface features may be investigated by a special form of large shallow lead-lined tank or sand table, which may be 10 or 12 ft. long and requires a water supply. Supplied with the table are moulding trays in which the surface features of the "ground" to be experimented with are modelled in sand. The action of rain, streams, and waves, and the formation of strata of sediment can be readily shown, and the tray then removed so that others can use the table.

Another feature of this room is a window facing due south with a table or bench immediately under it upon which work demanding the use of a drawing board can be done, and it is important that this window be of plate glass and devoid of unnecessary bars. Maps will be much used for demonstrations. These if on rollers may be hung rolled up vertically by hooks in a cupboard when they will take remarkably little space, or may be stored horizontally on pairs of brackets or shelves. Tables may have flat tops, for work on drawing boards. Another feature of this room may be a black globe about 2 ft. in diameter, upon which chalk can be used, suspended from the ceiling axially to represent the earth; in which case the room should be capable of being darkened and one of the lights used to illustrate solar effects with this globe.

In a room for physiography a good deal of cupboard space is necessary, partly for maps and paper but also for simple physical apparatus, and, where geology proper is not separately studied, for common minerals and rocks.

Elementary Laboratory—The chief work done in this room will be the identification of fossil and rock specimens, in which the use of the microscope, if employed at all, will be very subsidiary. The students usually work at small separate tables of ordinary height (about 2 ft. 4 ins.) seated on chairs. In Professor Watts' laboratory at the Imperial College, London, these tables are 3 ft. 3 ins. by 2 ft., and contain one drawer with lock and key, which latter is retained by the student. Good students' collections should be kept in this room in cabinets of drawers which can be removed and carried to the tables for use, and provision may also be made for works of reference. A rather larger table on a platform 6 or 8 ins. high is sometimes installed for the demonstrator. As wax has occasionally to be melted and fossils heated (boiled with size, for example), a small fume cupboard with a gas supply is useful in this room which should also contain some spare bench accommodation for putting things down. A water supply is sometimes considered desirable.

Lecture Theatre—As already stated the general principles which govern the design of lecture rooms are common to all branches of science, and the reader is therefore again referred to the description given in Chapter II. The demands of geology are, however, less than those of most other subjects. Apart from good lantern and diagram arrangements and ordinary lighting, no electric service is necessary, and the provision of gas and water is unusual. No fume cupboard is required, neither need a preparation room be provided in conjunction with the

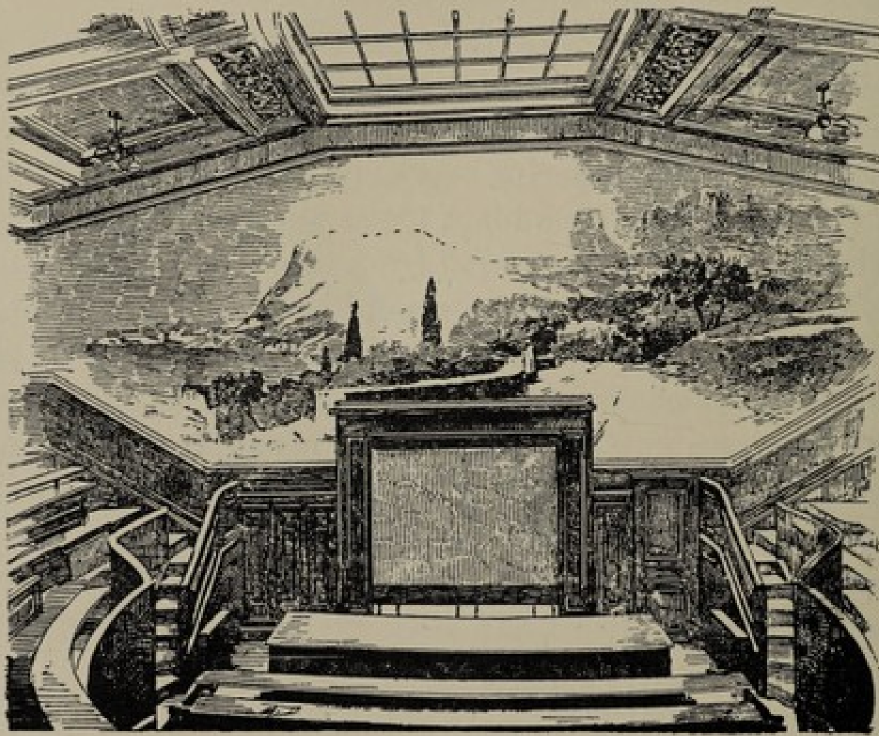


FIG. 57.—Geological Lecture Theatre at the new Sorbonne.

lecture theatre, which, however, may adjoin the laboratory or the museum for convenience in bringing in specimens. Hence most of the wall behind the lecturer may be devoted to much-needed blackboard surface. Most lecturers use large numbers of slides, which may be kept standing upright in nests of labelled drawers, the sets being provided with index cards.

Lantern work in geology is perhaps less intermittent than in other subjects, hence the location of the lantern at the end of the room among the students instead of on a stand near the lecture table is often considered preferable.

Fig. 57 gives an illustration, contributed by the architect, M. Nénot, of the geological theatre at the new Sorbonne, which has almost the suggestion of a court of justice.

Museums—The principles of fitting geological museums do not materially differ from those previously indicated. Some of the specimens are, however, of considerable weight and may occasionally need constructional considerations. Fig. 58 shows a section of one of the cases devoted to the illustration of the mining and use of clays at the Geological Survey Museum, London. The main shelves of these

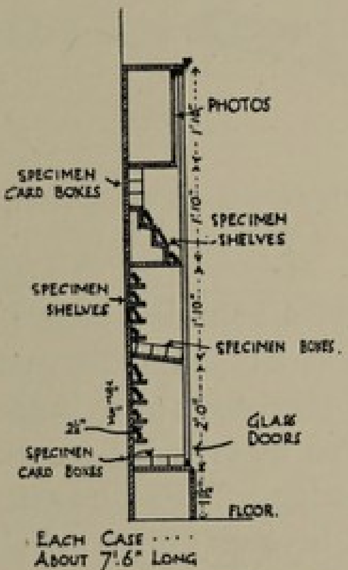


FIG. 58.—Section through Specimen Cases in Museum of the Geological Survey, London.

FIG. 59.—Top of Map Table, Geological Department, Imperial College, London.

cases are fixed at different angles to provide the best visibility for the adult observer. These cases are about 7 ft. 6 ins. long, and have a pair of doors glazed with plate glass which much assists clear vision.

In a large collection, several separate museums may be required. The palæontological section will be the most important with its fossil displays usually arranged stratigraphically. Petrology may demand considerable space for rock specimens, mostly of small and uniform size. Models and practical applications of geology may involve further rooms.

Map-drawing Room—The study and making of geological maps is so important a branch of geology that a special room is often devoted to this work, and should be arranged like a drawing office with good north light, the students working at separate tables on drawing boards. The tables used by Professor Watts at the Imperial College are 3 ft.

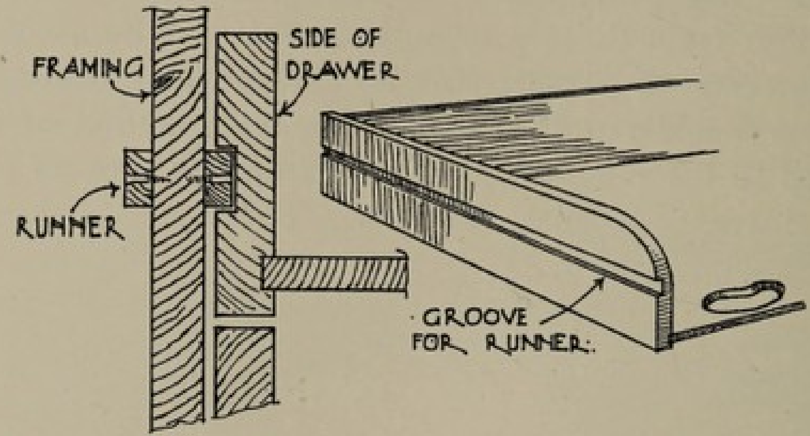


Fig. 60.—Map Trays showing Runners to Economize Height, Geological Department, Imperial College, London.

4 ins. long, 2 ft. wide, and 3 ft. high. They have a rounded edge in front, before which, attached by strong screws and half-inch distance pieces, is a wooden bar (Fig. 59) to prevent maps used for study being damaged by creasing on the table edge. The drawing board is kept on a shelf below the table, and the maps in cupboards containing draw-out trays 3 ft. 10 ins. long, 2 ft. 6 ins. wide, and 3 ins. high, which slide on runners, and framing between the drawers only exists in the middle of the cupboard, to keep it together (Fig. 60). The locks of these cupboards engage with a plate hook on the framing, thus making bolts to the doors unnecessary (Fig. 61). Mr. J. Allen Howe, at the Geological Survey Museum, preferred to fold the maps once, or for large

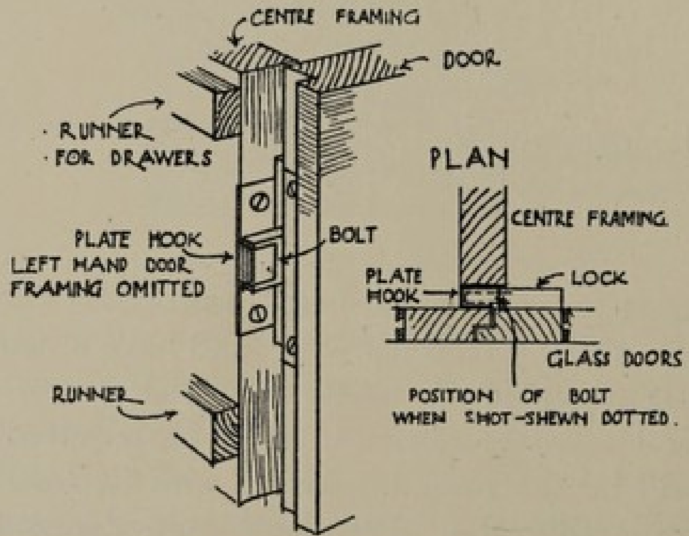


Fig. 61.—Lock to Pair Door Cupboards to render Bolts unnecessary, Geological Department, Imperial College, London.

sizes into four, when they are cut and backed with linen. They are then stored vertically in cases resembling fittings used for ledgers. Fig. 62 shows a detail of one of these cases. The advantage of this scheme is that the maps, many of which are hand-coloured, are not rubbed, and by attached tabs can be at once separately extracted. The expense of the linen mounting, however, is not inconsiderable.

Advanced Laboratory—An advanced laboratory will probably be devoted largely to petrology or palæontology, and on the assumption that the chemical analysis of rocks and minerals takes place elsewhere, the work in this room will be largely microscopic, hence a steady and ample light is necessary. Benches of a simple character, as described

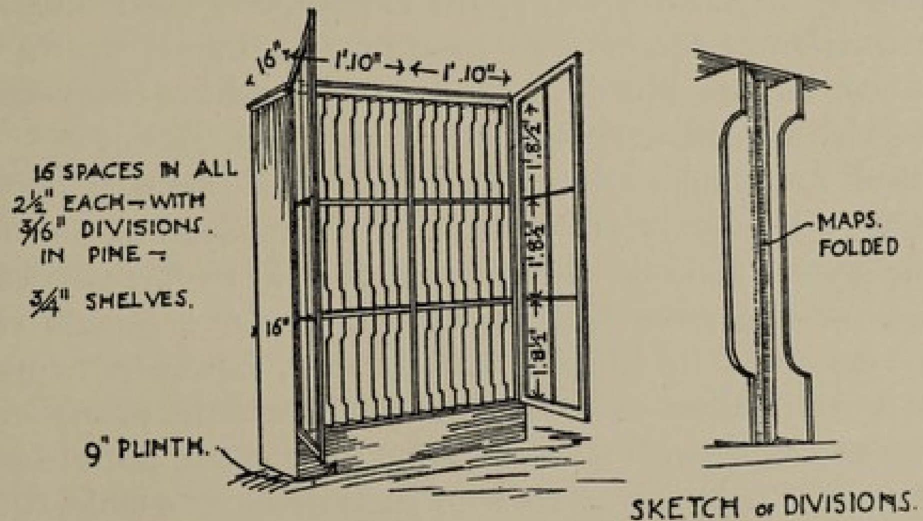


FIG. 62.—Cupboard for Folded Maps, Museum of the Geological Survey, London.

for botany, will be suitable, but in addition, ordinary tables and chairs, for the examination of hand specimens, and for notes, will be found useful. The remarks previously made on the subject of lighting, natural and artificial, for microscope work of course apply equally here. Neither gas nor water is necessary on the benches, though a sink with a supply, and one or two gas jets in some convenient position will probably be appreciated.

As in the elementary laboratory, a considerable number of drawers for students' collections will be wanted, both for specimens and microscope slides. The former should be about 3 ins. deep inside and of such a size that they can be readily carried when full from place to place. Subject to this, they should be as large as possible to reduce the cost and woodwork, and also to save space. A drawer 2 ft. square will be found heavy to carry about full of rock specimens, though something larger might be used for fossils. These drawers should have no glass tops nor divisions, card or metal trays used for holding the specimens taking the place of the latter. If constructed with runners, as described for the map trays, and without framing, the accommodation for a given height will be increased by perhaps 20 per cent. The use of bass wood or pine for these drawers will reduce their weight. The microscopes may be kept in nests of pigeon-holes 9 ins. by 6 ins, by 16 ins. high, with glazed doors admitting of immediate oversight. Cabinets for microscope slides, which are stored flat in drawers about ¼ in. deep and containing divisions 3 ins. apart, require very good cabinet work. The construction of the drawers or trays as a frame, with a card or thin plywood bottom glued on, appreciably reduces their cost, and almost does away with warping.

Chemical Laboratory—In the absence of a chemical department co-operating, a laboratory is desirable for the analysis of minerals and for specific gravity and other determinations. For full analytical work, the fittings for this room will resemble those for a general chemical laboratory described in Chapter II. It may, however, happen that blow-pipe work is alone necessary, in which case the provision of gas and one or two sinks with no elaboration of drawers, fume cupboards, or lockers, will be requisite. Professor Judd designed a table, still in use at the Imperial College, for the blow-pipe work of students training as mineral prospectors. These tables measure 2 ft. 10 ins. by 1 ft. 9 ins. and are 2 ft. 7 ins. high. They are designedly devoid of gas and water, the blow-pipe work being done by the aid of a vessel of melted wax. At one side, cut in the top, is a hole 14 ins. by 4 ins., below which is a box forming a well in the table 6 ins. deep, in which a set of small reagent bottles and other necessaries are kept. This arrangement has the advantage of allowing the tables to be used for drawing boards when not required for analysis.

Rock-cutting Room—A room for the preparation of specimens is essential in a department of any magnitude. Here rock specimens will be trimmed to size in a small slicing machine about 2 ft. square, consisting of a mechanically driven disc rotating on a vertical axis, standing on a very strong table about 2 ft. 6 ins. high. The specimens are subsequently ground on a somewhat similar machine. The diameters of the slicing and grinding plates are about 10 ins. They are preferably driven by small motors placed beneath the top of the table supporting the machine. Water and a gas supply will prove useful, also a dust-proof enclosure in which is a table shelf for the purpose of mounting slides, which involves the use of varnish. A large sink with good drainage, suitable for continuous washing away of clay from specimens, might find a place in this or in some other service room.

Research and Dark Rooms—Geological research in the realm of palæontology is not likely to require any special fittings which have not been covered in previous descriptions. For petrology, high-power microscope work will necessitate good lighting, and some provision in the way of a small glazed cupboard for bottles of liquids of different refractive indices. Other optical instruments of considerable size may be used for special purposes. Dark rooms are chiefly required for goniometer work—measuring the angles between crystal faces—which is best done by artificial light, though a darkened room, into which rays of natural light are admitted, is sometimes used. Photographic rooms are also required in connection with the preparation of slides, enlargements, and many other recording purposes.

Unpacking and Mounting Rooms—Unless specimens go direct to the rock-cutting room, a special room for unpacking, determining, sorting, and, where necessary, mounting hand specimens, is required. This should naturally be on the ground level and near an entrance if possible. Here, also, unless storage is provided elsewhere, drawers for duplicates may be arranged, as at least some of such specimens will probably be eventually repacked for transmission without leaving this room.

CHAPTER V

LABORATORY SERVICES

GENERAL **Considerations**—In this chapter it is proposed to deal shortly with gas, water, electricity, and other supplies, and with ventilation and drainage, as regards their special application to laboratory work. These are essentially engineering matters, and no attempt can be made in a small book of this kind to do more than indicate the general nature of the requirements in a lay manner sufficient to admit of their intelligent consideration in connection with any scheme, leaving to the architect—with, in a large project, such consultative engineering advice as he may deem necessary—the working out of the many problems which must arise, and which are so intimately connected with the construction of his building.

Enough has been said in the preceding chapters to indicate the extent to which the various services are required in the departments of natural science which have been dealt with, hence this subject may be now treated generally.

Gas, water, and electric services should enter the building near the central heating and local engineering plant, where they should be under ready control. When service pipes are extensive, they should be considered as a whole, otherwise the work of one firm is very likely to render that of another inaccessible. Many pipes, moreover, small in themselves, may require covering and then assume much larger proportions. Suitable ducts should be provided in the building in which service pipes can be run together. Central corridors usually give a means for forming such ducts. In a basement, pipes may be carried on corridor walls, or if no general basement is proposed ground floor corridor walls can be carried down to form a crawling way, which should be 4 ft. high or more if of considerable length and served with manholes at intervals. From this openings may be made below rooms on either side and shallow floor trenches provided with movable floor covers in such rooms in which branch pipes from the trench mains can be carried to fittings. If a long central corridor can have its ceiling at a lower level than the adjoining rooms, a crawling space may often be obtained in which all main runs of pipes can be placed for the supply of the floor above. Vertical shafts should be provided by the enlargement of the casing of stancheons or otherwise, in which rising mains can be grouped from floor to floor for extension of the horizontal mains, and it may be that the provision of such shafts and the location of the fittings served will render horizontal mains on upper floors unnecessary. The advantages of ring mains should be considered. Though these may involve more piping they admit of drawing supplies from two directions which reduces the chance of failure and facilitates repairs.

Before any system of mains is decided upon, the location of the principal fittings should be visualized.

All pipes should be accessible and may be largely exposed on walls, or if architectural considerations render this undesirable in any special situations, they should not be buried in walls but placed in recesses provided with movable casings in front. A scheme of distinctive colours for the painting of pipes may be an assistance in tracing them, and, where flow and return services differ, a further distinction in appearance may be made. The movable heads of different fittings should be of distinctive patterns, to avoid mistakes, and this distinction should, if possible, enable fittings to be confidently operated in the dark should occasion arise. The provision of stop-cocks should be generous, both to shut off rooms and benches out of use and to admit of repairs without inconvenience. Terminal fittings should be of gun-metal, lacquered or painted black. Recently fittings plated with chromium steel have been introduced and are in use in some institutions. Sufficient experience of this coating is yet lacking, but suggests that air charged with ammonia is detrimental to such plating. The author has suggested the application of the material known as "Bakerlite," largely used for electrical fittings, to gas and water terminals, but whether it becomes somewhat brittle with age has yet to be established.

Gas

Alternatives to Coal Gas—Although the use of ordinary coal gas is almost universal, a few words may be said on the provision which can be made in such exceptional circumstances as preclude its employment.

Setting aside the production of water gas, oil gas, and the like, which require plant and attendance in some degree commensurate with coal gas on a small scale, acetylene and petrol gas are the simplest substitutes. The writer's personal experiences of acetylene date back to what was probably the first installation for heating by acetylene in this country, which is still in operation.

Acetylene requires special Bunsen burners which work under a pressure of 4 or 5 ins. of water. The service pipes may be about half the sectional area of those required for coal gas, and an ordinary bench burner, consuming about 1 c. ft. an hour, gives a flame of about twice the effectiveness of a coal gas Bunsen consuming the usual 4 to 5 c. ft. The temperature of this flame has advantages and disadvantages; it enables heating operations to be rapidly performed, and the blow-pipe to be frequently dispensed with, and it also involves greater care, to avoid breakage of glass through sudden heating. Careful purification of the gas is necessary, otherwise platinum vessels are rapidly spoilt. Petrol gas, which consists of a non-explosive mixture of air with a small percentage of petrol vapour, gives a very hot flame. The plant required for a small department, for either acetylene or petrol, can be housed in an out-building with a floor area of a 100 sq. ft., or so, and attention for an average of, say, half-an-hour a day, by the laboratory or heating plant attendant, is sufficient to maintain the service.

Companies Gas Supply—Turning to ordinary gas, before formulating any scheme of piping it is necessary, unless the consumption will be trifling, to figure out roughly the probable maximum demand and then to ascertain the conditions of supply. In large towns where the arterial system is used—gas being made at two or more distant locations, and possibly increased in pressure by valve stations in addition—the mains supply any draw-off point in both directions, but in scattered districts a single main with a dead end, near which the pressure drops considerably, may alone be available. Since the gas pressure on delivery must not fall below a certain minimum, and is very appreciably affected by the sizes of the pipes to be employed in the building, the calculation of these sizes must be based on a knowledge of the pressure in the mains.

The calculation of gas consumption to be allowed for in a science department is not an easy matter and can only be effected approximately, for not only is the number of burners in use exceedingly variable, but the individual consumption for certain work considerably exceeds that of the ordinary bench jet.

Estimating Gas Consumption—Gas companies base consumption calculations on what is known as a " scale light," to which meters are referred, and which is a jet consuming 5 c. ft. per hour. Ordinary bench Bunsen burners, which will always form the bulk of the individual jets in laboratory and lecture work, may be taken as consuming, on an average, 4 to 5 c. ft. per hour. It is very unusual to find all the gas cocks provided supplied with Bunsens, or to find those so supplied all in use at one time ; hence, for purposes of calculation, 50 per cent. of the total number of cocks suitable for Bunsens, reckoned at 4 c. ft. per hour each, will generally give a safe margin for emergencies. This reduction, however, must be applied with discretion to special apparatus, such as ovens and furnaces, which may conceivably all be working at one time and may be individually equal to a dozen or more scale lights. The consumption at these special points, obtainable from the apparatus makers, is a matter upon which the advice of the professional staff must be obtained.

Gas Pressure—Gas pressure is measured in terms of the length of a column of water which such pressure will support. This is usually 3 ins. to 5 ins. in the companies' mains, and at the jets on the benches this pressure should be 2½ ins. or at least 2 ins. The pressure between mains and jets falls owing to several reasons, but, for ordinary low velocity gas under these small pressures, may be regarded as depending solely upon the length and size of the pipes, and on their sinuosity and internal condition. In good practice, where round elbows are used, and bends to large radius are employed in place of innumerable elbows and short lengths of pipe, and where T-pieces are restricted to the necessities of branches, bends and joints need not be calculated, while if steam pipes be installed for pipes one inch in internal diameter and over, the interior surface conditions need not be regarded as affecting pressure. In first-class work, therefore, it is only with the length and diameter of the pipes that calculations need be concerned. There is, however, one other condition that affects pressure in the case of a building of several stories which may be conveniently dealt with here, and this is the height of the jets above the main. Gas is only about half as heavy as air, hence it follows on hydrostatic principles that the higher the jets the greater will be the gas pressure, every rise of 10 ft. increasing the pressure by about $\frac{1}{10}$ in. This consideration may render some economy in the size of pipes possible upon the upper floors of lofty buildings. As gas will always tend to rise, the supply should be from below, not from above, but when the latter is necessary, as when pendants are used over tables to avoid making such tables fixtures, pipes should be a size larger than would be necessary for horizontal runs.

Length and Diameter of Pipes—As showing the very marked effect of pipe lengths on gas delivered, an illustration from a pamphlet by Mr. Webber may be cited. He says a hole in a gasometer 1 in. in diameter would deliver, under pressure of 1 in. of water, 1,463 c. ft. per hour, whereas, if a 1-in.[1] diameter pipe 100 ft. long be attached to this hole, the delivery at the end of this pipe will only be 280 c. ft. per hour. Mr. Webber points to practical data which show that the amount of gas discharged from a pipe is almost directly proportional to the pressure, in spite of formulæ in disagreement with such view. Thus, if the pressure be doubled, the volume of gas discharged, other conditions remaining the same, will be doubled. For very small pressures (a few tenths of an inch) the experimental data he gives show this to be true, but for pressures of more than an inch, the discharge does not increase strictly with the pressure but is less in proportion. Thus 50 ft. of $\frac{1}{2}$-in. pipe under $\frac{1}{10}$ c. in. pressure are said to discharge $9\frac{1}{3}$ c. ft., and under $\frac{4}{10}$ in. pressure nearly 38 c. ft., but under 6 ins. pressure (60 times $\frac{1}{10}$ in.) only 184 c. ft.

A simple rule often used by gas-fitters is that 100 ft. of 1-in. pipe will deliver 100 c. ft. of gas per hour with a loss of $\frac{1}{10}$ in. pressure. The maximum lengths of pipes which should be used for individual runs may be taken as follows :—

Internal Diameter.	Length.	Gas delivered in c. ft. per hour under ordinary pressure.
$\frac{1}{2}$ in.	30 ft.	—
$\frac{3}{4}$,,	50 ,,	—
1 ,,	100 ,,	100
$1\frac{1}{4}$ ins.	130 ,,	200
$1\frac{1}{2}$,,	160 ,,	300
2 ,,	200 ,,	750
$2\frac{1}{2}$,,	250 ,,	1500
3 ,,	300 ,,	2000

[1] Diameters of pipes referred to are always internal diameters unless otherwise stated.

In proportioning these pipes to one another, a 1-in. pipe will be suitable to feed two $\frac{3}{4}$-in., six $\frac{1}{2}$-in., or ten $\frac{3}{8}$-in. pipes. The use of pipes of smaller size than $\frac{1}{2}$ in. is not desirable except for very short and preferably vertical runs to single jets, or such as may be necessitated in work on students' benches when taps are placed at the front and jets at the back. The reason for this does not lie in the inability of such pipes when installed to carry sufficient gas supply for single jets, even if of some length, but $\frac{1}{4}$-in. and $\frac{3}{8}$-in. pipes leave so little licence for deposits of naphthalene and rust, which always gradually encroach on the bore of the tube, that the small saving in cost afforded by the employment of these sizes does not compensate for possible future troubles. Naphthalene is deposited as a fine crystalline powder, and may be readily blown back into the mains, where it again dissolves.

Laying out a Scheme—All schemes should provide for possible further calls, as it frequently happens that, with every forethought, additional points will be added, and to admit of pressure adjustment to compensate such variations, a governing valve should be placed on each floor which can be set to regulate the pressure after the building is completed. A generous provision of stop-cocks, not only to each room, but to each bench or group of jets, should be included so that local repairs or control may be possible without throwing out a large proportion of the service. A great point is often made of having full-way cocks and fittings, that is, cocks which, when open, have the same bore as the pipe to which they are attached, but it would appear that, provided the reduction on each side of a fitting is gradual—forming a cone—no detriment results from the actual opening being, within reason, smaller than the pipe, the checking on the supply side resulting in expansion, and thus a corresponding pressure increase on the side nearer the fittings.

In laying out a scheme, plans and sections of the building are, of course, necessary. The consumption at the fittings must first be ascertained and decided for the purpose of calculation, and the piping worked out from these fittings back to the mains on the basis of the drop in pressure allowable to retain a pressure of $2\frac{1}{2}$ ins. at all fittings. If the service is extensive, it is desirable to imitate the arterial system of mains by arranging that gas can be drawn off in more than one direction. This is best done by forming a ring round the walls of the lowest floor, and running " risers " (vertical pipes) at several points from it, possibly to further rings on the higher floors.

Occasionally a gas supply is required at higher pressure than that provided by the public mains. If this is necessary, the gas must be compressed in a small gasometer by a pump in the building, and, of course, delivered in a separate pipe service. Such a service, however, is not often wanted.

WATER

Water Supply and Pressure—Water from the public mains is usually supplied through the medium of open tanks placed in the roof of the building and fed automatically by a ball-cock. As a rule such tanks are demanded by the supply company, but should usually be provided to meet the necessity for main repairs. Except for certain delicate washings, for which a low pressure is essential, water is usually required in science buildings at fairly high pressure, and hence a supply direct from the mains is desirable, and, if tanks are installed, and a separate low-pressure system is not called for, they may be used as a " stand by " and be cut off from the supply pipes by special cocks until the water in them is required. If, however, the pressure in the mains is subject to much variation, tanks may be utilized for the general supply, particularly if the building is a high one, for pressure variations are detrimental to the use of filter pumps, and small turbines frequently employed.

Another use to which tanks may occasionally be put advantageously is for the collection of rain-water, often useful in biological work.

Water pressure is reckoned in pounds per square inch, and depends upon the height of the surface of the supply above that of the draw-off tap, and such height is known as the " head " of water. Every 2 ft. of head is equal to about 1 lb. of pressure per square inch, hence the pressure of water on various floors of a building and the main pressure in buildings on high and low land are very different. A main supply of 50 lb. pressure in the basement may, for example, give little more than 25 lb. on the 3rd floor of a building. This question of pressure is chiefly concerned with filter pumps largely used in all kinds of chemical work. These pumps (small glass or metal arrangements attached to the water taps over the sinks) operate best at pressures from 40 to 60 lbs. Below this limit they are not so efficient, though frequently used at pressures down to 25 lbs.; while above 70 lbs., owing to the amount of dissolved air in the water, they again decrease in efficiency. Thus it will be seen that these pumps can seldom be operated from storage tanks, owing to insufficient head. It will not often be found that the public supply is at too great a pressure for use, but it may often be insufficient. In such cases where hydraulic mains are available it was customary to admit high-pressure water from this source by means of a weighted piston working in a cylinder with a cut-off valve, which admits hydraulic water only when the pressure falls below a pre-determined amount in the laboratory services. Such a machine, placed conveniently near the point of water entry to the building, occupies about 4 ft. by 2 ft. on its bed and is some 4 ft. high for a large building. As the hydraulic pressure is great (about 700 lb. in London), a large proportion of water from these mains, which is rated by meter at a higher price than that from the general mains, is not necessary.

Hydraulic mains, however, are not generally available, and calls upon them are expensive. An alternative is to install a compression pump which forces water into a large cylinder, the upper part of which contains air. The pump may be made to start automatically when the pressure falls below a fixed limit. The constant solution of the air under pressure involves some arrangement for introducing more air frequently. If filter pumps are alone involved in this question it is better to operate them by a vacuum system (see p. 131).

Sizes of Pipes—It is not easy to calculate the necessary pipe sizes for water on a consumption basis, but they must be sufficient to prevent any checking of filter pumps when a good proportion of taps are open. To ensure a sufficient supply in a large scheme a ring main, already referred to under "gas," is desirable. From this ring three or four vertical pipes are taken to supply the upper floors, where branches are tapped off to supply the fittings. Vertical "risers," distant from main connections, should be made larger than others to equalize the flow.[1] The use of pipes less than ½-in. diameter is undesirable, as allowance must be made for deposits from the water. In a large scheme, pipes used in the building may range up to 3 ins. or 3½ ins., while a 1-in.

[1] The consumption in a large department may easily reach 10,000 gallons per week exclusive of boiler and any domestic requirements.

supply will serve many small institutions. Friction during flow has a considerable effect on discharge, and sharp bends and rough unbevelled edges in joints should be avoided. A square elbow is said to be equivalent in resistance to the following straight pipe lengths: in ½-in. pipe, 19 ins.; ¾-in., 29 ins.; 1-in., 38 ins.; 1¼-in., 48 ins.; 1½-ins., 57 ins.; 2-in., 76 ins.

Discharge of Water from Pipes—Though any accurate determination of the delivery from water jets is tedious and complex, it is often useful to obtain an approximate idea of their discharge rate. The following table (in which some decimals are suppressed) is taken from "The Modern Plumber and Sanitary Engineer," Appendix, Vol. 6, 1908, and shows the full bore discharge in gallons per minute:—

Internal Diam. of Pipe.	Head of Water Divided by Length of Pipe.			
	$\frac{1}{100}$.	$\frac{1}{10}$.	$\frac{1}{2}$.	$\frac{1}{1}$.
⅜ in.	0·22	0·83	2·0	2·9
½ "	0·46	1·36	4·2	6·0
¾ "	1·33	4·9	11·7	16·9
1 "	2·8	10·2	24·2	35·0
1¼ ins.	5·0	17·9	42·7	61·6
1½ "	7·9	28·5	67·7	97·7
1¾ "	11·8	42·2	100·0	144·2
2 "	16·6	59·3	140·1	202·0
3 "	47·0	166·0	390·7	562·2

The velocity of water falling freely is, in feet per second, eight times the square root of the height of fall (or head) in feet, or $v = 8\sqrt{h}$, and for average lengths and bends in a building, ⅓ may be deducted for loss due to friction, giving the following rough table for velocity from jets:—

Head in feet . . .	5	10	15	20	30	40	60	80	100	200
Velocity in ft. per sec. .	12	16	20	24	30	34	42	48	54	76

The consumption of water in a laboratory is not easily estimated. A firm making water fittings has given the author its experience as follows: daily consumption for an elementary Physics laboratory for 30 students, 150 gallons; advanced for 20, 160. Chemical laboratory as above, 1600 and 2300 respectively. Lecture room, 50. Preparation room, 200, and Biology laboratory for 10 students, 350 gallons. The consumption of water from 305 three-way taps possessed by one of the newer science buildings at Cambridge, for the Christmas quarter of a recent year was 454,000 gallons, at a pressure supply of 40 lbs.

Water pipes for laboratory work should usually be in steam quality iron. If lead is used it must be the thickest pipe obtainable to withstand main pressures, and even then may give trouble by bursting under high variable pressures. Lead is subject to damage by rats seeking water, and pipes want support to prevent sagging. In soft water districts, difficulties may occur through rusting in iron pipes, and copper distributing pipes should be used, large pipes being of coated cast iron. In this connection galvanizing is often resorted to, but is of little permanent use. Any internal treatment of pipes to prevent rusting requires consideration, as bacteria have been known to result from the use of certain preparations, a very serious matter in a biological laboratory supply.

Fittings—Capstan head fittings are most suitable for water, and, when pressure is not excessive, steep-pitched screw-down valves (sometimes called quarter-turn taps) will save time in their very frequent use. Nozzles, except possibly over wash-up sinks, should be elongated, tapered, and corrugated for the attachment of rubber tubes, but very fine jets working under high pressure, if opened rapidly, tend to the breakage of delicate glass vessels.

Hot Water—A limited supply of hot water will be very much appreciated in any laboratory, chiefly for the purpose of washing up apparatus in service rooms, but also in the laboratories themselves where water has frequently to be heated for experimental work. Usually a supply will be available for ordinary sanitary fittings, in which case this service may be taken into the laboratories with the provision of little additional boiler power. A steam supply in operation when required may also be readily used for producing hot water by means of a calorifier, the condensed steam being returned to the boiler. In the absence of these means, and a special plant not being justified, local heating must be resorted to. There are various small gas water heaters which can be placed over sinks, and which readily produce small quantities of very hot water with a ½-inch gas supply. Of these the enclosed vertical type—miniature bath geysers—are usually found more liable to damage by overheating than the open horizontal type. No flue is necessary for these small heaters used intermittently in a room of reasonable size. Recently electric heating of water has developed. It is hardly yet applicable to a number of distant points worked from a central plant, and is usually expensive if such a heater is applied to more than one position. Very considerable lagging to the apparatus is necessary which renders it somewhat bulky, but the absence of any combustion products may have great advantages in certain situations. This service has a special interest in connection with operating theatres. Where steam is not available the choice lies between gas and electric heating for sterilizing water and instruments. In many cases this has resulted in a compromise, gas being used for heating the large water containers and electricity for the smaller sterilizing trays for instruments.

Electricity

Electricity is produced either as a continuous flow, known as " direct " or " continuous " current, or as a series of rapidly reversed pulsations, known as " alternating " current, according to the construction of the dynamo. Current which is measured in " amperes " flows in conducting wires conveying it at pressures depending on the potential difference of the dynamo poles. A large current requires large mains, just as a voluminous water supply demands a large pipe. Pressure, analogous to water pressure or " head " is measured in " volts." High voltage involves good insulation. The current in amperes, multiplied by the pressure in volts, gives the electric power measured in " watts."

Alternating and Direct Current—Science buildings usually require both alternating (A.C.) and direct current (D.C.); certainly in a physical and chemical department direct current will be necessary for charging cells, electrolysis, X-ray work, and many other purposes, though in a biological department alternating current alone may sometimes serve. A generous provision is indispensable for modern laboratory work, electric motors being required for refrigerating plant, centrifuges, mixing and stirring, timing pendulums, kymographs, and many other purposes. Special lighting again for projectors and microscope work may involve preciable current consumption. Public supplies are now usually alternating, and for ordinary use—lighting and small power—this current is generally supplied at 200 to 250 volts. The increasing use of A.C. has brought improvements in machines, and small A.C. plant can now be readily obtained for most purposes. A great advantage possessed by this form of current is its ready transformation to different voltages by means of two stationary coils of insulated wire, at a trifling loss of energy.

Where direct current has to be made from an alternating supply several methods present themselves. A rotary converter may be used, which is an alternating motor driving a direct current dynamo which supplies the current. To ensure a constant supply a set of cells—accumulators—is generally included in such a plant, and the current may be supplied from such cells alone charged from time to time by the converter.

Mercury lamps have now reached a stage of development which renders them reliable for conversion from A.C. to D.C. and are obtainable in a variety of sizes up to considerable magnitude. On a small scale valves as used for radio work may be employed. Metallic oxide rectifiers, probably best known at present in the form of "trickle chargers," for wireless low-tension battery charging, are now made in large sizes capable of dealing with a considerable output. They require no attention, and are said to be almost permanent in action. Available types being proprietary they are somewhat expensive at present, but this simple form of conversion should certainly prove of increasing value. Selection of the type of converter will depend upon the circumstances of each case, but where steady currents of magnitude are required at many different voltages accumulators are essential, and by the use of distribution boards to which the cell terminals are brought, can provide a very wide range of alternatives.

Wiring Systems—Little can be said here on this subject; drawn steel tube makes the best conduit, but usually braized or welded tube is used. These tubes have screwed joints. Light steel tube with connections which grip the ends, or less desirably, merely slip on, is used in second-class work, such tubes being mostly open at the seams. Wood casing is never now installed, though in a dry situation not liable to damage by nails it may be considered superior to slip-tube work. Lead-covered twin wires are frequently employed, and make good earthing easy. In situations where they are not liable to damage such a system is quite satisfactory, and very useful in alteration work owing to its pliability. Good insulated cable, such as C.T.S. (cab tyre sheath) used without casing is very serviceable for laboratory leads where appearance does not matter. It is rather more costly than lead-covered wire. Cable sizes will be governed by local electrical rules which generally err on the side of safety and admit of much greater currents for short periods than those laid down.

Distribution—If a battery (set of accumulators) is installed the charging board will comprise ammeter, volt meter, two-way volt switch, automatic cut-out, and double-pole fuses. From this battery will run a series of bare copper wires terminating on a distributing board, arranged so that by " plugging in " connections to pairs of leads to the various laboratories a considerable variety of supply up to the maximum voltage of the battery can be obtained at terminals in these rooms. Such boards may be exceedingly elaborate and may involve very heavy cables. They must be designed for specific requirements, but the principles involved may be gathered from the simple examples shown in Fig. 63. A to J represent ten cells connected, as shown, to four " bus " bars in the centre of the diagram, through fuses appropriately wired; each of these bars possesses five terminals to admit of their use for five connections at once if necessary. On either side are terminals numbered 1 to 10 to which the positive and negative ends of ten pairs of leads running to the bench positions can be attached. Suppose point No. 5 requires current at 2 volts, the + and — No. 5 terminals are connected to bars I. and II., if 8 volts to I. and III., or 20 volts—the whole battery—to I. and IV., and four other points can obtain like voltages at the same time.

Connections to bars II. and III. will give 6 volts and to bars III. and IV. 12 volts. The bars may, of course, be increased in number to give more voltage steps. Connection between the + and — terminals are made by heavy flexes with spade terminals to clip rapidly under the terminal screws. As a further measure of flexibility each cell might be brought up to a separate terminal in the switchboard room when flexible connections to the bus bars would be possible, enabling " tired " cells to be given a rest. Such a board is not very amenable to instruments, but portable instruments applied on the working benches are often sufficient.

Power Schemes.—In a school great variation and extent of electric power may not, of course, be necessary or justifiable. Possibly 8 or 10 cells of small size will form the battery, the switchboard will be behind the demonstrator's table in the physical laboratory, and the converter in the preparation room adjoining. Perhaps A.C. current from the public mains, but controlled by fuses at the benches and on the board

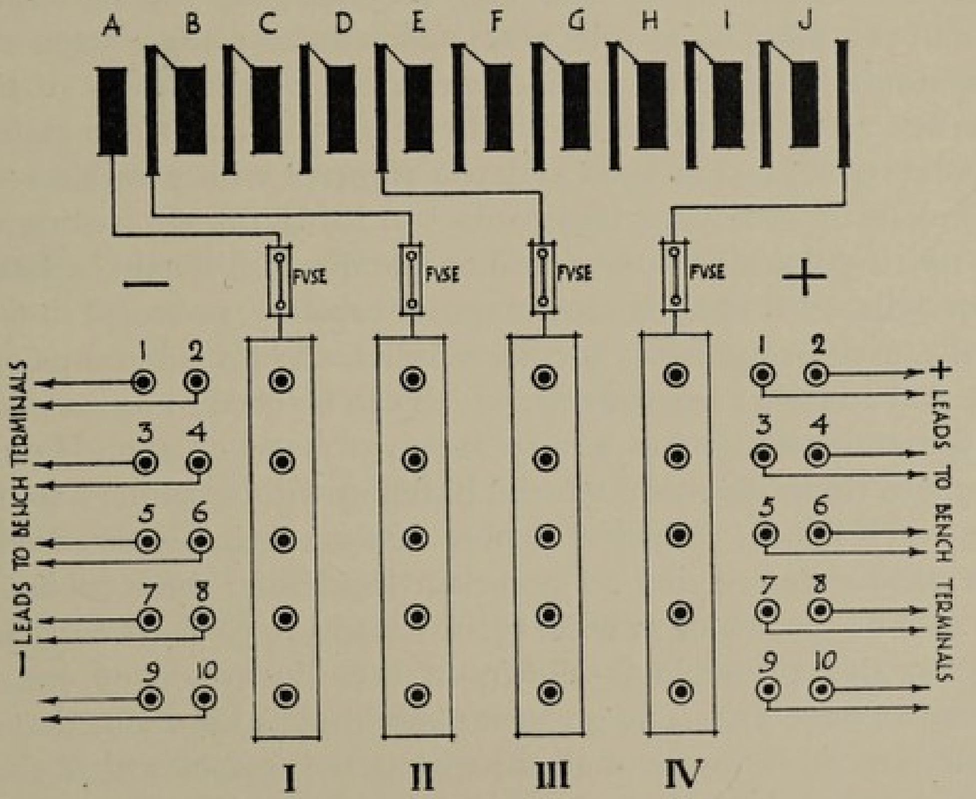


Fig. 63.—Diagram of Battery Board.

(where a switch will also be supplied), will be laid on round the walls to feed all but the island fittings. The battery wires, say from each pair of cells, will come back to the switchboard where an interchange of connections will be possible, giving large currents at 4 to 20 volts to the benches by another pair of heavier mains from the board. A resistance of wire coils and one of glow lamps may be included and operated from the board to admit of further variation.

As showing the importance attached to electric services in America, it may be mentioned that the regulations for the Boston High Schools require on the lecture tables current from 2 to 20 volts from 10 cells, and both direct and alternating current at 110 volts up to 30 amperes.

In illustration of one or two schemes of magnitude the following descriptions may prove of interest. The plant installed at the Electro-chemical Laboratory of Liverpool University[1] consisted of a large 28 kilowatt motor generator converting the public supply at 230 volts to 80 volts and thus giving 350 amperes, but, by rheostat arrangements, the voltage may be varied between 70 and 120 volts. This machine is used for direct supply and also for charging the battery. Two 5 kilowatt machines of 20 volts giving 250 amperes, the voltage of which can be similarly raised to 40, and which can be run singly or in series or parallel. A single-phase alternator at 80 volts and 1,000 amperes, or on another winding 150 volts and 500 amperes with possible reduction to 40 volts. A stationary transformer to bring the alternating current down to 10 volts and thus give 8,000 amperes. Lastly, a battery of 36 large cells, each of about 200 amperes capacity, arranged in 6 groups of 6 cells, each group being further subdivided into subgroups of 2 and 4 cells, and 20 rather smaller cells which can be used in series with those already mentioned, giving a very steady voltage of 110. Four main 500 ampere cables run through the building with secondary feeds from them at each floor. A special feature of the scheme is the use of bare copper conductors carried on porcelain insulators, these cables having only a coat of varnish to provide against inadvertent short circuit. The wiring on this principle is shown in the illustration of one of the laboratories, page 51. The greatest pliability has been aimed at, which is assisted by the exposure of all the wiring, the cost of which was naturally much reduced by the absence of insulated covering, while the current-carrying capacity, owing to greater rate of cooling, is thereby increased. There are seventy places in the building for taking current, two pairs of leads make it possible to obtain direct or alternating current at two voltages, and, by parallel switching, to take 100 amperes. A supply from the town mains for light and small motor work is also provided.

In the Chemical Department of Bristol University the plant consists of a motor and dynamo converting 500 volt direct current to 72 volts. The motor has a variable speed, and the dynamo can give varying voltages

[1] Many of the particulars are taken from "Zeitshrift für Electrochemie."

up to 110. A second motor generator is employed for operating the ventilating fans. The battery consists of 72 cells in 12 groups of 6 each; either half can be used for the 72 volt supply, leaving the other half for experimental purposes. There are two further groups, each consisting of 1, 2, and 4 cells, and the connections admit of almost any combination. The battery can produce 150 amperes at 172 volts or 2,100 amperes at 12 volts for 1 hour, and, of course, anything intermediate. The town supply is 105 and 210 volts alternating, and this is available both for lighting and power, in addition to 250 and 500 volt direct power current. The charging panel of the switchboard is self-contained, and as it is not permanently connected to any source of current is available for the heaviest experimental work, alternating or direct, as required. The distribution switchboard is in the physical chemistry laboratory, directly over the main switchboard, from which each pair of terminals is connected directly to only one point. Sixty pairs of wires run from this board, and these are independent and can be used simultaneously; further, the same pair of wires can be used at different times for currents of either kind at various voltages. This board also has six trunk cables leading to the main board by which direct connection from the town mains, motor transformer, or battery can be obtained.

In the Physics Department of University College, Bangor,[1] the supply is brought into the building at 200 and at 400 volts. The 200 volt circuit supplies fifty-four points in the building with current up to 25 amperes, while the 400 volt circuit supplies seven points with 50 amperes. Switches are all double-pole knife switches with enclosed fuses.

For battery charging a shunt-wound 440 volt 1,400 r.p.m. motor is provided, coupled to a D.C. shunt-wound generator having an output of 15/200 volts 40 amperes. This set is illustrated in Fig. 64. The battery distribution board, Fig. 65, is able to supply 25 amperes to thirteen positions and 125 amperes to three positions in the laboratories.

Before instruction can be given on any electrical scheme it is necessary to ascertain the maximum demand. As far as lighting is concerned electricians will usually be prepared to assess this themselves, but power consumption is so variable and usually so large in comparison with light that it must be assessed by the prospective users,

[1] A plan of this building will be found in Chapter VI.

though the information is usually very difficult to extract. This is not only a matter of the necessary size of cables, but, in most supply systems, of enabling the electrician to balance his loads by an appropriate arrangement of his circuits.

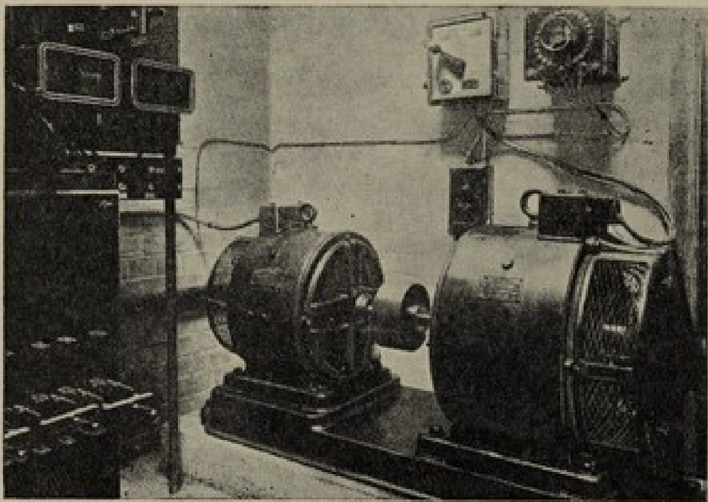


FIG. 64.—Distribution Board, University College, Bangor.

Special Lighting—The lighting of a building is not a subject for discussion here, but a few words may be said on some special needs outside the sphere of an ordinary lighting scheme. High-power lights are required for projector work, and when a large epidioscope picture is necessary such lights may want 20 ampere wiring. Arc lights previously used for this purpose have now largely given way to high-power filament lamps, and though equal concentration is hardly possible such lamps are of course much more convenient, and for pictures of moderate size (4 to 5 ft. square) may require as little as 2 amperes. When voltages are high it is often worth while to consider installing a small transformer for a number of projectors or for continuous working. Microscopes require small individual lights of which there are many types. Steadiness and concentration are essentials, and these lights are often very low voltage lamps which enables quite small bulbs to be used, and if these are of opal glass even distribution of

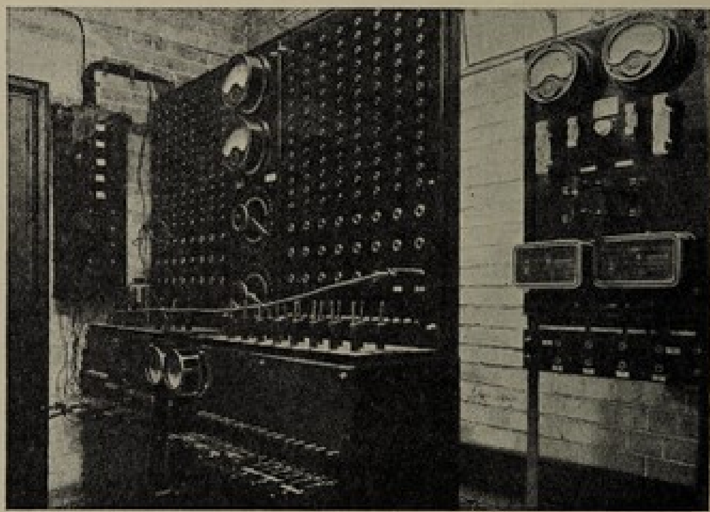


FIG. 65.—Converter, University College, Bangor.

light without filament image can be readily obtained on the reflecting mirror. With alternating current the necessary reduction in voltage from the supply can be readily effected by a small stationary transformer placed at the end of each student's bench. The lights are usually enclosed in some form of small case standing on the bench whence the beam can be transmitted in the desired direction only.

Steam

A steam supply is by no means universal even in large institutions, but is undoubtedly useful for distillations, evaporations, heating ovens, sterilizing, and many other purposes. In the absence of a hot-water supply it may readily be used for heating water.

The steam-heating of buildings in this country is not common, hence this supply is not often available apart from special installation. The consumption for experimental work often does not justify a boiler fed with solid fuel, and as the requirements are usually very intermittent such a boiler may prove difficult to manage. The alternative is a gas-fired boiler arranged to be automatic in action, the gas being cut down when the pressure reaches a predetermined limit. The supply pressure need not be great: 5 lbs. is sufficient on laboratory benches, 10 to 15 lbs. being preferable for drying ovens, while a somewhat higher pressure again (25 lbs.), is usual for sterilizing apparatus.

A boiler pressure of 25 lbs. would meet most requirements, reducing valves being used to give 5 lbs. on the working benches. To work the boiler at 5 lbs. would mean specially heavy mountings, larger mains and less efficiency. Obviously condensed steam cannot be returned to the boiler under less than boiler pressure, hence circuits which have to return steam such as those required for large sterilizers must be separate from those delivering at low pressure after passing reducing valves.

Data as to the consumption of steam for experimental work is difficult to obtain. A little vertical boiler, 15 ins. in diameter and 4 ft. 6 ins. high, with a 1½-in. main supplying gas at 3 ins. pressure, is stated by makers to produce 46 to 77 lbs. of steam per hour with a 15 and 40 ft. height of flue respectively. The writer has found such a plant sufficient for some sixteen distributed jets, but the use was probably small and included nothing continuous. Even a small bored jet can pass a surprising amount of steam if open for a preciable time.

In a small installation mains will probably be inch pipes, for a large building, with, say, 50 points, probably $1\frac{1}{2}$ ins. with 25 lbs. boiler pressure. Terminal pipes may be $\frac{1}{2}$ in. The supply is by no means proportional to the pressures.[1] Sharp bends are equivalent to 1 to 2 ft. of pipe in checking the supply.

Pipes should be of steam quality iron and must be lagged at least $\frac{3}{4}$ in. for mains and $\frac{1}{2}$ in. for branches. Heat losses can be reduced 75 per cent. by reasonable lagging.

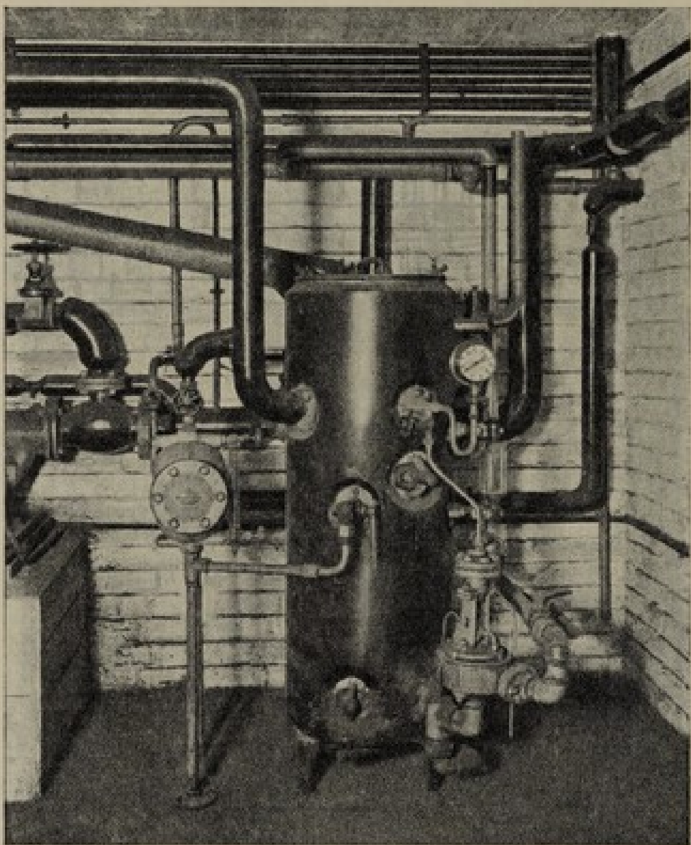


Fig. 66.—Gas-operated Steam Plant, Clifton College.

Horizontal runs should be avoided as far as possible, but in any event the whole system should be laid to admit of drainage to the boiler, and separators (valves to pass condensed water while not ejecting steam) thus avoided. The scheme should provide a series of vertical pipes taken up on the main walls through the several stories, and if the cocks for use can be confined to wall benches near these vertical pipes the system will be much simplified. Bench terminals usually have wheel heads similar to radiator valves and the heads must of course be of non-conducting material. Nozzles must discharge over sinks and should be bent down slightly to reduce the chance of accidents by scalding.

Fig. 66 shows an illustration of a small gas-operated plant in a large school science building supplying some eighteen points on two upper floors.

[1] 20 ft. of inch pipe deliver 2 lbs. of steam per minute at 1 lb. pressure, and 4 lbs. at 50 lbs. pressure.—"Steam Pipes," Booth.

Vacuum

In recent years great improvements have been made in small vacuum plants, and the installation of such plants should be considered for filtration purposes if for nothing else. Where difficulties in obtaining adequate water pressure exist vacuum is a simpler solution of the problem than water compression (see pp. 118-19). A bench filter pump uses about 80 gallons of water an hour, and as such water is usually paid for by meter (which may cost as much as 1s. 6d. per 1000 gallons) the running cost of these pumps is preciable. A half h.p. motor operating a vacuum plant can deal with a dozen or more suction points at very small cost, at usual power rates. Such a plant comprises a small rotary oil-immersed pump, motor, and cylinder, containing caustic soda to dry the air, which need not occupy an area more than $3\frac{1}{2}$ by $1\frac{1}{2}$ ft., and may even stand under a bench. The exhaust should be taken to the outside air or to a flue, though sometimes allowed to escape into the room. Service pipes may be of lead suitably protected, and air-tight joints are most easily made in this material. Alternatives are copper and iron, but owing to the moisture generally present in the air dealt with iron is liable to some corrosion. If screwed joints are necessary these must be carefully made. Pipes may be small, for a few points a $\frac{3}{4}$-in. main will serve and more than 1-in. mains are seldom necessary. Branches may be $\frac{1}{2}$-in. or $\frac{3}{8}$-in. pipes. To meet the eventuality of water getting into the system mains should be laid to fall, and one or more draw-off cocks[1] be provided at the lowest point or points.

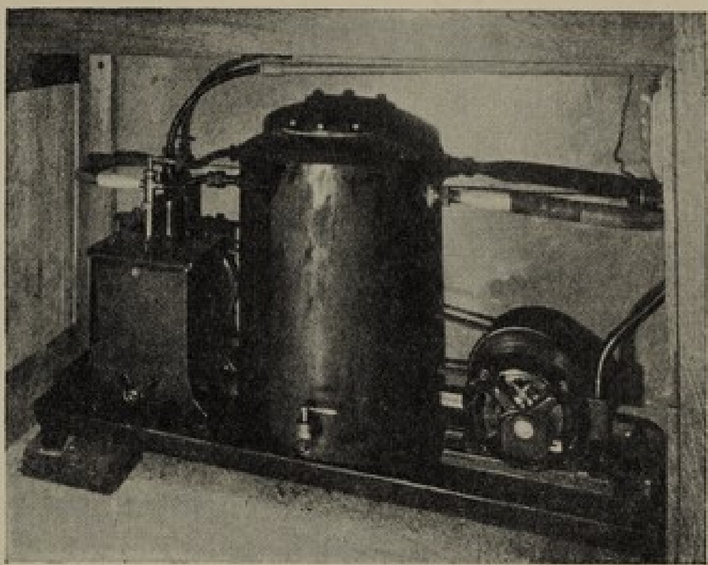


Fig. 67.—Vacuum Plant.

Special terminal jets are required of the cone pattern, and when wasteful use is anticipated these should be throttled down to prevent

[1] Ordinary plumber's fittings are not good enough for vacuum plants.

undue loss of vacuum from any one opening. Filters may also be placed in the jets to prevent entrance of solid matter. Where high vacuum is required in some special situation a separate direct lead may be run from the pump.

It is a great convenience to be able to operate the plant from distant points which is readily contrived by running a pair of electric leads in parallel from the motor starter to desired positions. Switches placed across these leads put the pump in operation, the last switch turned off breaking the circuit. A vacuum system has of course many other uses besides filtration, such as evaporations and distillations under reduced pressure.

Fig. 67 gives an illustration of a small vacuum plant recently installed in a new school building for filtration work in the chemical laboratories and for physical experiments. It has a special line to a lecture table for experiments requiring "absolute" vacuum.

Compressed Air

Plant supplying compressed air has many uses, as for aeration of water, combustions, drying, raising liquids, and pressure tests. Compression is effected by a motor-driven pump which may be reciprocating or rotary. The former type is to be preferred, and is suitable for the low pressures required for institutional work, assuming that the duty is intermittent, as will usually be the case. The lower the pressure the less is the leakage and cost of running, and 15 lbs. is enough for ordinary purposes.

These small plants are single-stage compressors. A cylinder is required in which the air is compressed before entering the mains, which acts as a storage, preventing the pulsation of the pump being transmitted to the system. As compression is practically adiabatic considerable heat is generated, hence the incoming air—the source of which should be considered—should be as cool as possible and inlet valves should be large, say one-tenth the piston area. Very little oil, and that of high quality, should be used for lubrication, and an oil separator is advisable between the plant and the mains.

Fig. 68 shows a small reciprocating plant with motor and compression cylinder by a British maker.

Even when the number of jets is settled it is very difficult to determine the capacity of the plant necessary, but with the usual partial and intermittent use a $1\frac{1}{2}$ h.p. motor will serve a large building, the motor and pump occupying about 3 ft. by $1\frac{1}{2}$ ft. with some 2 ft. square added

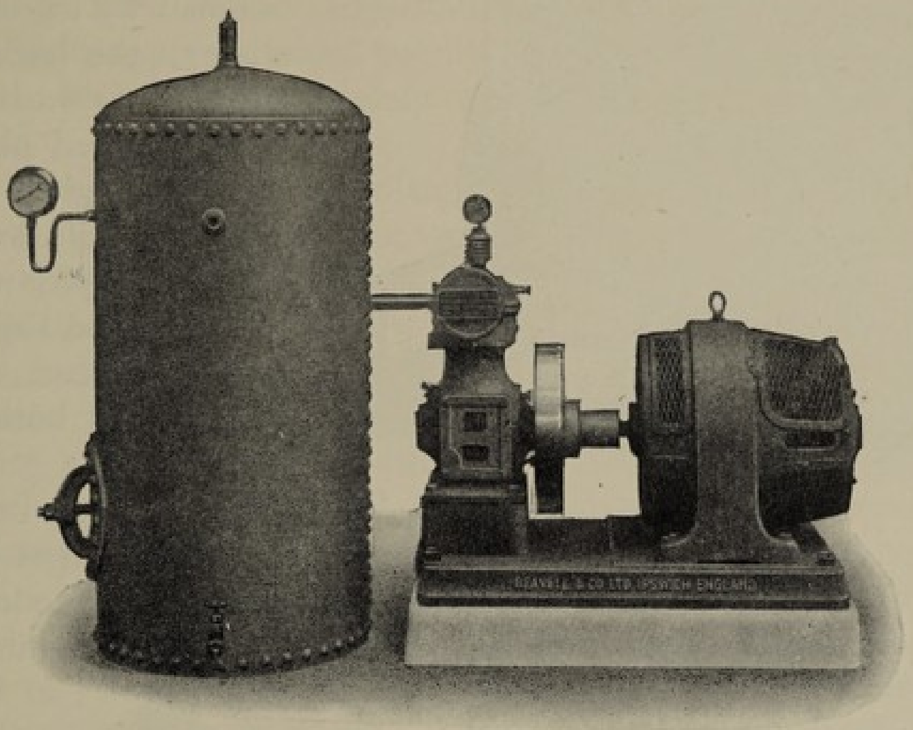


Fig. 68.

for the cylinder. The plant may be automatic in action, the motor coming into operation when the pressure falls below a limit decided upon. Mains—screwed iron pipes—may be 1 in. for a small system to say $1\frac{1}{2}$ ins. for a large institution, and branches in $\frac{3}{8}$-in. or $\frac{1}{2}$-in. pipes.

Refrigeration

Means for producing and maintaining a temperature near the freezing-point of water and of making ice are required in most laboratories, particularly those devoted to zoological subjects. By this means changes can be arrested admitting of prolonged preservation of material, and in many cases this material can be dealt with in a solid condition in a manner otherwise impossible.

The production of cold commercially depends on the application of the principles of heat absorption by rapid evaporation of liquefied gases.

The compounds usually employed are carbon dioxide, ammonia, sulphur dioxide, or methyl chloride. The first two are generally associated with central plants serving various rooms by distributing mains; the last two are mostly used in small self-contained plants.

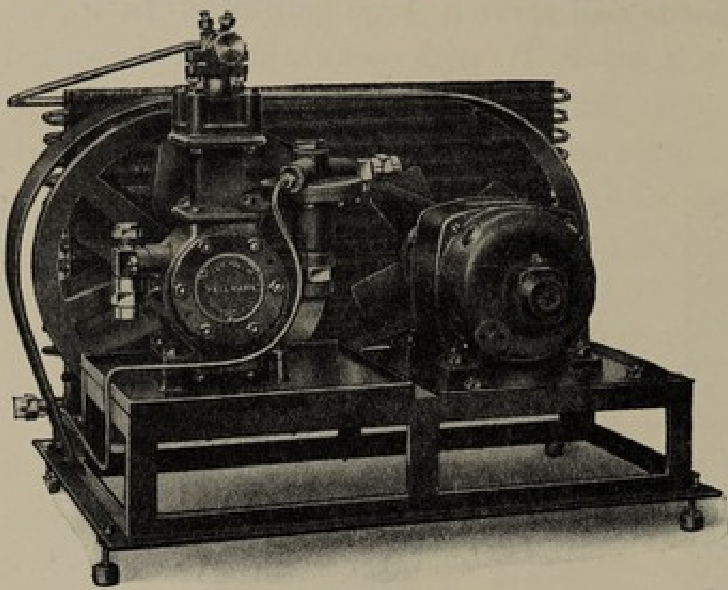


FIG. 69.

Fig. 69 gives an illustration of a small plant operated by methyl chloride, and Fig. 70 one using ammonia as the refrigerant, both motor driven.

In a large institution a first decision will be whether a central plant or several small plants are to be used. If the duty is heavy and a considerable amount of ice is wanted a central plant will be an economy. As a rough guide the writer suggests that, say, six cold rooms of about 300 c. ft. each and 1 cwt. of ice a day would justify a central plant, assuming the rooms not at very great distances apart—an important factor in power losses. If a central plant is decided upon a choice will probably lie between carbon dioxide and ammonia. The cost of these plants does not differ greatly, but the former will probably involve a motor of higher horse-power, and in hot climates have a much lower efficiency. Some prejudice against ammonia plants still exists in institutions, partly because the presence of ammonia is

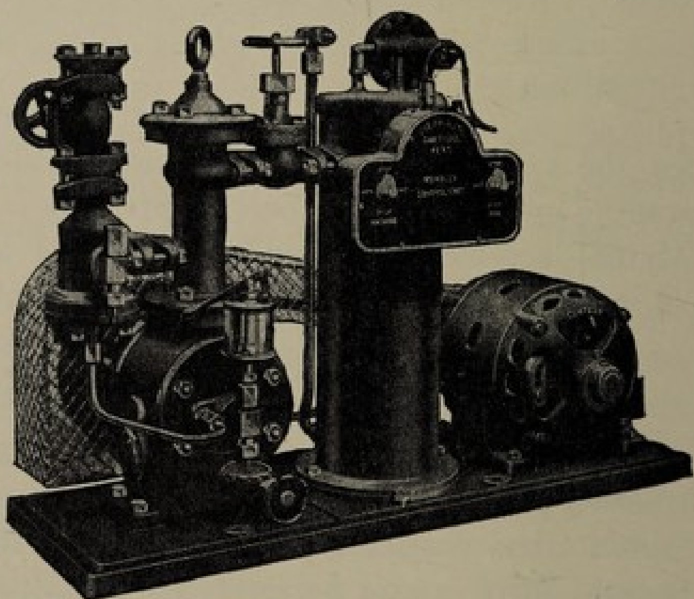


FIG. 70.

dreaded as detrimental to certain experimental work, but it would appear that, for service in buildings, plant worked with ammonia is becoming very general, and requires rather less attention. A firm dealing with refrigerating plant recently supplied the author with data as to the use of these two refrigerants in a large number of institutions, from which it appears that of twenty-two which seem to be concerned with laboratory research exactly half use carbon dioxide and half ammonia.

The general nature of the plant is the same in both cases and consists of an electrically driven motor, not likely to be less than some 10 h.p. operating a compression pump, a condenser consisting of jacketed pipe coils cooled by running water in which the compressed gas is liquefied, and an evaporator whence the re-formed gas is returned to the compression pump. The usual medium for cold circulation is brine, which has a freezing-point considerably below that of water. The brine is stored in a tank and made to circulate by a pump, part of this circulation passing through the plant evaporator where the latent heat of evaporation reduces the brine temperature. The pipes are concentrated in the various cold rooms in the form of coils or grids as required to give the requisite temperature, say 30° F.; elsewhere they must be heavily lagged, compressed cork made in semi-cylindrical form being effective and readily applied. This is usually 2 to 3 ins. thick. As losses on pipe runs, even when lagged, can easily amount to 25 per cent. of the capacity of the plant, concentration of cold rooms near the plant is an obvious economy. For a like reason when ice is required—formed by surrounding water containers in a tank with brine pipes—this should be placed as near the plant as practicable.

As a considerable amount of water is required for cooling in the process of condensing the gas to liquid—a plant of moderate size may require 1000 gallons an hour for example—unless such water can be run to waste, provision must be made for its storage, cooling and pumping. The services of a skilled attendant are necessary for plants of this character, though not continuously. Usually such plants are situated on the lowest floor of the building associated with other machinery. As far as ammonia is concerned it will be observed that this is confined to the plant itself, hence if this can be placed at a reasonable distance from bacteriological laboratories there seems little objection to the use of this medium from a research standpoint.

Where very slight temperature variations can only be tolerated in cold rooms, a D.C. motor is found the best for refrigerating plants.

Liquefied at much lower pressures, sulphur dioxide and methyl chloride are suitable for use in smaller plants operating single chests or rooms or perhaps two or three small rooms closely associated. Small domestic plants for kitchen purposes belong to this class. These plants are self-contained, and for mere cabinets may require as little as ¼ h.p.; they need hardly any attention and as a rule no water supply for condensation. The motor may be actuated by a thermostat rendering them automatic. A limited amount of ice may be made by them.

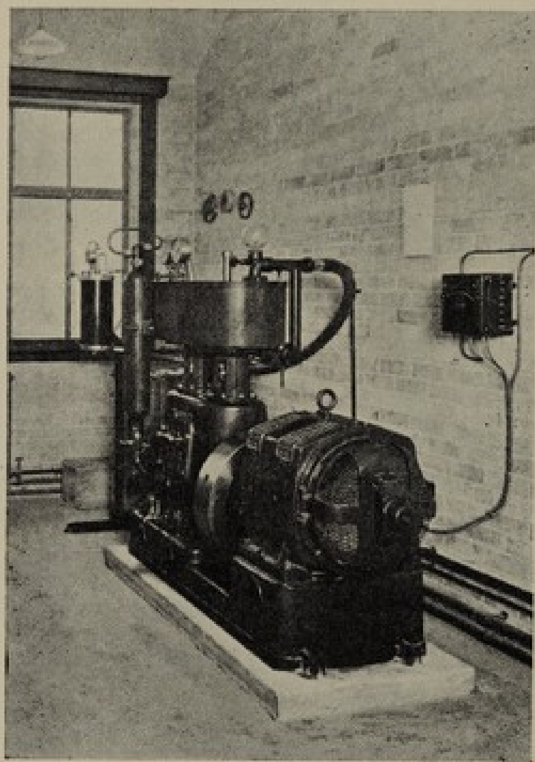


FIG. 71.—Liquid Air Plant, University College, Bangor.

Cold rooms, of course, require special insulation, usually consisting of cork slabs four or more inches thick. The general construction and fittings in the matter of shelves is similar to that for constant temperature rooms (see p. 97).

LIQUID AIR

Though not strictly a service, as liquid air is required for many different branches of science the necessary plant may be conveniently referred to here. The general principles of its production involve the intense compression of purified air, part of which is then allowed to expand, which causes great heat absorption sufficient to cool the remaining compressed air to the liquefaction temperature. The air is first passed through a drum or cylinder containing lime or other ingredient to remove carbon dioxide and moisture, when it enters a powerful compression pump, motor driven and usually direct-coupled, where it may attain a pressure of some 150 atmospheres,[1] effected in

[1] Atmospheric pressure is about 15 lbs. per sq. in.

the pump in two stages. This is followed by passage through a high-pressure purifier to remove the last traces of carbon dioxide and water. The air then passes to the liquefier, a cylindrical vessel containing metal coils through which part of the compressed air flows, while the rest is released in the cylinder and by its expansion produces intense cold, liquefying the compressed air, which is drawn off into vessels at the coil outlet. The pump is lubricated with distilled water which requires some injection gear, and of course adequate safety valves and gauges are necessary. A plant capable of producing one litre ($1\frac{3}{4}$ pints) of liquid air per hour will require a motor of about 12 h.p. and liquefaction will probably begin about twenty minutes after starting running. Such a plant, direct-coupled, may be some 5 ft. long and 5 ft. high and should have a good concrete bed under it. A small water supply—half inch—and a waste, say $1\frac{1}{2}$ ins., to take drainage from the separator, are necessary. It is desirable that this plant be placed in a separate room under the personal control of the operator alone. Fig. 71 shows such a plant recently installed in the Physics Department of University College, Bangor, plans of which will be found in Chapter VI.

Ventilation

The general subject of ventilation is beyond the scope of this book, but some reference to the special needs of laboratories is necessary. Owing to the noxious gases evolved in certain work, the extent of which has been indicated for different subjects by the provision of fume cupboards enjoined, natural ventilation by windows and chimneys is insufficient, and special arrangements are necessary for carrying off these gases. Fume cupboards, combustion hoods, and chemical lecture tables all require special flues, which are generally operated either by electric exhaust fans or draught caused by gas jets.

Ventilation by Fans—When a fan system is proposed all the flues may be combined and operated by one fan which is best confined to this duty, but is sometimes responsible for general ventilation of rooms in addition, or each flue or group of flues may have its own fan. For the continuous work of a large department making heavy calls on special ventilation probably the single central fan system is the better, but these central fan systems usually require large and often complex exhaust trunks and necessarily absorb much power, hence for work which varies in volume and is intermittent, which is usually the case in institutions not concerned with routine work, individual fans, or fans operating small groups of fittings, are to be preferred.

Fans are of two types, centrifugal and disc fans. The former are constructed on the principle of a paddle wheel, and on rotation, throw the air towards the circumference, thus creating a partial vacuum near their axes which causes a flow of air. The latter resemble ships' propellers but have, however, usually more blades. The air in this case is " screwed along " parallel to the axis of the fan. Centrifugal fans are necessary where appreciable resistance to the movement of air exists, which is usually the case when systems of flues and trunking are involved, and the most efficient types are said to be those which possess a large number of small vanes near the periphery, being light in weight and requiring the least power. Ranging from about 1 ft. to 5 ft. in diameter, with respective speeds of say 1000 and 200 revolutions per minute, the rated discharge of the former size may be 2 to 3,000 and of the latter 50 to 70,000 c. ft. per minute when these fans are attached to average systems of trunking, equal to perhaps a maximum of 1½ in. water gauge. Such fans will require respectively about 1 and over 20 horse-power. A 12-in. fan and motor will occupy an area of about 2 ft. by 2 ft. and stand some 2 ft. 6 in. high. Where direct current is available, these fans should be driven by a direct coupled motor which is more silent and compact than belt driving, the motor, of course, being placed outside the fan casing which takes the form of a partial volute. This enlargement of the casing towards the free opening is necessary to prevent loss of efficiency by pressure from the expelled air. Centrifugal fans are also used as blowers when large volumes of air at low pressure are required, as for blast furnaces.

Disc fans are most suitable for use in free air, as, for instance, in a wall opening where air from a cupboard or hood is to be discharged freely into the atmosphere outside. They are usually smaller, lighter, simpler to fix, and less costly than centrifugal fans. Disc fans are also often used for simple duct systems of no great length and of efficient size, and for cases in which the velocity of the air is not to be more than 600 to 800 ft. per minute, Mr. Hubbard[1] gives the following simple

[1] " Power, Heating, and Ventilation," Part II., C. L. Hubbard, U.S.A., 1914.

rule for finding the extraction of disc fans. Multiply the diameter of the fan in feet by its area in square feet and by the number of revolutions per minute and the result by 0·7 (or roughly, take $\frac{3}{4}$ of the result) which will be the number of cubic feet of air discharged per minute. Fans may, of course, be run by other sources of power than electricity, but no other source is, in practice, applicable to a number of small fans. A great objection to fans is the rapid rate of corrosion of those parts exposed to chemical fumes. A simple disc fan placed in the side of a much-used fume cupboard seldom has a life of much more than a year. Careful attention to cleaning and painting the blades will do much to prolong service, and occasionally teak blades are used in place of metal, though this makes the fan rather cumbrous.

The only means of entirely eliminating corrosion is to use a type known as an "ejector fan." This, instead of sucking up fumes, discharges a current of fresh air through a nozzle surrounded by an annulus, which forms the termination of the extract trunking system. The strong air current induces a draught in the annulus which gives the necessary ventilation current. If the nozzle and annulus are made of glazed earthenware no metal whatever is in contact with the corrosive gases. Such fans require a good deal more power to produce the same draught as the ordinary type and are less certain in action. Probably the exact relation between nozzle annulus and trunking which should exist to produce the best result has yet to be established. They also occupy rather more space and are slightly higher in cost. Perhaps on the whole they may be recommended for very corrosive local situations rather than for general systems.

Details of an ejector used at one of the schools, illustrated in Chapter VI., are shown in Fig. 72.

Fan motors of course require a starting panel with a resistance which can be thrown out of circuit gradually, and this starter should be placed where control is most frequently required. An independent starting switch close to the fan will be found useful for repairs and cleaning. Fan and motor, generally in the roof, should be reasonably accessible, otherwise maintenance tends to be neglected. Noise may be reduced by some vibration-absorbing seat and slow running, which means a larger fan for a given output; high-speed fans are generally noisy.

Fans are sometimes placed in a basement where they are more accessible for the engineer in charge of other plant, and where large main ducts are more readily arranged. When lower floors only require this service in a large building, such downward suction may sometimes be preferable.

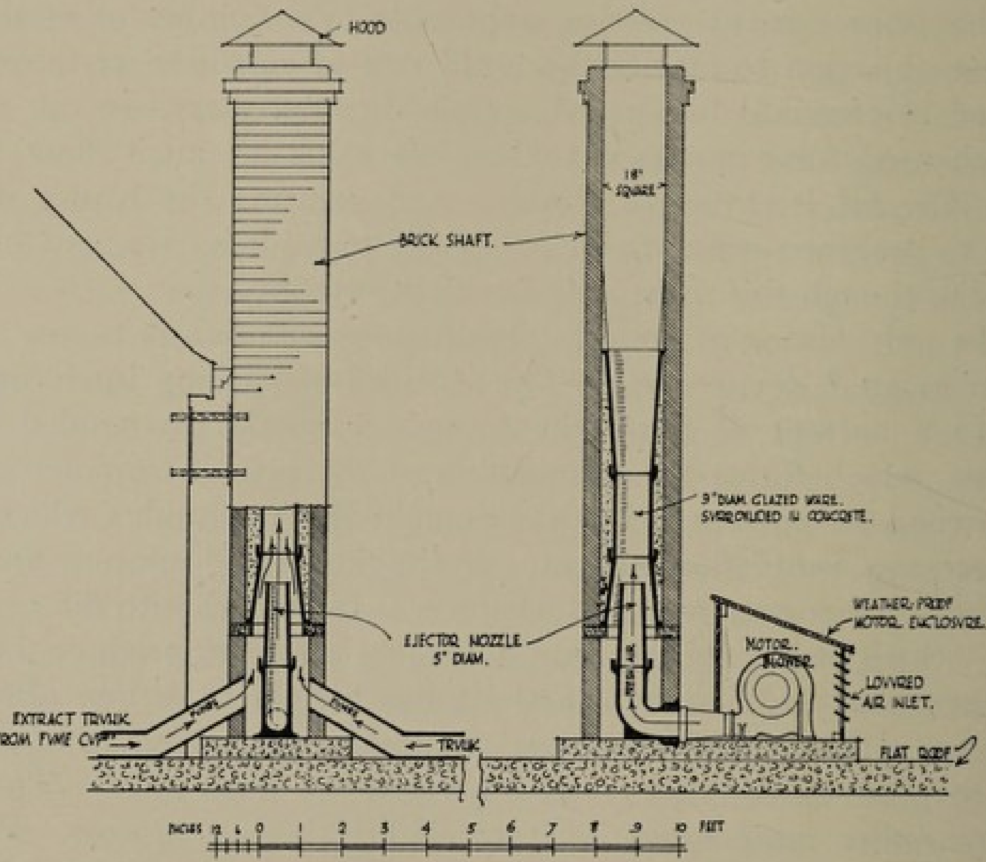


FIG. 72.—Details of Ejector Fan Exhaust.

Ventilation by Gas—The use of gas jets for ventilation depends upon the production of a column of hot air in the flue which, being lighter than cold air, tends to rise. Apart from the exceptional condition, in which the flues are combined with a chimney shaft, the movement of air in which is maintained by furnace gases, each flue requires a separate gas jet at its junction with the fitting to be ventilated. Experiments seem to have shown that the placing of bodies over the flame to absorb and distribute the heat is not effective, and that it makes no difference whether the flame is luminous or burnt mixed with air. Usually a Bunsen burner is employed, but of a more powerful type than those used on students' benches. It is impossible to give the consumption necessary for efficient ventilation, which depends on the length, directness, and size of the flue, and also on the air temperature. In winter, owing to the warmer air in the building, flues will often work with very small jets, but the gas piping for each flue should be arranged in anticipation of, say, a consumption of 20 c. ft. per hour. Metal soon corrodes in these flues, and porcelain burners are to be recommended, but corrosion of metal burners may be much reduced by placing them below the actual mouth of the flue itself, and by frequent painting. The use of gas has the advantage of allowing each fitting to be ventilated only when in use, and also saves much complex trunking, though it may involve thicker wall piers. It will be found in practice, however, that if gas is to be economized, it must be capable of being readily lighted, extinguished, and observed.

Construction of Flues—If the location of fittings requiring ventilation can be definitely settled before the contractor's drawings are prepared by the architect, flues may be built in walls as far as such flues are substantially vertical. Such construction is specially applicable to gas-operated individual flues. These may be 6 to 12 ins. in diameter according to length, and are best lined with collarless pipes which ensure a smooth and regular interior. Where walls or partitions are too thin to admit of flues, pipes may be built up against them and cased in partition slabs. Flues, however, are often fixed on wall surfaces, and are then best made of material consisting of cement, inert matter, and asbestos, as now commonly used for roofing and lining walls. This material must contain a sufficient proportion of asbestos to make it to withstand reasonable heat and remove the brittleness conferred by the other ingredients. Its plastic nature enables it to be moulded in any form, and exposed flues may be rectangular in section which will improve their appearance. The action of acid fumes on those flues does not appear to be great, but it is desirable to give them a good coating of pitch internally, and they should be jointed in special cement supplied by the makers.

Trunks made of sheet metal, even when protected internally, have a very short life when conveying chemical fumes. The author's experience is that this is true even of sheet steel coated with lead, recommended by some engineers as suitable for this purpose. If metal flues must be used occasionally in certain circumstances, where their light weight gives them paramount advantages, they should be heavily coated with bitumen inside and well painted outside, and all but small sizes require stays at frequent intervals. Smoothness and the absence of sharp bends has a very considerable effect in aiding efficient draught. The general principle to be adopted in arranging a flue system is to provide a trunk section throughout, of progressively increasing sectional area in the direction of the draught, equal in area to the sum of the branches openings into the various fittings behind it. For example, if a 4-in. diameter (12½ sq. ins. in sectional area) opening from a fume cupboard is attached to a trunk, on the entrance of another 4-in. flue, the trunk sectional area should increase from 12½ to 25 sq. ins. and acquire subsequent enlargements equal to the sectional area of every branch picked up. Junctions should not be at right angles, but enter acutely in the direction of the air current. The same rule, of course, applies to the junction of any branch trunks into the main trunk. This means that in a large system, the main trunk may become a very preciable constructional item, possibly five or more feet square. If the length of horizontal flues is very great, the sectional area should increase slightly more than that of the sum of the flues picked up, because such lengths have no natural up-draught. All suction of air in a downward direction should be avoided if possible as the exhausted gases are invariably warm, but if this is necessary owing to the main trunk being in the basement, a still greater area allowance should be made. No system can be apportioned with such accuracy as to provide for every variable factor, for which reason some means of adjusting the draught in different branches after the laboratory is in use is very desirable. This may be effected either by sliding doors similar to dampers in kitchen flues, or by pivoted discs fixed in the flues and capable of rotation on a central axis so that they can be placed to practically close the flue or in any intermediate position until, with their edges in the direction of the current, they offer no appreciable resistance (Fig. 73). The baffle may alternatively be placed with a vertical axis. Means should be provided for permanently fixing any such adjusters when a satisfactory condition of equality between the draught in the different branches has been obtained by trial. The smaller and longer the flues, and the sharper and

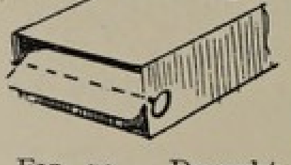


FIG. 73. — Draught Adjuster in Flue.

more numerous the bends, the greater is the frictional resistance, and since this increases very nearly in proportion to the square of the velocity of the air current at high speeds, a low velocity will prove an aid to efficiency.

Flue Terminations—Condensed vapours are liable occasionally to drip from fume cupboard flues, hence flue mouths in the fittings should not be over areas likely to be used for apparatus. To meet this, the openings are often in the sides or back of the cupboards and not in the tops. When built into walls terminations will naturally be vertical openings, and should be lined with glazed bricks or tiles. When *on* walls pipes may have a terminal bend to make a side junction with the cupboard. Sometimes the flue is continued to near the bottom of the

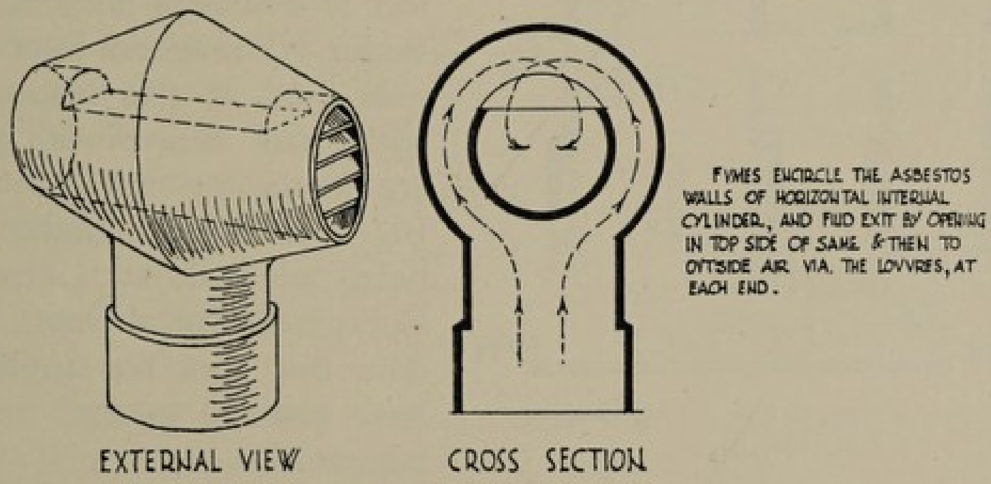


FIG. 74.—Torpedo Cowl for Ventilation.

cupboard where a small hole for conveying noxious gas, given from a tube of some apparatus, is provided. The passing of such tube into the flue itself ensures a much better atmosphere in the cupboard, but such an operation is not practicable in most experiments.

Flue exits into the open air, more particularly those from gas-operated flues which have no great power behind them, require placing so that winds in certain directions will not cause down-draughts. If a vertical outlet be placed in a wall, when wind blows against this wall, down-draught is exceedingly likely. Open chimney pots, owing to higher surroundings or other more obscure causes, sometimes fail in a similar manner. Naturally single story buildings and top story departments present most difficulty owing to the very short flues available which with gas give little up-draught. Brick stacks covered with a stone slab and with side openings opposite one another are often suitable.

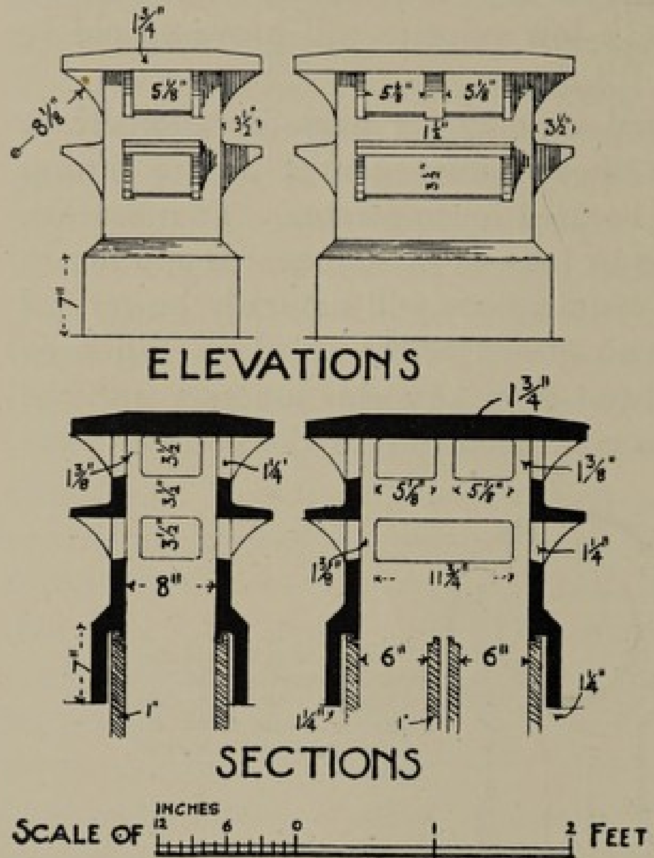


FIG. 75.—Detail of Flue Exits, Chemical Institute, Berlin.

A series of experiments made a few years ago on a one-story building in a windy situation[1] resulted in the decision to terminate asbestos flues with the cowl[2] illustrated in Fig. 74, which was placed with its long axis at right angles to the prevailing winds. This cowl has been found efficient. Much attention was paid to this subject at Fischer's laboratory in Berlin. The special terra-cotta pots used at this institution, with their dimensions, which are important, are shown in Fig. 75. This pattern has been adopted at University College, Chemical Dept., London, but does not appear to have attained general use in laboratories.

DRAINS

Laboratory drains differ widely from house drains, and although local sanitary authorities without experience in these matters sometimes seek to impose upon science buildings regulations in every way proper to house drainage, some of these requirements (particularly in the matter of traps) are not applicable. Ready accessibility is a first essential, hence long lengths of drain, except where vertical or at such high angles as to make this impossible, should not be formed of enclosed pipes but of channels with movable covers, or if these are impracticable with ample inspection openings, including one at every change in direction.

Wastes from Fittings—From the actual fittings, the short lengths

[1] By the late Professor Orton and the author at Bangor.

[2] Torpedo Cowl—patent of an asbestos company.

of drain necessary for discharges to floor channels are usually either of lead, $1\frac{1}{4}$ or $1\frac{1}{2}$ ins. in diameter,[1] or better in stoneware pipes 2 ins. to 3 ins. in diameter. These pipes should not be trapped, except where smells from drains are anticipated, as in certain biological work, or where volatile liquids, such as bromine, are much used in chemical laboratories. The amount of corrosion which takes place in lead pipes when vertical is exceedingly small, and they are more compact and readily fitted than sanitary pipes, which are only made in lengths of from 2 ft. to 3 ft., and have walls about $\frac{1}{2}$-in. thick, which allowance must be doubled for the collars at each junction. These wastes usually require some support by wood framing or hinged iron holderbats (holdfasts) and should end 2 ins. or 3 ins. above the channel, into which they discharge to clear the flow from other fittings. Further, a slight bend to make the opening face the direction of the flow is desirable to prevent local overflow, or the vertical deposit of any solid matter (Fig. 76). This is readily arranged with lead pipes, and in the case of glazed pipes, special shoes are obtainable. Sink outlets connected to these wastes have been referred to on page 25.

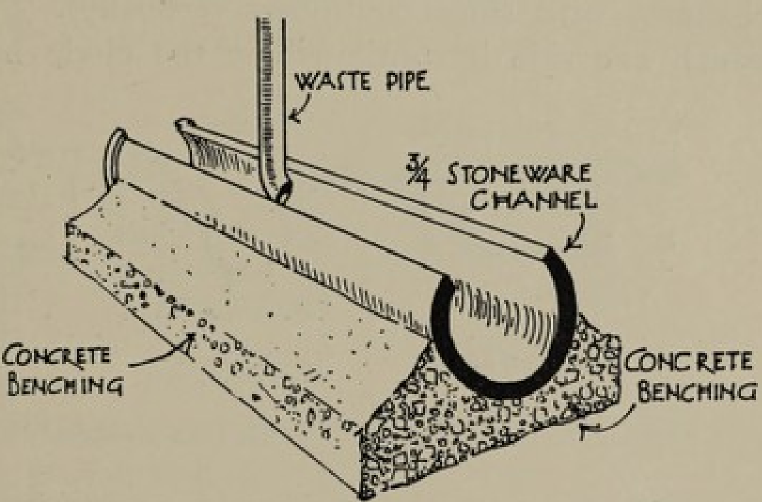


FIG. 76.—Waste and Drain to Laboratory Benches.

Channel Drains—Drainage channels of lead are often found in old laboratories, but these are very vulnerable to mercury and nitric acid and buckle with hot liquids. The writer has personally interested himself in trying to find some new suitable material, but at the present time is unable to recommend anything for general use equal to the usual glazed ware channel. Vulcanite seems a promising material, and he has used this as single 10-ft. lengths in two recent improvement schemes in inorganic laboratories, where it is successful. Cast iron of certain special composition is said to be acid-resisting, but is at present far too costly to be considered.

[1] "Diameter" always refers to internal diameter unless otherwise stated.

10

Ordinary cast iron, unless frequently cleaned and painted with bitumen, develops rust nodules. Steel pipes are now made with a bitumen coating spun on internally, but its melting-point is too low to admit safe use for chemical drains. Wood coated with bitumen is occasionally used, and such drains, well made and attended to, can be quite satisfactory, but are not widely employed.

Glazed channels are made in a great variety of forms, 3, 4, 5, 6, 9, and 12 ins. in diameter, in lengths up to 3 ft., and also in appropriate bends, junctions, and taper pieces. The usual forms are half channels (semi-circular in section), three-quarter channels and troughs (half channels with sides continued vertically). "Benched" channels, in which one side is continued on the circle higher than the other for

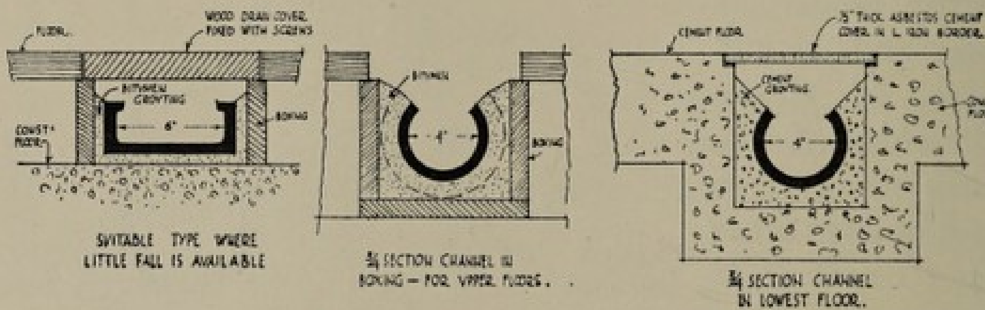


FIG. 77.—Laboratory Drain Channels.

flow round curves, are also made, as are flat channels (three sides of a rectangle in cross section).

One of the essentials for successful use of these pipes depends upon their support upon material not likely to move. When placed in the centre of benches, they should rest on brick or concrete, or be placed in solid floors and should not be supported by the bench framing, unless the whole drain be placed in a wood trough entirely filled in with pitch, which in this case will form the jointing material to the pipes, and can give a very satisfactory result. Raised slightly above the floor they are more accessible from the ends and locker backs of the fittings than when sunk in the floors. No perfect jointing material capable of resisting all organic liquids which find their way down sinks has yet been discovered. Probably the best plan is to joint and bed the pipes in strong portland cement mortar, rake the joints well out before the mortar sets, and when set, fill the joints thoroughly with bitumen worked in and smoothed with a hot iron. This filling should have a high melting-point, and near any hot-water waste is likely to soften and should here be used sparingly. When sinks are only necessary at the ends of benches, as, for example, in double chemical benches accommodating four students, no drains in the benches are necessary, and this condition should always be aimed at.

Channels in Upper Floors—Difficulties often occur in taking drainage through suspended floors to the outer walls, and unless a double floor—certainly the simplest solution—is provided, it is usually essential to design the drainage in relation to the floor construction in order to reconcile it with steel joists or concrete beams. Some fall must be given to the drains, and as many modern floors, apart from their surface coverings, are not more than 6 or 8 ins. in thickness, drainage lines in such cases may govern the constructional floor members.

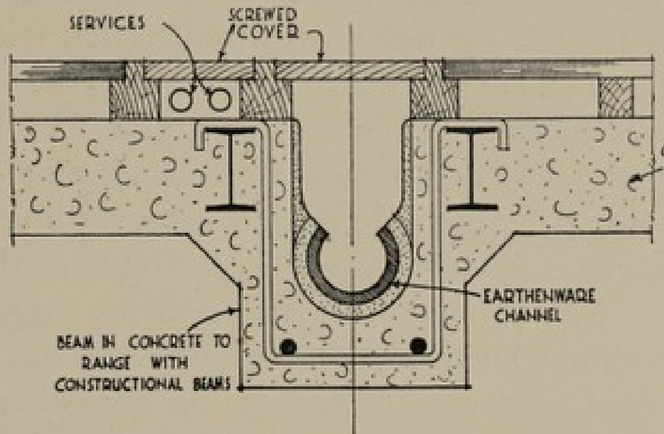


FIG. 78.—Floor Drains and Services.

Deep steel joists may sometimes be drilled for the passage of such lines of drainage, or when parallel to drainage lines. Sometimes these may be run as twin joists with a drain between them, or a section of a floor, suitably reinforced, may be dropped to give the necessary depth. These, however, are architects' problems. A rebated frame and cover, provided for floor drains, may sometimes also conveniently enclose gas and water services if these have, as is usual, to cross floors (Fig. 78).

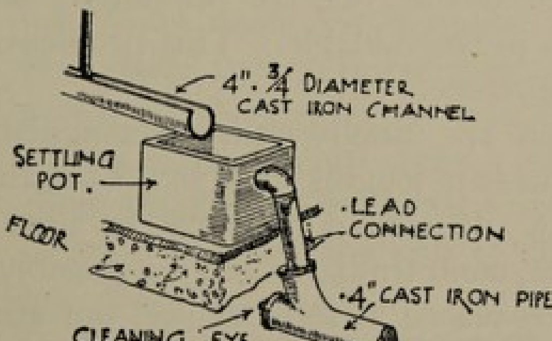


FIG. 79.—Settling Pot and Connection to Drain slung on Ceiling.

As to the size of these channels, a 4-in. three-quarter channel is usually sufficient, but if the system is extensive, or it is anticipated that large washing-up sinks will be discharged when nearly full and without the use of grids, a 6-in. channel will be desirable for the main trunks, but such sinks will be often on outside walls, and are then best arranged to discharge directly into the outfall, instead of into the floor channels. This outfall is usually a large open head attached to a heavy and well-tarred iron pipe, for the drains of upper floors, but may be a glazed ware pipe suitably cased in.

Cases often occur, especially where drainage has to be contrived in existing buildings, in which it is quite impossible to take the drainage out in the thickness of the floor. In such instances, heavy cast-iron pipes (which are made in 9 ft. lengths) with elbows jointed in " blue lead " (metallic lead) cut through the floors, may be suspended from the ceilings below. A piece of lead pipe may be used to make a suitable connection with the floor or bench drains in such cases, and this will be assisted by the interposition of a settling pot, further referred to on page 150. A cleaning eye is desirable at the upper end of the ceiling pipe. Fig. 79 shows the arrangement suggested. If painted to match the ceiling, such pipes are much less of an eyesore than might be expected, and can, of course, be encased as beams, though best left exposed. The corrosion of iron pipes has already been alluded to, and if these are used they should be scraped and well tarred inside periodically. Glazed ware drains in a box filled with pitch, which would admit of suspension of a reasonable length, form an alternative to iron drains. It must be confessed that up to the present no wholly satisfactory material for suspended chemical drains of any length seems available. Certain nickel alloys are promising but are prohibitive in cost at present. Vulcanite is likely to prove valuable. This problem, however, should not be of frequent occurrence.

Wood Channels—Wooden channels are usually either rectangular or V-shaped in section. They can be made in lengths equal to the length of boards obtainable, say, 12 ft. to 16 ft. If rectangular, 3 ins. by 3 ins. internally is sufficient for small branches, main trunks increasing possibly to 5 ins. by 5 ins. Junctions are often placed at right angles, but are better, though less easy to connect, splayed, to follow the current. These channels must not be placed in the ground, nor should they be bedded in concrete, but supported on wood bracketings with free air round them to avoid the possibility of rotting. They may be made of any wood—deal is quite suitable—which must be well seasoned and about 1 in. thick. Though sometimes grooved and tongued together, straight jointed boards, strongly and carefully nailed, are really as good, given an efficient covering. Junctions in straight lengths of channel are best made with iron tongues. The ends of the boards should be grooved and well covered with pitch, after which the tongue, carefully bent to fit, is driven well home into one section and the other side then driven into it when the bed and bearing is ready so that the joint need not be afterwards disturbed (Fig. 80).

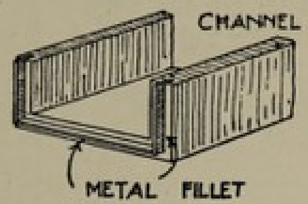


FIG. 80.—Iron Tongue at Straight Junction in Wood Drain.

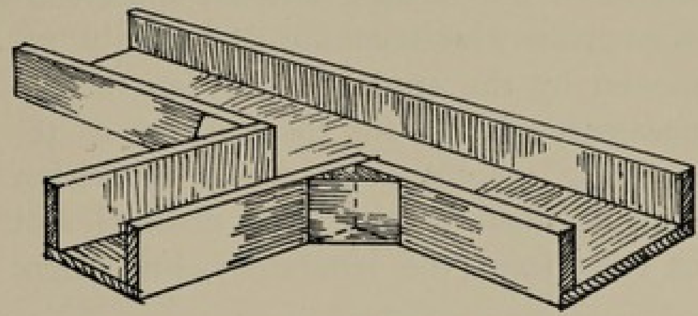


FIG. 81.—Cross Junction in Wood Drain.

The use of tongues for right angle and splayed junctions requires great care, as the groove is then across the grain of the wood, which is apt to split, and probably butt (flat) joints nailed together after the faces have been well covered with hot pitch are the best, strength being added by the use of external angle fillets (Fig. 81).

Wood drains are found most frequently above floor level in the fittings, in which case the V-shape is probably most common. They have been used, for example, in the chemical department at Bristol University, where, in benches 9 ft. long, with two sinks, they are about 4 ins. in vertical depth and about the same widths at the top internally. As in the instance cited, small fillets are often placed at the top to increase the capacity and to allow for splashing (Fig. 82). The V form has advantages in the matter of discharge to lower levels at the end of the bench. At Bristol University, these channels are movable and are drawn out through doors at the ends of the benches for annual re-pitching, a very desirable arrangement.

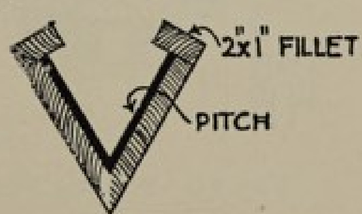


FIG. 82.—V-Shaped Wood Drains as Used in Benches.

Wood drains should be put together with hot bitumen on their jointed surfaces, then be given a good coat applied hot at the shop, and a further heavy coat melted down with a blast lamp to form a complete, and finally, hard, almost glossy surface after fixing junctions and branches.

Settling Pots—Opinions differ as to the use of settling pots or gulley traps in laboratory drainage for the purpose of catching material which should not find its way into the drains external to the building. Where there are no drains in the fittings, and all sinks contain grids which cannot be readily removed by the students, they are hardly necessary, except for the purpose of recovering mercury, for which provision may be made at the main channel exit or exits from the laboratory, but where

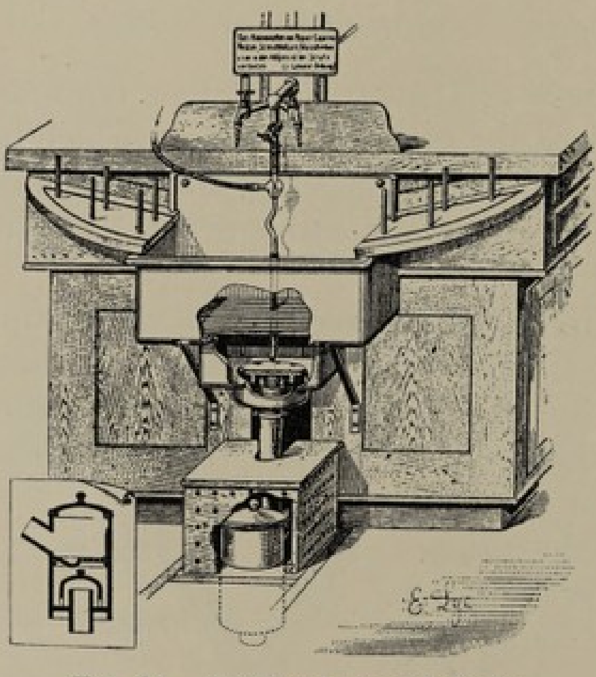


Fig. 83.—Settling Pots at Leipzig.

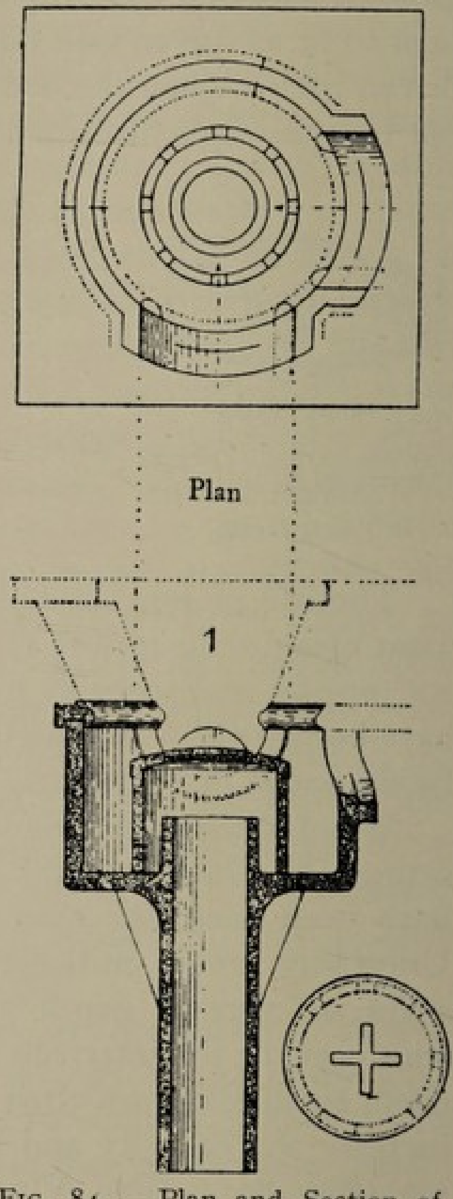


Fig. 84. — Plan and Section of Settling Pots Used in the Chemical Institute, Berlin.

a sudden drop is necessary, as often occurs at the end of bench drainage, some enlargement for the cascade is required and a settling pot meets the difficulty. Usually of earthenware, 10 ins. to 12 ins. square inside and the same depth, but sometimes cylindrical, these pots have spouts well below the top, the sectional area of which should exceed the sum of the areas of the sink wastes, or grids if provided, behind them, to allow for their slight discharge head. The discharging spout is sometimes carried down as part of the earthenware inside the pot to prevent floating bodies passing on to the drains, and enables the pot to discharge as a syphon.

Very elaborate forms of pots are used in some institutions. Fig. 83 shows the arrangement at the bench ends at Leipzig and Fig. 84 a plan and section of those at the Berlin chemical laboratories described in Chapter VI.

CHAPTER VI

LABORATORY DESIGNS

THIS final chapter is devoted to the description of designs for science buildings, mostly recent, and a few older examples. School laboratories are taken first, followed by university types subdivided into (1) chemistry and physics departments ; (2) biological subjects, foreign designs being placed at the end of each group. In the case of British designs, kindly contributed by architectural colleagues, acknowledgment is made by appending their names to the plans loaned. For a number of the examples shown from abroad the author is indebted to the Rockefeller Foundation of America for permission to reproduce illustrations from its books on Medical Education, and such illustrations are indicated by the letter " R."

Probably no selection of designs would be free from criticism on the score of omissions, and with an obvious limit imposed, those shown represent an attempt to illustrate different types for the subjects under review.

SCHOOL EXAMPLES

The London Orphan School, Watford

This little building, shown in plan, Fig. 85, is given as an example of a very small scheme where the greatest possible economy had to be effected in the matter of outlay.

The building is of stock brick with 14 ins. external walls and slated roof. The walls are plastered internally, the floor of wood blocks on concrete. The building is 11 ft. high to the plate with the roof collar ceiled at 14 ft. The laboratory is 36 ft. by 22 ft. 6 ins., and possesses four double benches giving a length of 3 ft. 6 ins. each for 32 boys, with, however, only 25 sq. ft. of floor per head, a very conservative allowance, in extenuation of which, it may be added, that 14 is the maximum leaving age. The benches have teak tops, drawers and open shelves in place of cupboards below, and movable reagent shelves and sink covers to admit of the use of the benches both for chemistry and physics. Cases are fitted into the windows for balances, and gas for light and heat is supplied by an overhead system, the pipes not being fixed to the benches. One of the fume cupboards and a large sink serve both the laboratory and preparation room, from which room a step ladder gives access to a floor over and to the roof (as shown in the section, Fig. 85), the whole of which is made available for storage.

Fig. 85.

The lecture room, 14 ft. wide, has staging to the desks on a raised steel and concrete floor, under which is the boiler house, and the open passage, floored over at 9 ft., gives some further storage space which is thrown into this room. The laboratory was erected in 1907, and as the whole details of cost happen to be in the author's possession, including that for equipment, it may be interesting, for comparative purposes, to give the figures, which were: Building, including heating plant, £880; Fittings, including desks and blinds, £277; Apparatus (elementary chemistry, mechanics and heat), £187; Total £1344.

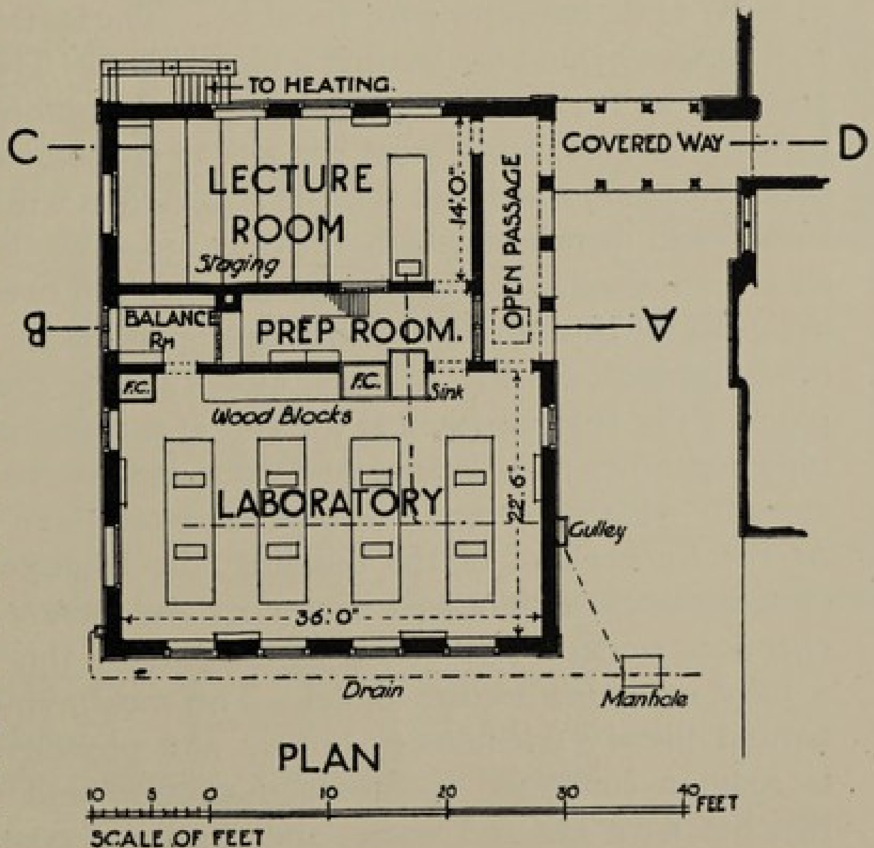
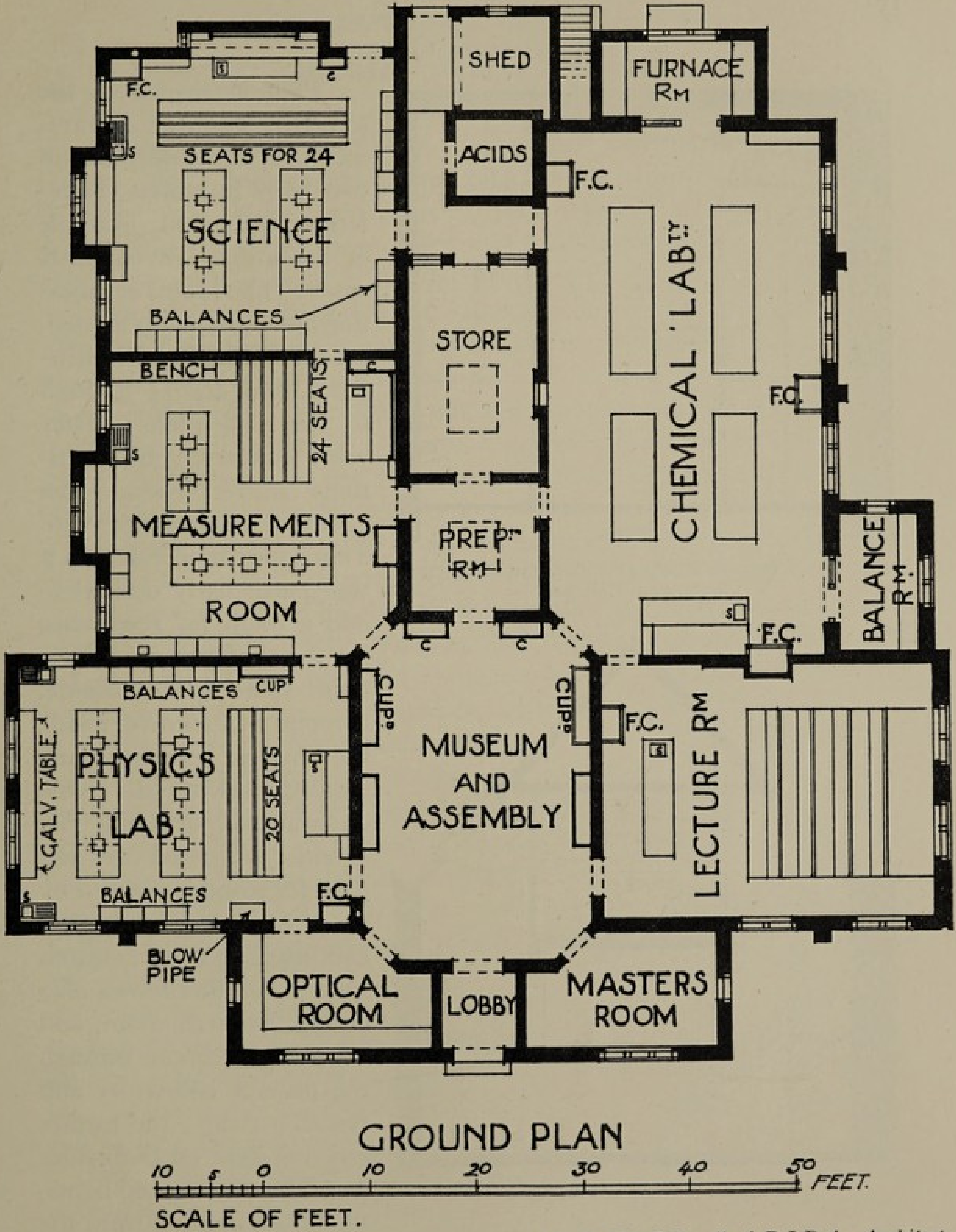


Fig. 86.—Science Block for the Boys' Side, London Orphan School, Watford.

Science Building, Shrewsbury School

This one-story building for the teaching of chemistry, physics, and natural history, is shown in Fig. 87. The purpose of the design was to centralize the attendant's and store rooms and to avoid waste of space in corridors, and it will be noticed that the entrance hall, also used as a museum, gives access to three of the four laboratories and the lecture room besides the two smaller rooms on the frontage. The remaining laboratory has an external door or can be approached through the measurements room, and the attendant can obtain independent access to all the rooms. The doors are made of extra thickness to reduce the transmission of sound. To deal shortly with the individual rooms—the master's room is fitted up as a small laboratory for private use. The lecture room, 31 ft. by 24 ft., has seating for about 60. The lantern screen is a prepared wall surface behind the lecturer's blackboard. The chemical laboratory, 50 ft. by 25 ft., contains 28 places. Water pumps are provided on the benches and also small pilot gas jets to economize the gas used by the bench burners, which can thus be relighted at will. By the use of space under wall benches, which provides 30 extra lockers, 86 lockers in all are obtained. On these side benches are twelve balances specially designed for this laboratory with opal glass backs. The bench tops are of teak, waxed, the floor of maple blocks and the drains of glazed channel pipes. The furnace room at the end of the laboratory is used for blowpipe and other noisy or noxious work and is separated from the laboratory by a glazed screen. A separate store room is provided for acids. At the further end of the building, the laboratory called "Science" on the plan, is a combined laboratory and lecture room and is used for chemical work. The recess at the side of this room accommodates a fully equipped lecture table. The measurements room, in which natural history (elementary botany and physiography) is also taught, is again a combined room for theoretical and practical work. The benches have gas and water, and the room contains twelve balances. The adjoining physical laboratory, fitted like the preceding rooms, provides for a class of 22, and off it is an optical room. Dark blinds are installed in all the rooms except the large chemical laboratory.

The plan, which is somewhat unusual, is interesting as showing what can be done in economizing space.



[*A. E. Lloyd Oswell, A.R.I.B.A., Architect.*

FIG. 87.—Science Block, Shrewsbury School, as arranged by the Senior Science Master, Mr. C. J. Baker.

Cheltenham College

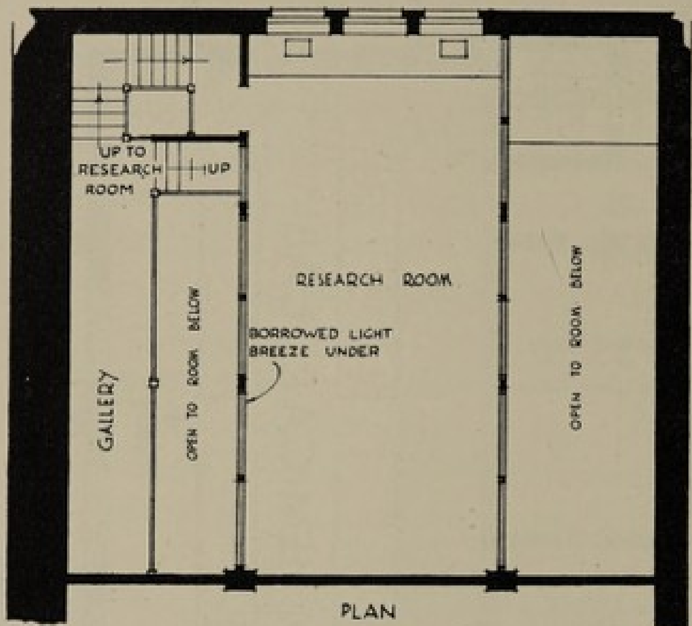


Fig. 88.—Research Room and Physics Laboratory, Cheltenham College.

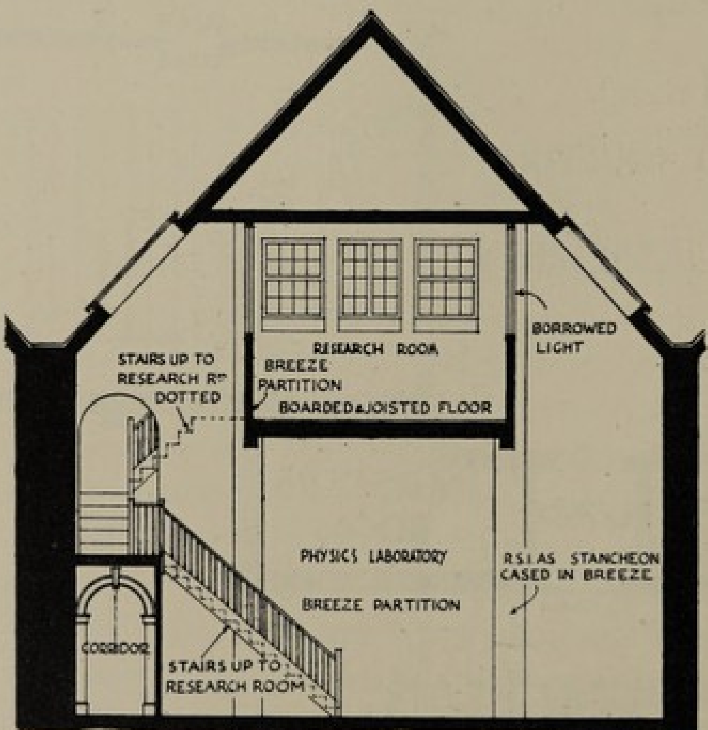


Fig. 89.

This extension of the existing science department, by the absorption of two large museums, is referred to as an example of the utilization of waste space. The rooms in question are entirely top lighted, except for high gable windows, and are 25 ft. high to the wall plate. They were converted by partitions into physical and chemical laboratories, with a corridor for access. As it was particularly desired to add a room for researches by the staff for which no floor space was available, a room was formed inside the physical laboratory suspended between the gable end wall and partition. The corridor is floored over and used for storage, reached by a stair from the laboratories, continued up to the research room. Fig. 88 shows a plan of this research room, and Fig. 89 a section through the physics laboratory and research room; the former receives light on both sides from the existing top lights, the latter, lighting from the gable windows and by the use of glazed screens to the upper part of its side walls, borrowed light also from the skylights of the laboratory.

Beaumont College, Windsor

This is an example of a recent school laboratory, opened in 1930. It is confined to one floor shown in Fig. 90. The building is designed for two upper floors to be erected and used for other school purposes at a later date, space being reserved for a staircase at either end. On the frontage are two large elementary laboratories for physics and chemistry, each 40 ft. by 25 ft., the former with a small store and optics room, and the latter with store and balance room next the central entrance. Flanking the chemistry laboratory is one for biology, 41 ft. by 20 ft., and at the other end a lecture room for forty-eight boys with preparation room adjoining, next the side entrance for goods and close to the general store room and workshop, whence a corridor gives connection to the school buildings. At the back are advanced physics and chemistry laboratories, with top lighted store and balance room between them. The system of departmental stores adjoining each laboratory, into which materials are drafted from the general store, should be noted.

These stores have hatches to the corridor for distribution external to the laboratories. The building is of brick faced with 2-in. multi-coloured bricks and portland stone dressings. The floors are wood blocks in the rooms and terrazzo in corridors. Joinery is in oak.

Fittings are of Douglas fir with teak tops, fume cupboards, and combustion bench tops in red tiles. In the lecture room, owing to wall space requirements at the lecturer's end, the lantern screen is arranged with a counterpoise to assume a horizontal plane at ceiling level when out of use. Chemical ventilation is effected by a central fan attached to asbestos trunking. A 100-ampere cable supplies A.C. current as such to the benches and transformed to D.C. by a large Westinghouse stationary transformer on the principle of a " trickle charger," obviating the necessity for accumulators. Hot water is supplied to wash-up sinks by heavily jacketed electric heaters and by gas heaters to other sinks requiring it. For filtration a vacuum plant has been provided which also serves the physics laboratory for vacuum experiments, a special line to give absolute vacuum being arranged to the lecture table.

The building, which included somewhat extensive foundation work, cost, with its heating, lighting, and drainage, 1s. 9½d. per cubic foot, while the fittings and services complete, apart from apparatus, cost, in addition, £2900, a few fittings being old ones re-modelled.

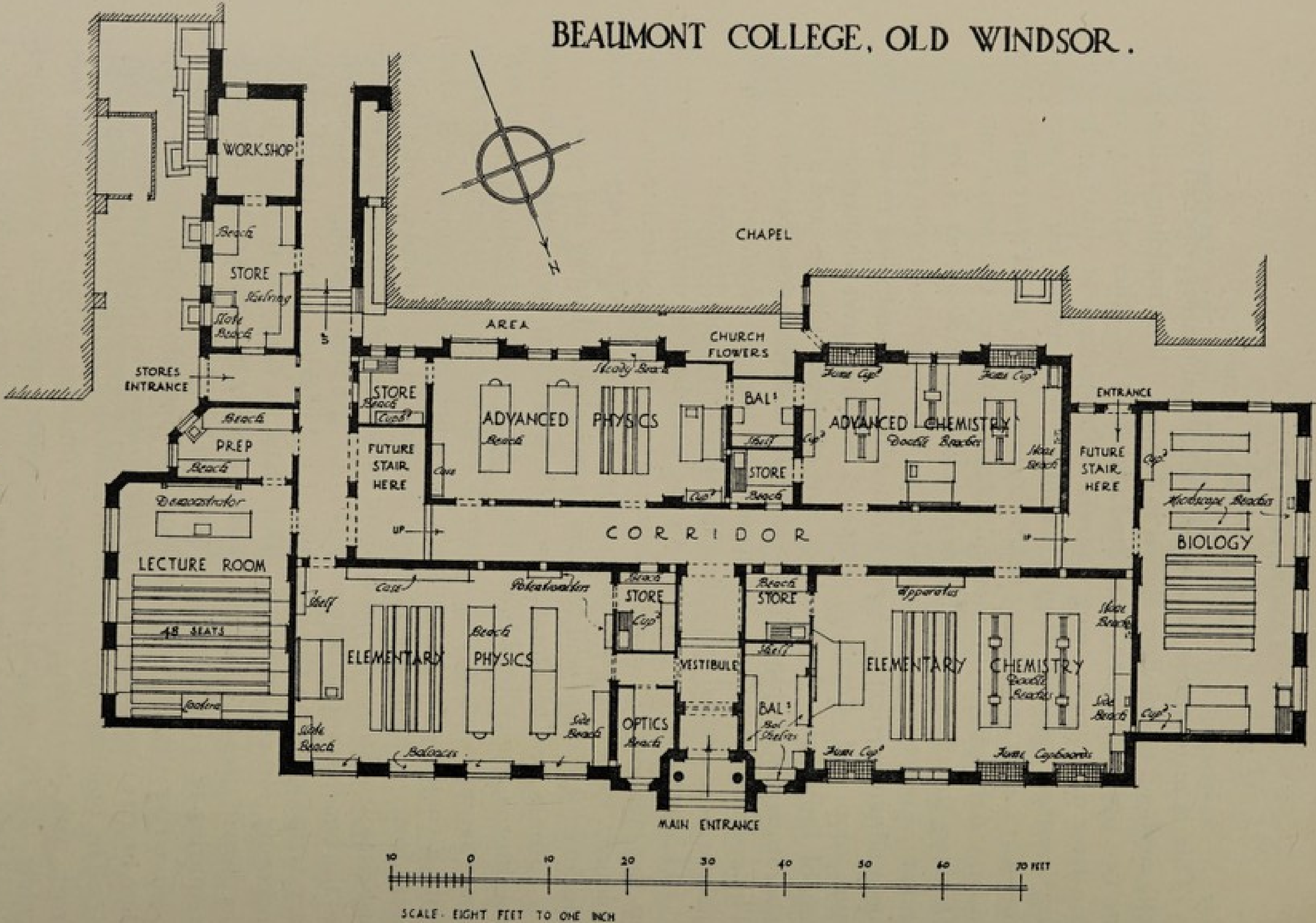

BEAUMONT COLLEGE, OLD WINDSOR.
N
CHAPEL
AREA
CHURCH FLOWERS
WORKSHOP
STORE
STORES ENTRANCE
PREP
LECTURE ROOM
48 SEATS
STORE
FUTURE STAIR HERE
ADVANCED PHYSICS
BAL^s
STORE
ADVANCED CHEMISTRY
ENTRANCE
FUTURE STAIR HERE
BIOLOGY
CORRIDOR
UP
UP
UP
ELEMENTARY PHYSICS
STORE
VESTIBULE
OPTICS
STORE
BAL^s
ELEMENTARY CHEMISTRY
MAIN ENTRANCE
10 0 10 20 30 40 50 60 70 FEET
SCALE. EIGHT FEET TO ONE INCH

FIG. 90.

Highgate School Science Building, Highgate, London

This building, opened in 1928, forms two sides of a court completed by the existing main teaching block, and provides for chemistry, physics, biology, and engineering. Fig. 91 shows the ground plan. The engineering shop contains a great variety of plant, including aeroplane engines and the conversion power plant for the laboratories. A carpenters' shop with an aeroplane body in the bay adjoins the engineering department. On the Southwood Lane frontage at a lower level is the large lecture hall, seating 150, with table fully equipped for experimental purposes. This frontage was only acquired after the rest of the building had been erected. The first floor, Fig. 92, contains an elementary physics laboratory, 49 ft. by 29 ft. for 36 boys, separated by a store room from an advanced laboratory, 39 ft. by 20 ft. for 24, adjoining a dark room, the physics lecture room for 48 being on the other side of the corridor. In the wing is a combined biology lecture room and laboratory, 48 ft. by 27 ft., with preparation room, and a geography room.

The floor over, Fig. 93, is allocated to chemistry, the rooms being disposed similarly to those below, with balance room between the two laboratories and store near the second staircase. Over the biology room is a large museum devoted to natural history and local collections. Buildings above this floor include an art room and full-sized aeroplane shed, the remaining area being flat roofs forming possibly the highest vantage-ground round London. The whole of the walls of the chemical laboratories are in white tiles. Fume cupboards with red tile bases and sinks are in the windows, and are ventilated by a central fan connected to " asbestos " trunking. Hot water is supplied by small local geysers. Gas and electric supply are conveyed to the physics tables by floor trenches, rendering these tables movable. Portable accumulators are used for low voltage current in preference to distribution from a battery. The fittings generally are in Douglas fir with teak tops. In the museum the detached table cases have fixed glazed tops, the bottoms sliding out as drawers which admits of the contents being removed bodily for re-arrangement.

The building is in brick and portland stone, and owing to a 13 ft. difference in level between the two frontage roads involved a good deal of excavation. It cost 2s. 1d. a cubic foot, while the fittings (apart from engineering) cost £5563.

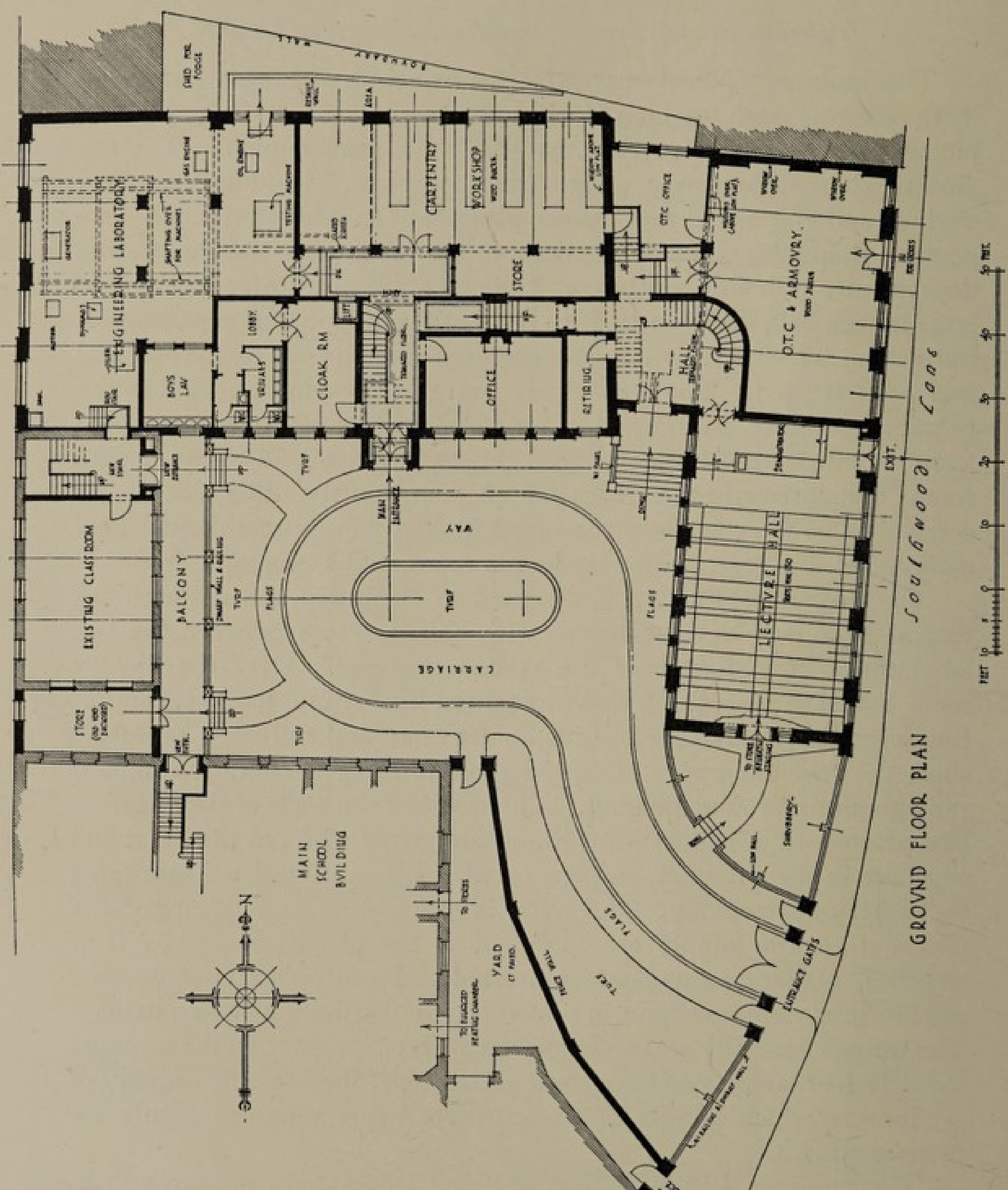


FIG. 91.—Science Buildings, Highgate School.

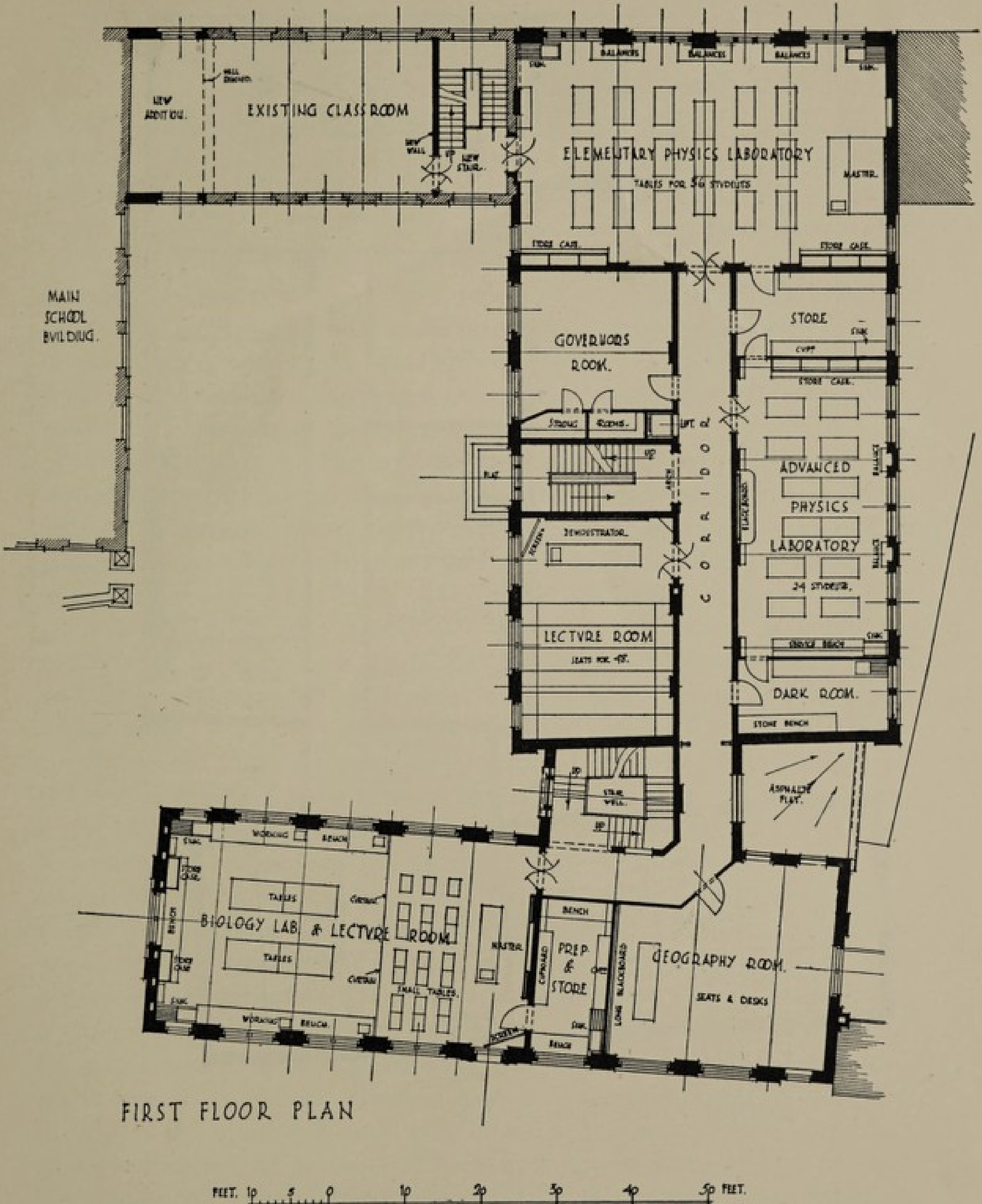


FIG. 92.—Highgate School.

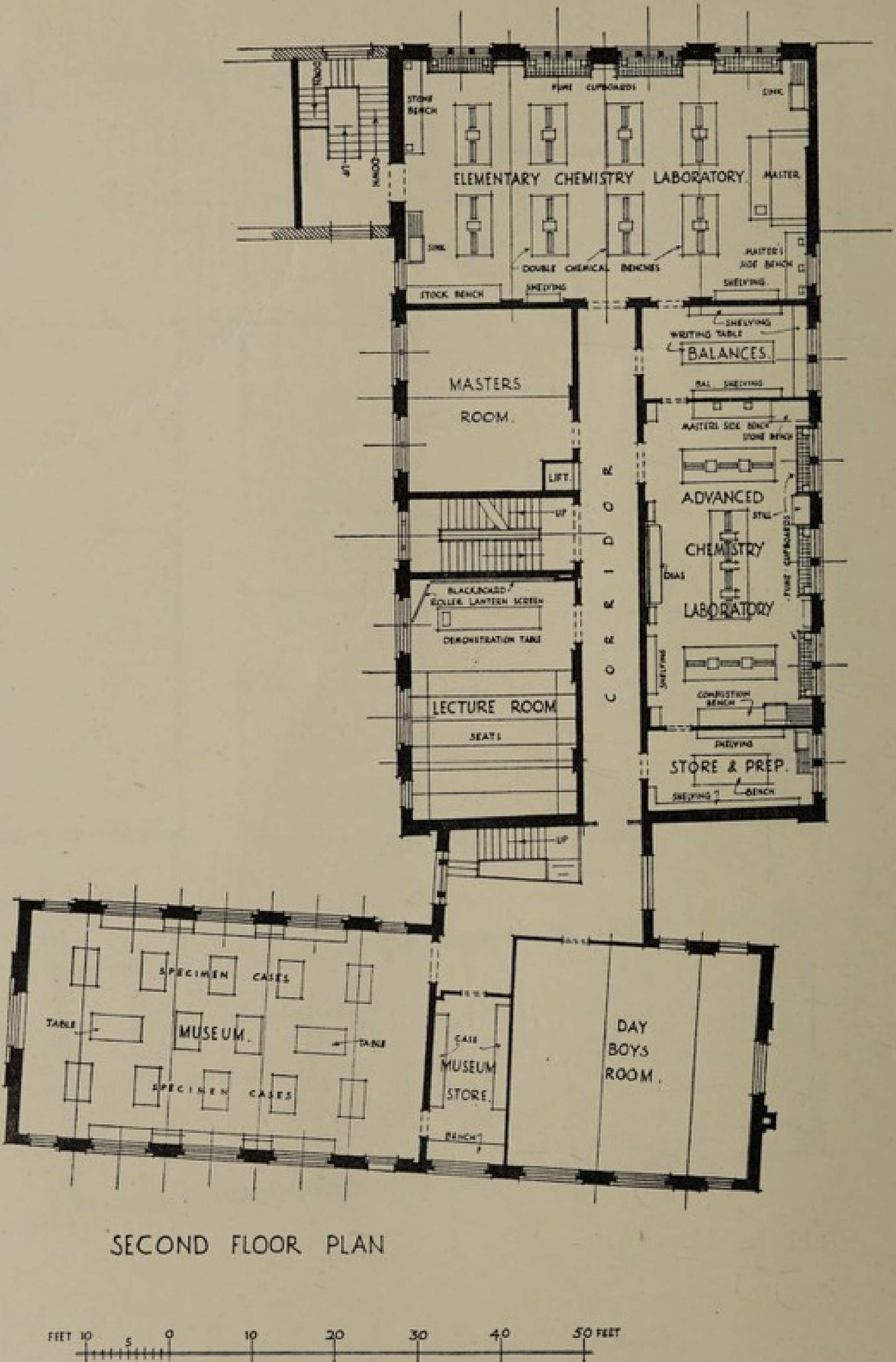


Fig. 93.—Highgate School.

Clifton College Science Building, Bristol

This building, opened in 1927, provides for physics, chemistry, and biology. It consists of two complete floors, a basement at the back, and a second story on the frontage. The ground floor, Fig. 94, is devoted to physics. There are two similar elementary laboratories, each 40 ft. by 32 ft., for classes of 30 boys. Flanking these rooms are two lecture rooms for 60 each, with preparation rooms attached. On the other side of the corridor is an advanced laboratory, 38 ft. by 20 ft., with store attached, and on the other side of the central staircase a workshop, master's private laboratory, and office, with small research room off it, next a little dark room on the corridor.

On the first floor, Fig. 95, there are two elementary chemistry laboratories on the frontage over those below, and between them a common balance room and dispensary for chemicals and apparatus. Two lecture rooms with preparation rooms also serve this department. The advanced laboratory, 31 ft. by 29 ft., has its own small balance room, with general and acid store adjoining. Over the workshop is a biology room, 17 ft. by 20 ft., next the master's room, again laboratory and office, while a small room for polarimeter work is also provided. The height of the rooms is 13 ft.; on the first floor corridor is a flat at a lower level.

Above the large laboratories in the roof, extended as a continuous dormer at the back, is a science library on one side and a geography room on the other, approached by the main stair carried up. In the basement, in addition to the heating plant, there is a large store and unpacking room, switchboard, and battery room. The floors are in maple blocks in rooms and terrazzo in corridors. Drainage in the large chemical laboratories is carried out in channel pipes between twin girders cased as beams. Ventilation is effected by a central fan of the ejector type and "asbestos" trunking. A steam supply is provided for experimental work and making hot water, operated by an automatic gas-fired boiler. Electric power A.C. and D.C. is supplied through a distribution board, with motor generator and cells admitting of a great variety of service. The fittings are in Douglas fir and teak. The surrounding buildings dictated a Gothic design, and by the adoption of a late period ample light has been secured. Erected in local stone, with Bath stone dressings, this building cost 2s. per cubic foot, while the fittings and services involved an outlay of about £7000.

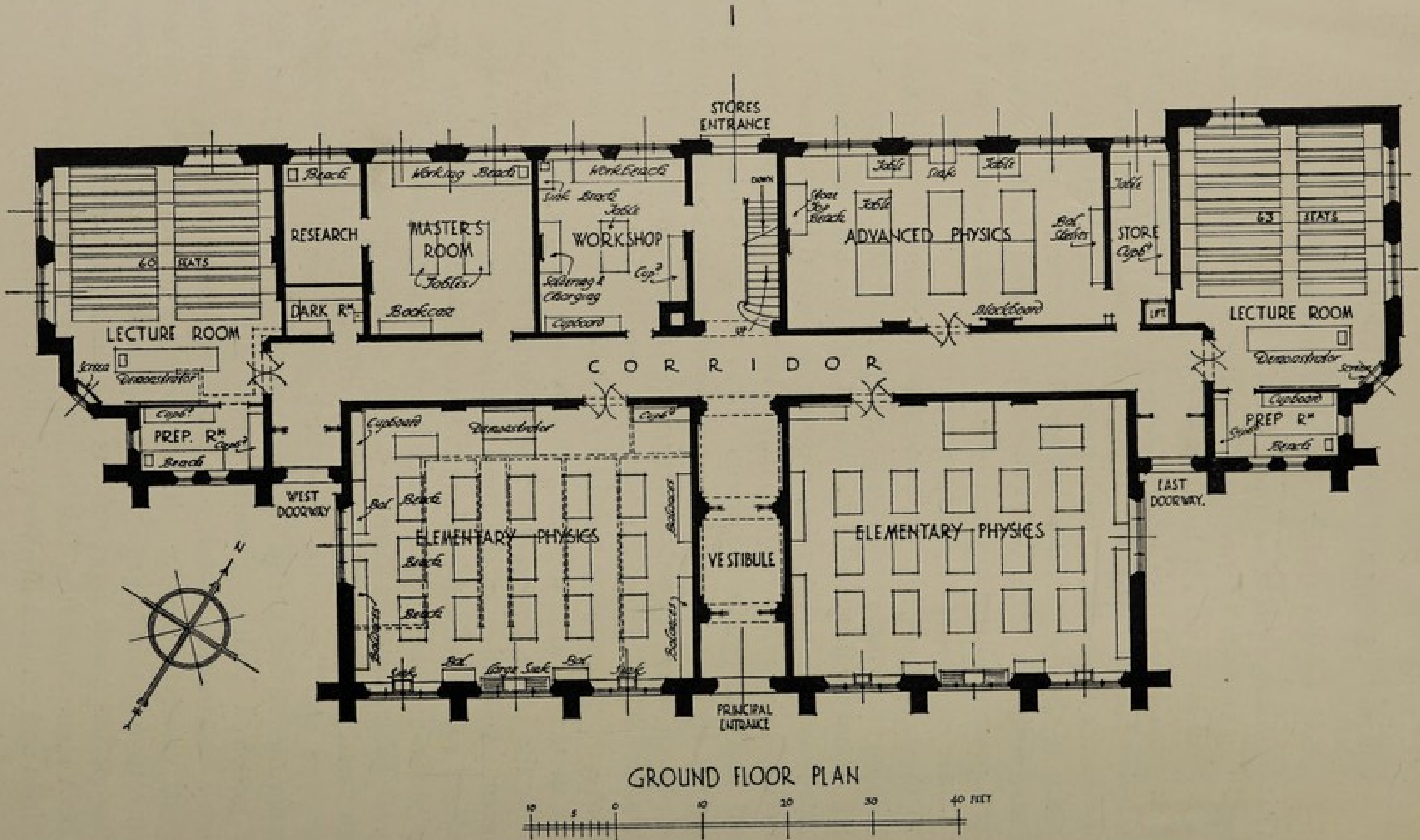


FIG 94.—Ground Floor Plan, Science Buildings, Clifton College.

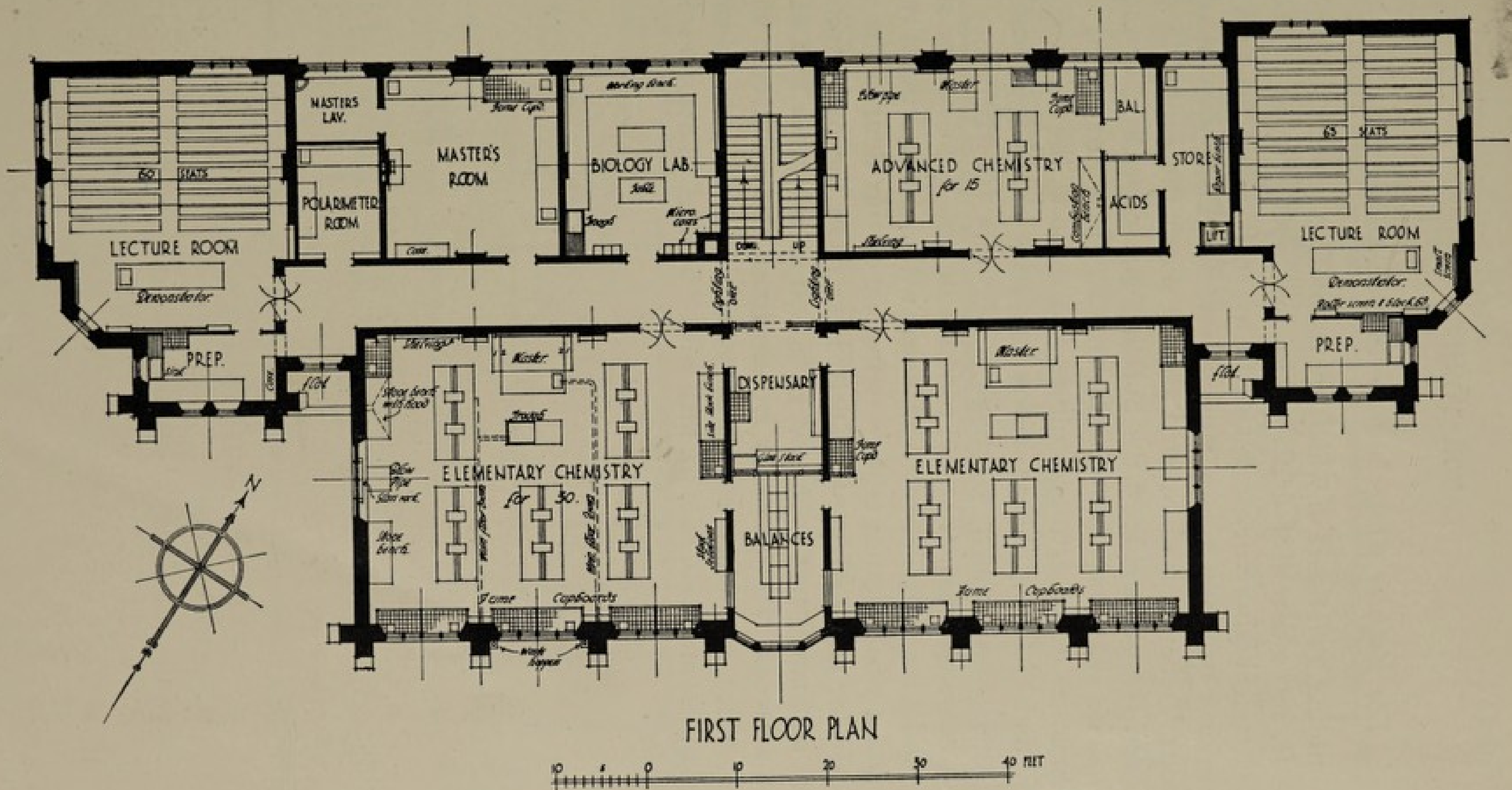
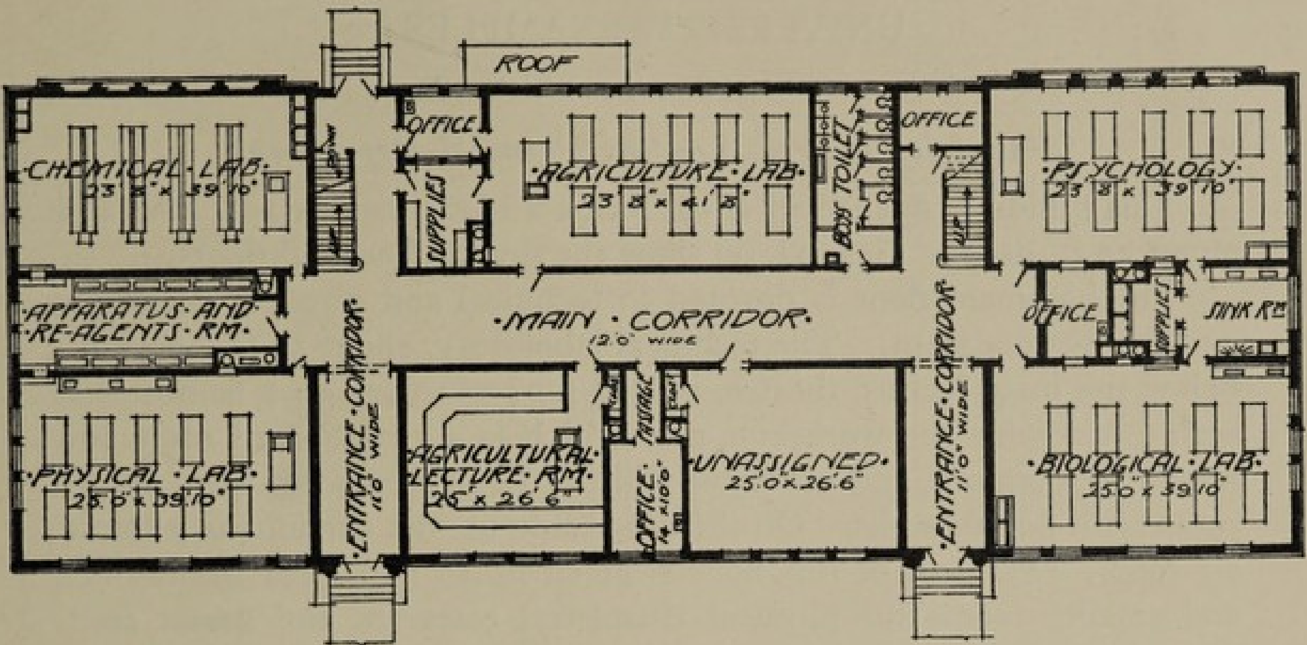


FIG. 95.—First Floor Plan, Science Buildings, Clifton College.

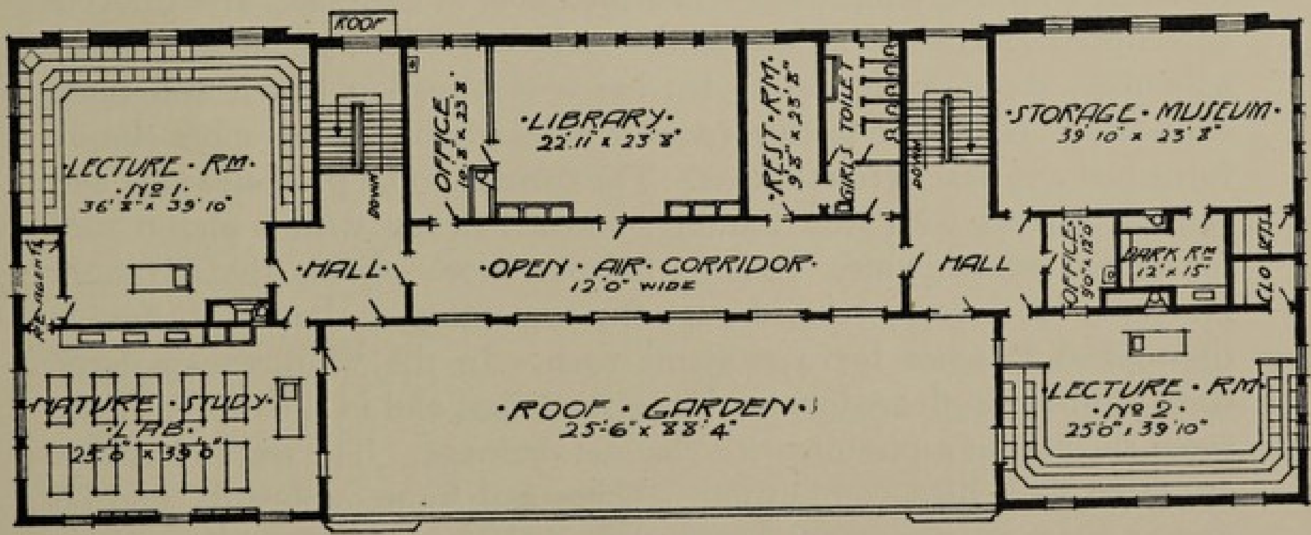
Los Angeles State Normal School, California

This building, two floors of which are devoted to science, has a frontage of 172 ft. and a depth of 65 ft. The first floor, Fig. 96, shows on the left a chemical laboratory about 24 ft. by 40 ft. equipped with four double working benches for 10 students each. These benches have a continuous V-shaped lead-covered trough down the centre in place of sinks. On the other side of the building is a physics laboratory of about the same size, and between the two an apparatus room. The central rooms are devoted to agriculture and those at the other end to psychology and biology. These end laboratories are of the same size and hold the same number of students as those for chemistry and physics. The second floor, Fig. 97, contains on the left a nature study laboratory and a large lecture room arranged with seats and desks round the walls and a small lecture table. A feature of this floor is the wide open-air corridor and roof garden 88 ft. long. On the main frontage is a library and small rest room for girls, and at the other end of the building is a second rather smaller lecture room and a museum with a dark room, office, and store rooms between them. All the chemical drainage channels are made of 4 lb. lead with " burnt " joints, no soldering being used.



FIRST FLOOR PLAN

FIG. 96.



SECOND FLOOR PLAN

[*Messrs. Allison and Allison, U.S.A., Architects.*

FIG. 97.—Los Angeles State Normal School, California.

UNIVERSITY EXAMPLES:

I. CHEMISTRY AND PHYSICS

University College, London, Chemical Department

This building, opened in 1916, forms a block over 300 ft. long and about 50 ft. deep. Figs. 98, 99 show the first and second floors.

The basement floor is devoted to technical and physical chemistry and the heating plant. The technical laboratory, about 52 ft. by 45 ft., below the main lecture theatre, is used for researches on a commercial scale; it adjoins the workshop, next which is a switchboard room and research laboratory, and under the main entrance a constant temperature room with double walls. On the other side of the corridor is a liquid air room. The rest of this floor is given up to two large laboratories and smaller rooms for physical chemistry, research, and minor uses. The physical chemistry laboratories contain double cross benches 13 ft. long with gangways 6 ft. 3 ins. wide between them. The special benches along the wall between the two laboratories have been figured on page 50.

On the ground floor the main lecture theatre, 52 ft. by 45 ft., which runs through two floors, accommodates 240 students. The lecture table, 23 ft. 8 ins. long, has a small tiled area at each end, and drawers and cupboards about 6 ft. long at the ends only. The preparation room adjoining, about 34 ft. by 21 ft., has a combustion bench and fume cupboard. A smaller lecture room is similarly but rather more simply furnished and seats 110 students. The furnace room possesses side and central benches with iron framing, and a balcony with a glazed roof for special experiments. A large balance room adjoins the advanced inorganic laboratory, 72 ft. by 43 ft., containing twelve 12 ft. double tile-topped benches for 4 students each. In the windows are large fume cupboards, floored with white glazed tiles, and in the centre of the room shelves for aspirators with channel drainage. The research rooms are fitted with tiled combustion benches and fume cupboards, and on one or more of the walls narrow teak shelves supplied with services.

The first floor, Fig. 98, is devoted to organic chemistry, and is planned similarly to the floor below. The main laboratory benches have a low-pressure steam supply and the tops are of teak. In the windows again are eight fume cupboards. The ovens are heated by steam at 30 lbs. The second floor, Fig. 99, is devoted to elementary inorganic and organic laboratories, and to research and medical work.

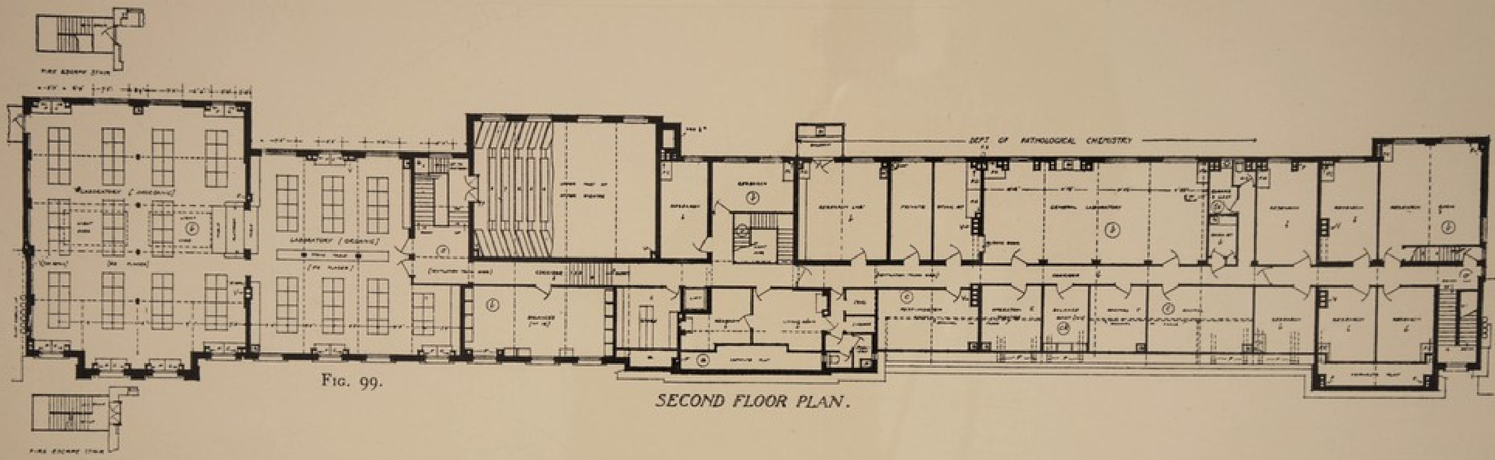
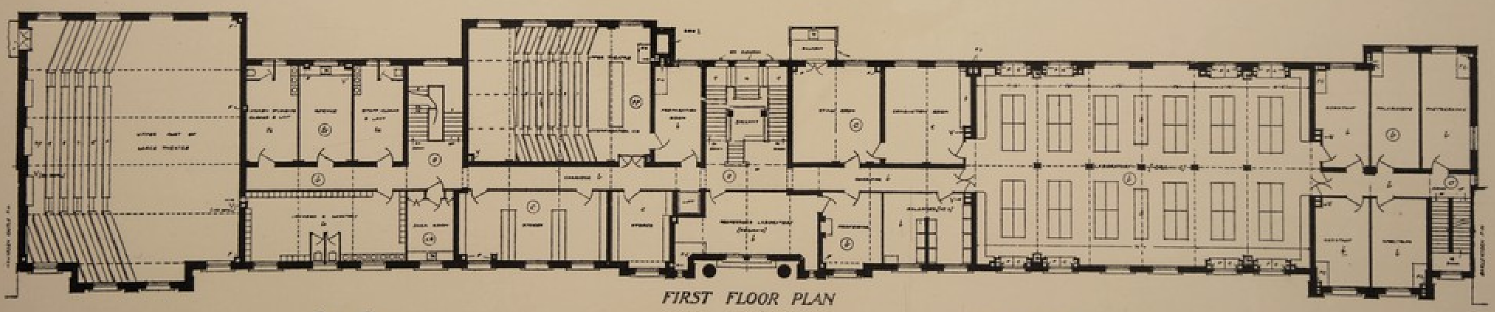


Fig. 99.

SECOND FLOOR PLAN.



FIRST FLOOR PLAN

Fig. 98.

SCALE OF FEET.

Chemical Department, University College, London.

[F. M. Simpson, F.R.I.B.A., Architect.

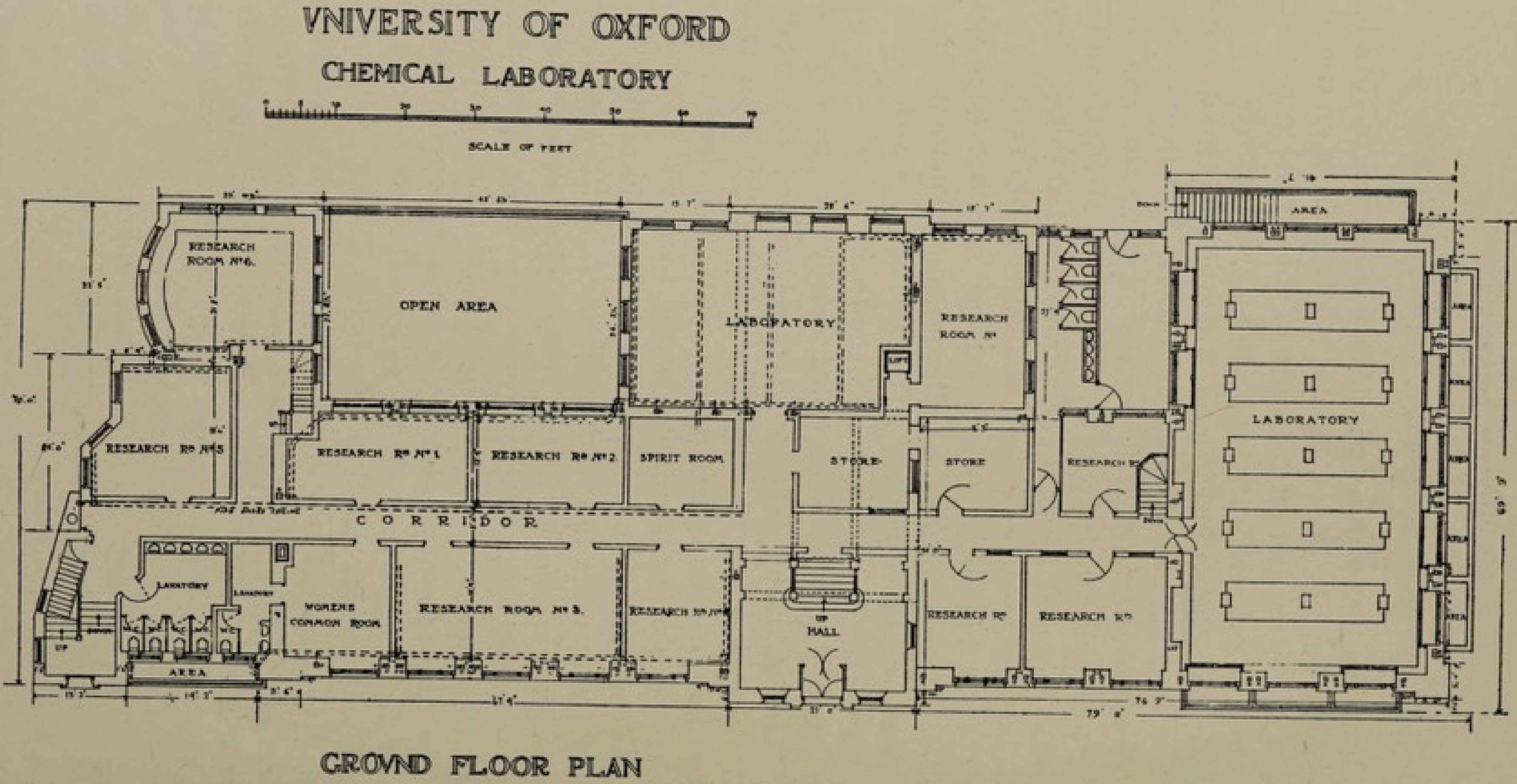
[To face page 168.

Organic Chemical Laboratory, Oxford University

This building, the first portion of which was opened in 1914 under the direction of the late Dr. W. H. Perkin, has recently been completed by the addition of the section on the right of the central entrance. It is devoted entirely to organic work for teaching and research.

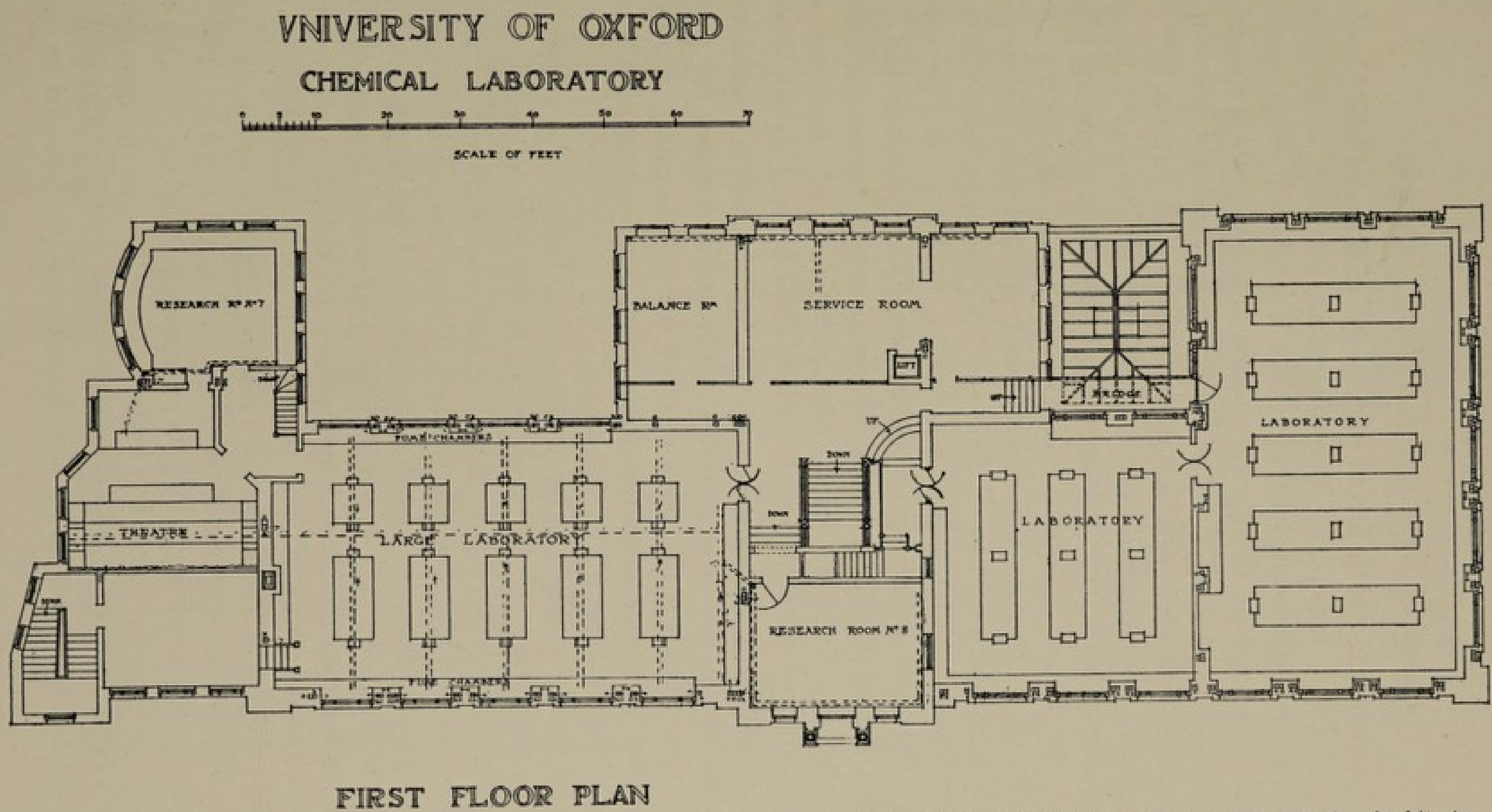
The ground floor, shown in Fig. 100, which is slightly sunk, by the provision of a wide sunk area, below the road level, is mainly devoted to research. It contains ten research rooms differing in size, and ranging from about 13 ft. square to 22 ft. by 23 ft. and 32 ft. by 16 ft., the adjoining laboratory at the rear, 40 ft. by 25 ft., being also devoted to this purpose. In addition to store rooms there is a special spirit room, 15 ft. by 12 ft., in the centre of the building. At the extreme end is a large general laboratory, 62 ft. by 36 ft., lighted on all sides, and containing nine large fume cupboards in the windows. The working cross-benches are 5 ft. 6 ins. wide with 5 ft. gangways between them.

The first floor, Fig. 101, is occupied chiefly by general teaching laboratories. That on the left, 64 ft. by 35 ft., is equipped with five double benches, 11 ft. long, and five others, 5 ft. long, giving thirty places in all. These benches have central open drainage channels in lead discharging into end sinks. Fume cupboards are in the windows. The room is 20 ft. high, and in addition to high windows has a large roof lantern. The laboratory on the other side of the staircase is 36 ft. square, and that at the extreme end is similar to the room below already described. Both these rooms have large lantern lights. The floor provides a large service room for apparatus, making up solutions and dispensing to students. The single balance room, 15 ft. by 20 ft., appears somewhat divorced from the laboratories. At the other end of the block is a small lecture theatre with steeply raised staging, below the upper part of which is a small and very attractively arranged library, with direct approach from the large laboratory. These rooms can also be separately entered from a staircase with external door. Behind the lecture theatre is a preparation room adjoining a research room. Over the central part of the building there is a T-shaped second floor containing five research laboratories. The ventilation of the fume cupboards is effected by a central fan. The combustion rooms are fitted in a manner resembling generally the furnace room below.



[Paul Waterhouse, P.P., R.I.B.A., Michael Waterhouse, F.R.I.B.A., Architects.

FIG. 100.—Ground Floor Plan, Organic Chemistry Laboratory, Oxford University.



[*Paul Waterhouse, P.P., R.I.B.A., Michael Waterhouse, F.R.I.B.A., Architects.*

Fig. 101.—First Floor Plan, Organic Chemistry Laboratory, Oxford University.

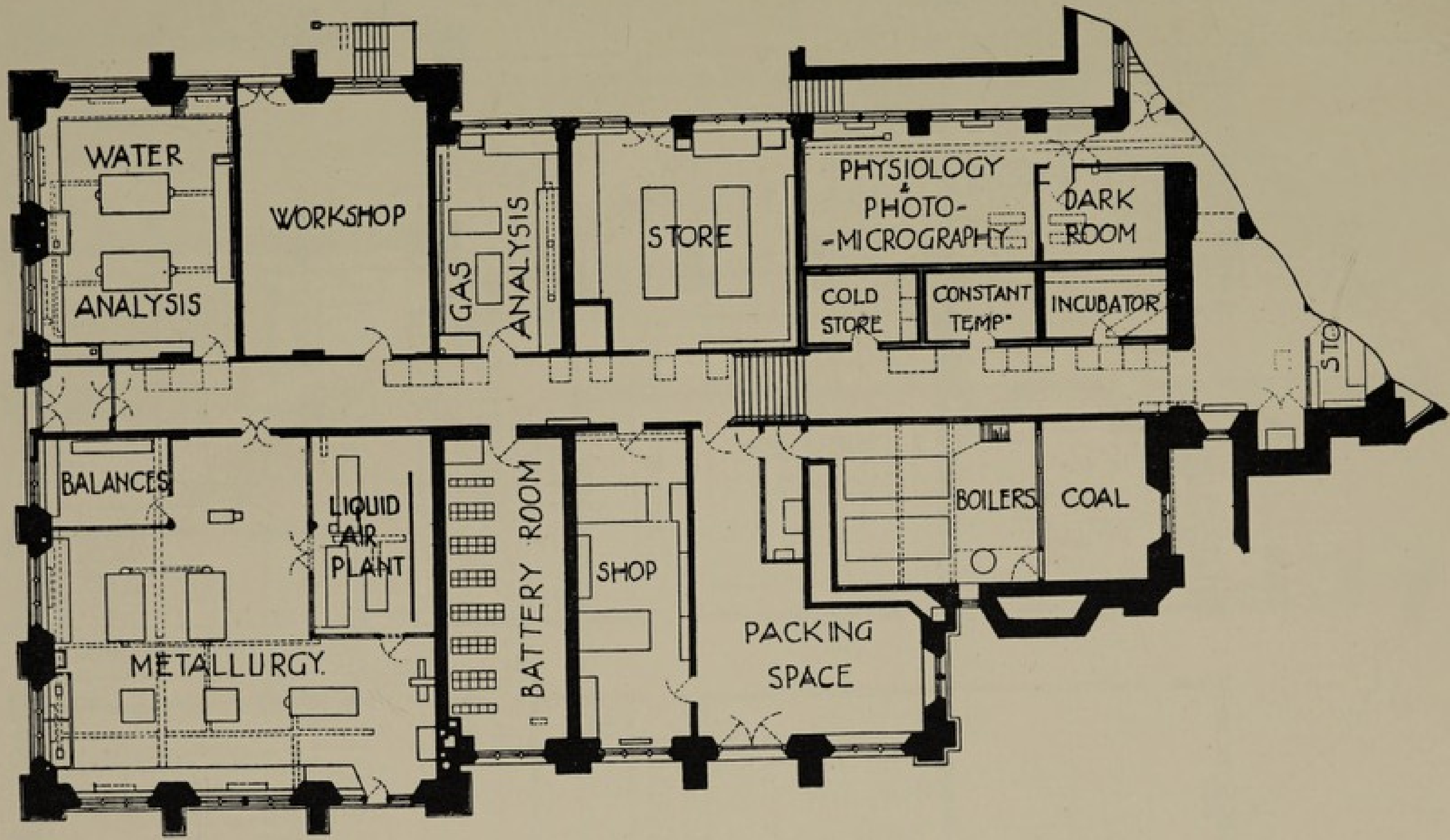
Chemical Department, Bristol University

This department, which forms part of the main university buildings, is shown in Figs. 102-3-4. The basement contains a metallurgical laboratory, liquid air room, battery room, a workshop large enough to enable students to make their own repairs, laboratories for special purposes, stores, and packing room. Dangerous chemicals are stored in a small detached concrete erection outside the packing room.

The ground floor contains the main lecture theatre, 40 ft. by 37 ft. Next its preparation room are laboratories for electro and general physical chemistry, the larger of which contains the main distribution board, about 12 ft. by 9 ft., over the switchboard on the floor below. The professor's laboratory is placed between the physical and the senior organic laboratory. The latter, a room 45 ft. by 30 ft., possesses a balcony for open-air work with noxious gases. Combustions and closed tube work are also provided for in this room, which possesses a shower rose to meet accidents by fire. The partition walls between these laboratories are not constructional. Plate glass is used in the windows to prevent distortion. Other rooms on this floor include a second lecture theatre, a museum, which is provided with gas and water for possible alternative use, so that it can be converted into a laboratory should expansion render this necessary, two dark rooms, and a second laboratory designated " Spare Room " on the plan.

The first floor contains the large elementary laboratory, a lofty room 80 ft. by 45 ft. Here are 12 benches, 12 ft. by 5 ft., giving 4 ft. each for 72 students, and at each end of the room near the inner wall are private benches for the demonstrators. These, in partial enclosures, also serve for dispensing. General benches and fume cupboards are placed in the windows and ovens and distilled water apparatus on the other side of the room. The alcove, shown on the plan, on this inner wall is for blow-pipe work. The students' benches have draught flues and hoods. Adjoining the laboratory is a large balance room and a store and preparation room with a lift from the basement stores.

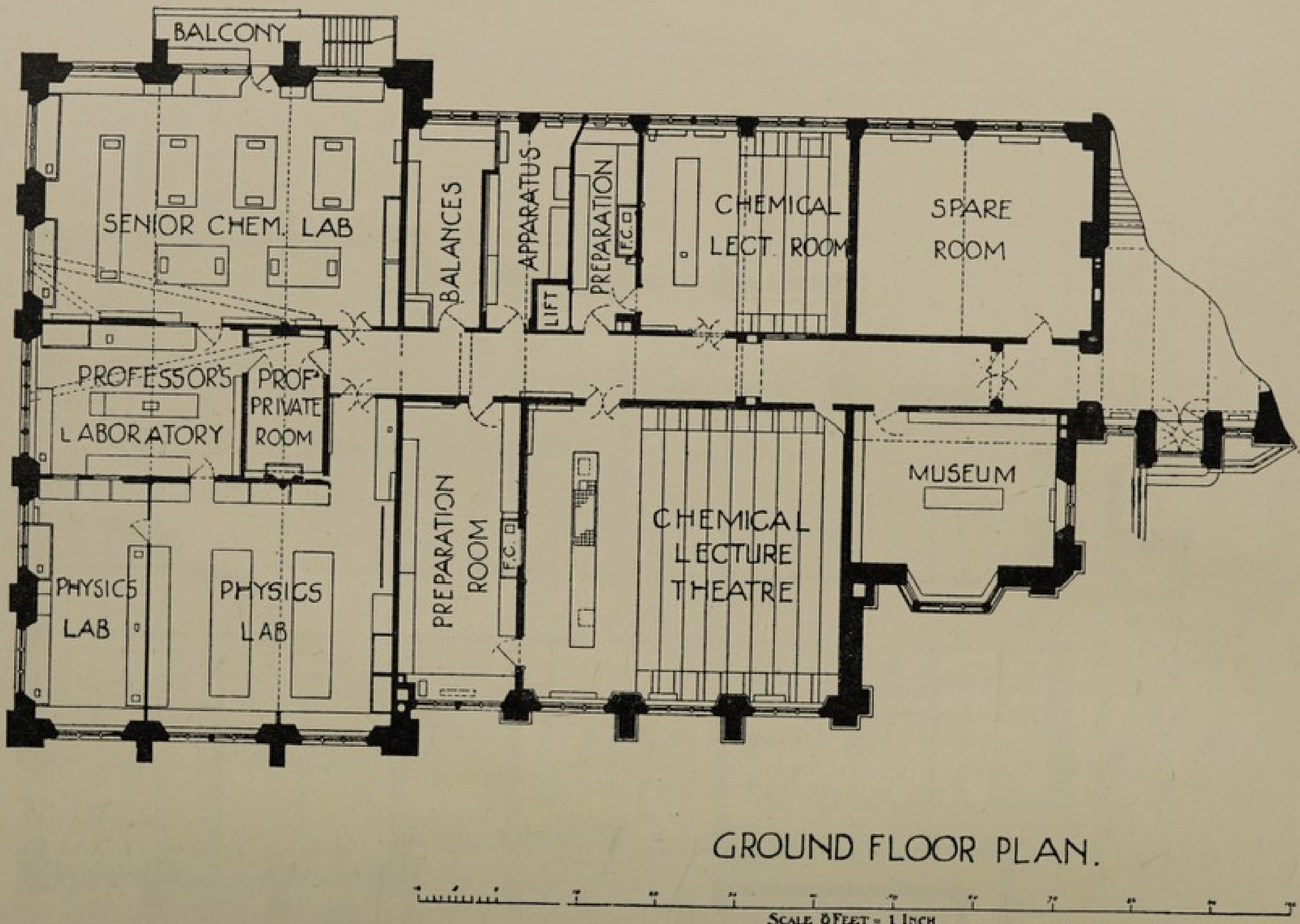
The bio-chemical laboratory is fitted much as that for organic work and has two attached rooms for incubators and bacteriological work. A lecturer's room and small library complete the accommodation, which was designed for 200 students. The department was opened in 1910.



BASEMENT PLAN.

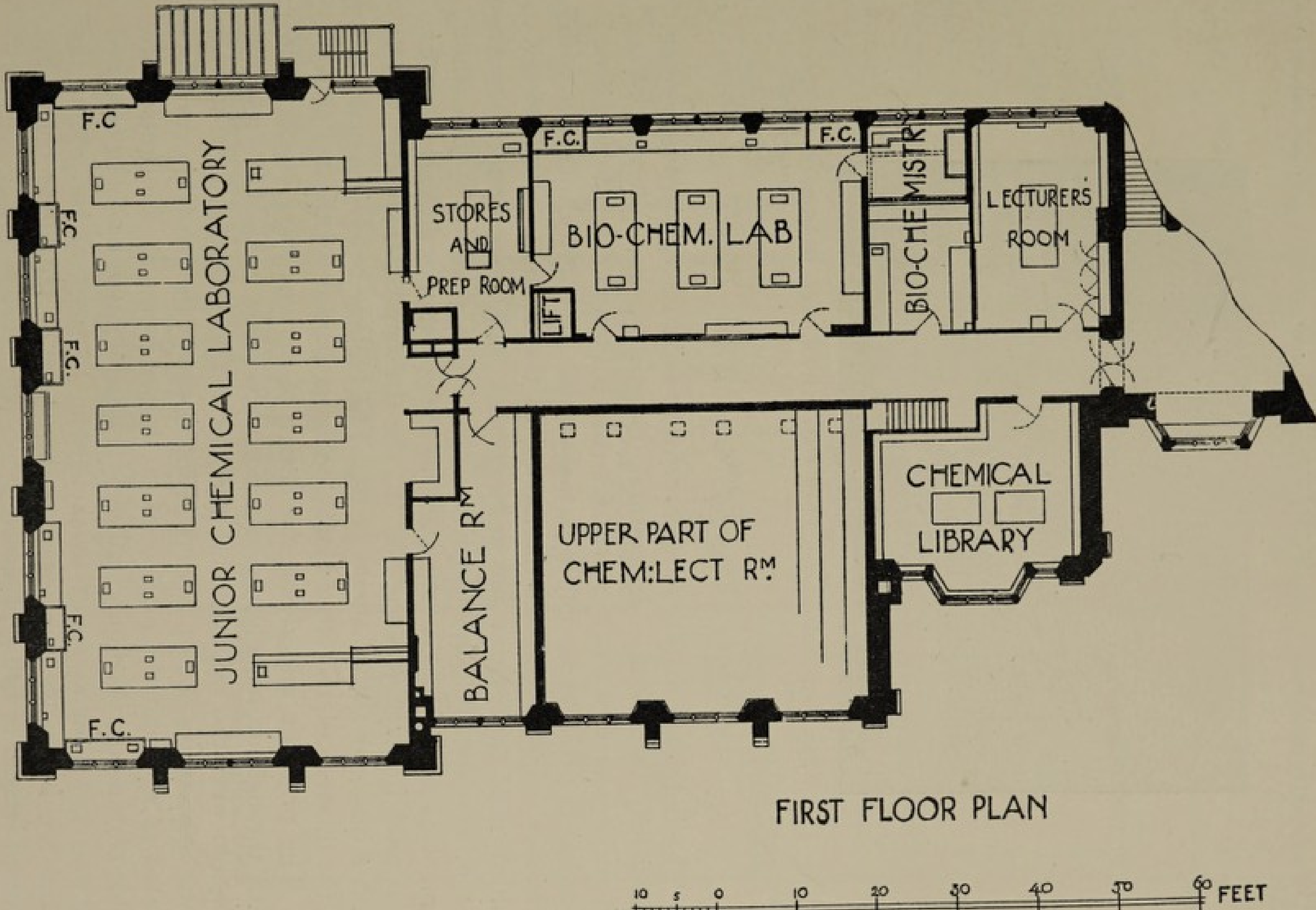
[*Oatley and Lawrence, F.F.R.I.B.A., Architects.*

FIG. 102.—Chemical Department, Bristol University.



[*Oatley and Lawrence, F.F.R.I.B.A., Architects.*

FIG. 103.—Chemical Department, Bristol University.



[*Oatley and Lawrence, F.F.R.I.B.A., Architects.*

FIG. 104.—Chemical Department, Bristol University.

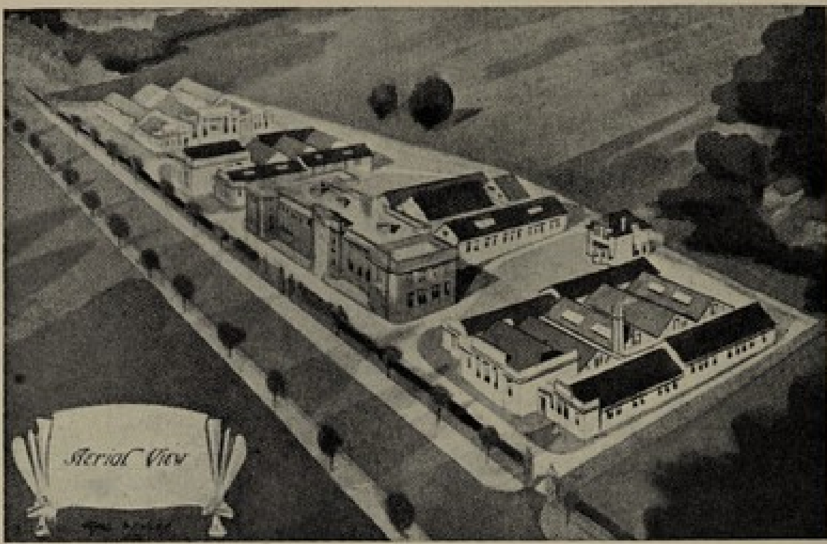


FIG. 105.—Science Buildings, University College, Bangor.

University College of North Wales, Bangor

The buildings in this scheme provide accommodation for biology, chemistry, agriculture, agricultural chemistry, and physics. Very extensive floor area was required for strictly limited expenditure, hence the design presents an effort at the utmost economy consistent with efficiency. Fig. 105 shows the lay-out of the blocks. That for agriculture is of two stories and built in brick with stone dressings. All the others are one-story brick buildings with 9-in. walls and white cement as an external covering and have open timber and slated roofs. The total frontage is some 700 ft., the site sloping from west to east with a diagonal fall of about 33 ft. The biology block is on the left of the illustration, the other blocks being in the order indicated above.

The principle underlying the design of the one-story blocks is the same throughout, namely, the concentration of as much floor space as possible with the minimum of corridor. These blocks each contain some 10,000 to 11,000 sq. ft. of floor space, and by the use of low corridors roofed as flats and the placing of the larger rooms in the centre with gable ends on the corridors very good general lighting has been obtained without any general resort to skylights. In most of the rooms the floors are in granite cement, and the walls of sand-lime bricks are pointed instead of being plastered.

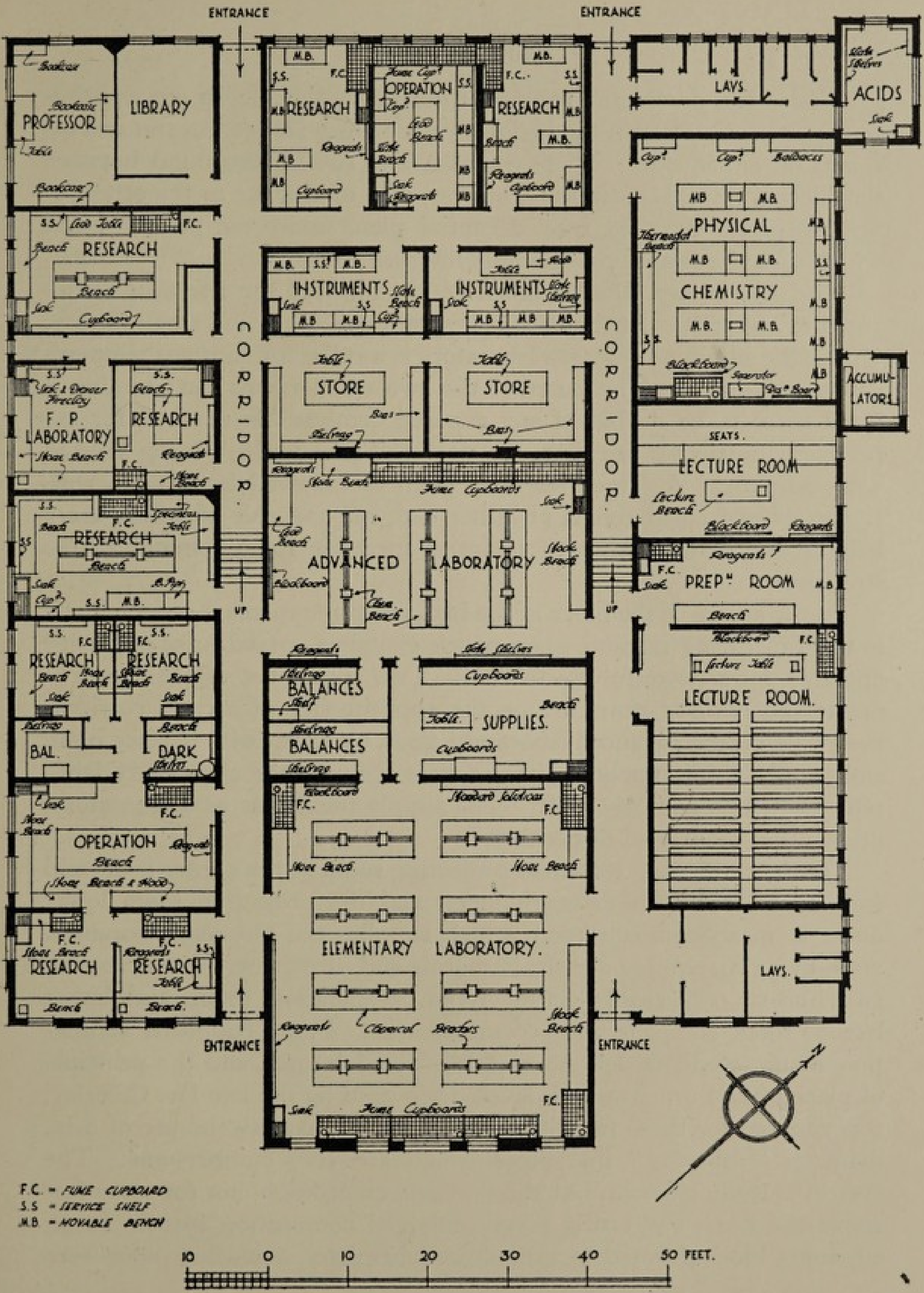


FIG. 106.—Chemistry Department, University College, North Wales.

Under the corridors generally throughout the blocks are trenches some 4 ft. deep wherein the various service pipes and cables run serving rooms on either side. These trenches also run underground between the blocks, giving continuity from one end of the site to the other for heating pipes, supplied from a central plant under the physics block which is at the lowest part of the ground.

The Chemistry Block—Illustrated in Fig. 106 the left wing is devoted to research. At the back is a professor's office and small library. Under the adjoining research laboratory is a cellar for constant temperature experiments. The outer of the two small rooms next to this is fitted so as to be devoid of any exposed combustible material for experiments involving fire risks, the door and roof timbers being sheeted with asbestos. A larger research room is followed by a suite consisting of two small rooms at either end, off one pair of which are a balance and dark room, with a central operation room common to the workers.

In the centre of the block at the back are three rooms devoted chiefly to work involving noxious gases which contain a special fume cupboard operated by a powerful ejector fan. Two rooms for valuable instruments and two for stores are on the opposite side of a cross corridor, next which is the advanced laboratory, 40 ft. by 25 ft., with balance room and supply room attached, giving access again to the elementary laboratory which is 40 ft. by 45 ft. The supply room acts as a laboratory, preparation room, and dispensary.

On the right wing the small projecting room at the corner is an acid and ether store with external doors, and the projecting room lower down is an accumulator room which supplies the physical laboratory, 26 ft. by 33 ft., equipped with alternating and direct current and its own switchboard. A small lecture room, preparation room, and larger lecture room complete the accommodation. Fume cupboard ventilation in the students' laboratories is effected by gas, and the principle of placing the burner at floor level, discovered by the late Dr. Crossley, was adopted for these fume cupboards. This involves the use of 9-in. diameter "asbestos" flue pipes which are very cumbersome. The system is quite efficient, but the flue gets exceedingly hot for some feet above the floor, suggesting a very enlarged combustion space. In an adjoining block devoted to agricultural chemistry, 6-in. flue pipes were used with gas jets in the usual position at the tops of the cupboards, and a comparison of the efficiency of these two systems (both for the same story height) does not suggest that the former has outstanding advantages.

Filtration is effected by water pumps, the pressure available being some 70 lbs. The fittings and services of this block cost £5430.

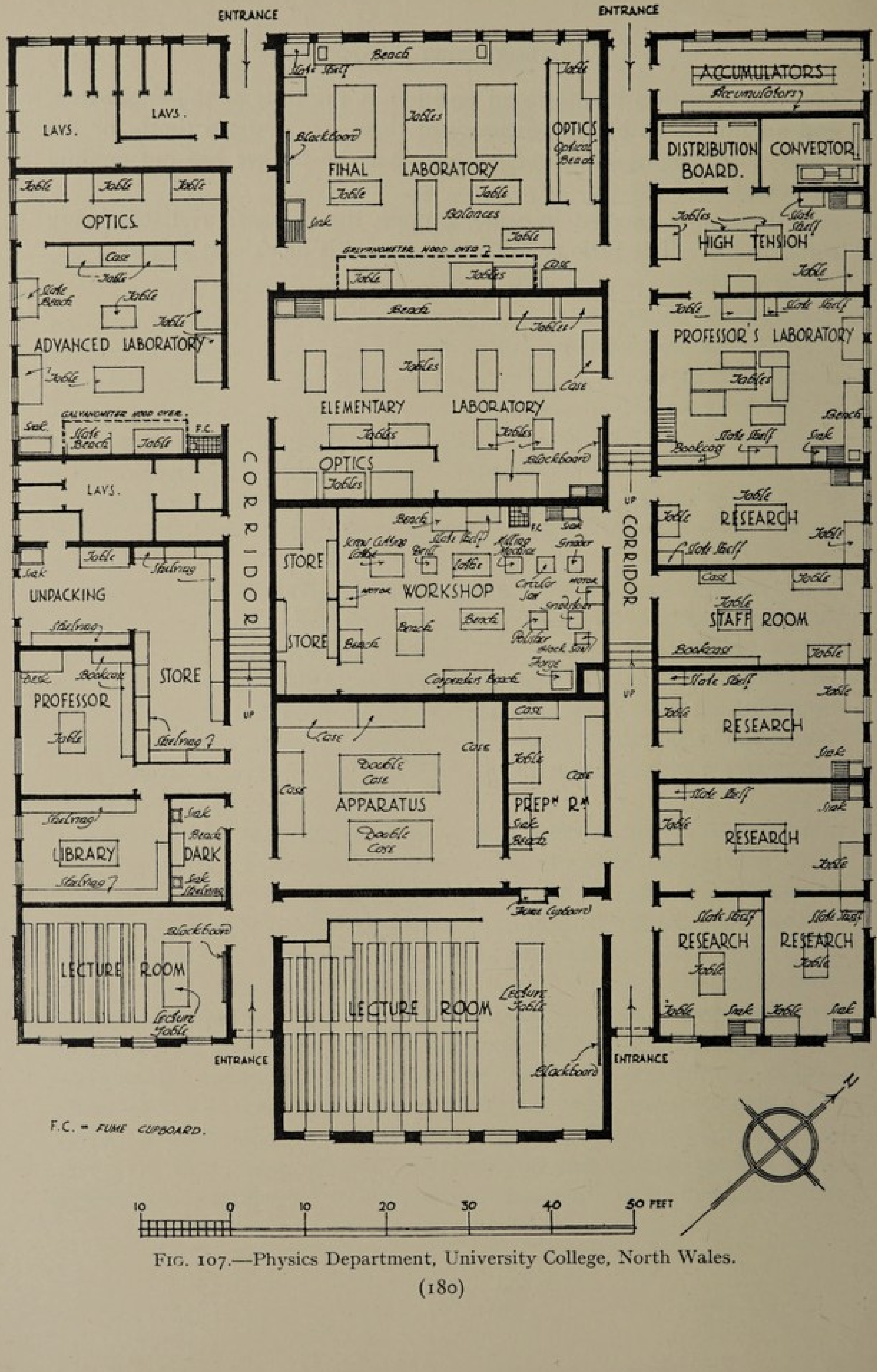


FIG. 107.—Physics Department, University College, North Wales.

Physics Department—The plan of the physics block is shown in Fig. 107, the main laboratories are in the centre, the side rooms being mostly devoted to research. In the centre at the top of the figure is a students' laboratory for honours work, 38 ft. by 31 ft., with an enclosed space at one end which can be darkened, and a galvanometer bench surrounded by curtains opposite the window wall. Next to this is the elementary laboratory, 38 ft. by 25 ft., also with optical enclosure, and beyond this the workshop, an illustration of which has been given on page 71. The equipment is indicated on the plan and is operated by overhead shafting run by two motors as shown, one a small one for use for light work, the other for the heavier machines. A large apparatus room with preparation room attached adjoins the lecture room, 38 ft. by 28 ft., on the frontage which has steeply raised staging. The left wing contains an advanced laboratory with optical room attached, an L-shaped unpacking room and store with goods entrance, a small professors' private room next a little departmental library, and on the frontage again is a small lecture room without raised seats.

At the far end of the right wing is a battery room, illustrated in Fig. 41 (Chap. III), containing 75 cells with external door. This room, has glass louvres in place of windows. The distribution board room and machine room (converter) adjoin the battery room next which is a laboratory reserved for high-tension work, 26 ft. by 13 ft., off the professor's laboratory. The remaining small rooms are research laboratories, except one which contains the liquid air plant illustrated in Fig. 71 (Chap. V). The extensive electric power service is partly distributed through trenches, but largely carried on walls in the research rooms themselves in C.T.S. cable to admit of flexibility and alterations. The fittings and services for this block cost £4350.

The cost of this building and that of the other one-story blocks was about 1s. 1d. per cubic foot. The whole of the fittings and services[1] to the buildings comprised in the scheme (Fig. 105) cost about £19,000.

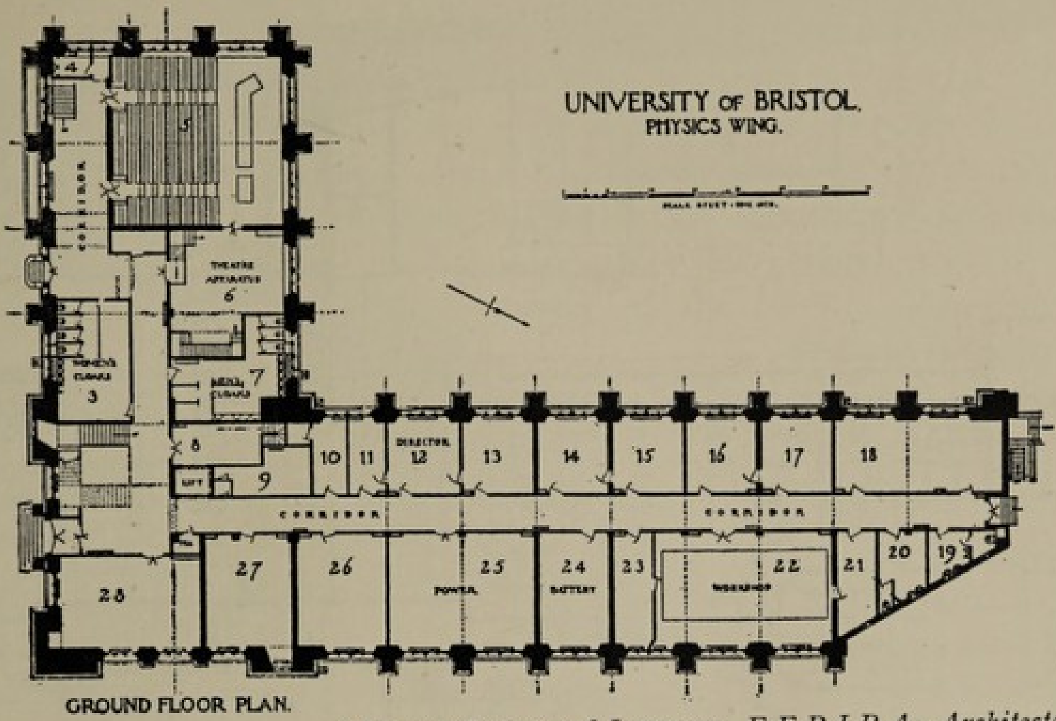
[1] "Services" mean electric plant, gas, water, drainage, etc., special to science.

The Henry Herbert Wills Physics Laboratory, Bristol University

This building, opened in 1927, occupies a commanding position overlooking the city. It should be noted that the plans reproduced show buildings now erected which are only a part of the donor's scheme. The L-shape was dictated by the presence of an existing building retained on the site which balances the short arm of the block. The extensions will take place at the end of the long arm of the L. The walls are of local stone with Bath stone dressings, the floors of reinforced concrete thick enough to give freedom from vibration. Wood blocks are used for the laboratory floors and rubber largely elsewhere. Joinery is in teak. There are four stories in which most of the rooms are planned on a unit of 17 ft. with depths of 16½ and 26 ft. respectively on either side of an 8-ft. corridor. The ground floor (Fig. 108) is devoted to research rooms and to power and workshop requirements. Referring to the lettering on the plan, 5 is the senior theatre, 40 ft. square; 10 to 17 are rooms for private research; and 18, 26, 27, 28, other research rooms; 9 a photographic room; 22 to 25 workshop and power rooms, with a special steel frame for shafting, free from walls and ceiling; 8 and 21 are stores, and 6 for apparatus.

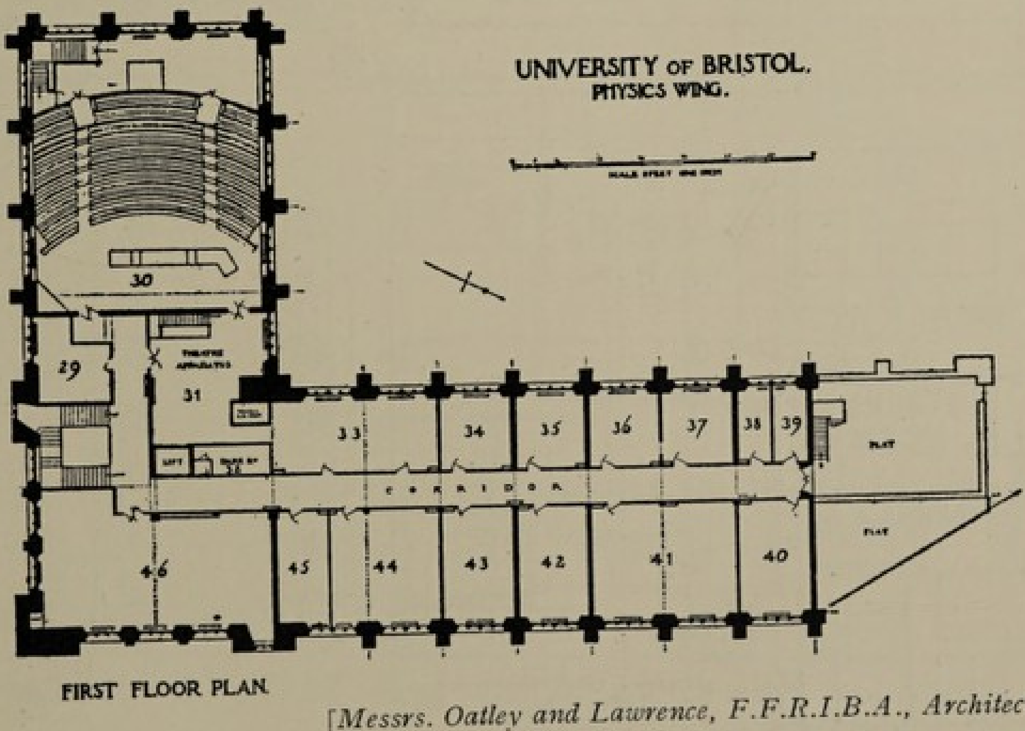
The first floor (Fig. 109) contains the main theatre, 64 ft. by 52 ft., which seats 300, and considerably more for public lectures, and has very lavish space round the lecture table. Rooms 34 to 39 are for private research; 41 to 43 and 45 and 46, senior teaching laboratories; 29, 31, and 33 apparatus rooms. There are two further floors not shown which are planned similarly to those below. The second floor provides laboratories for senior optics and junior teaching laboratories, and the third, the library, 53 ft. by 26 ft., with gallery, and private rooms. The tower at the junction of the two arms of the building, which is 64 ft. square, contains research rooms on a fourth floor, and has a shaft 90 ft. long from one turret to the ground level. This shaft is intended for Young's modulus and other experiments requiring great vertical length. The large pitched roof space is used for storage.

In addition to public supplies, both A.C. and D.C., two 660 ampere hour batteries supply current at 110 volts. The other services include compressed air and vacuum, supplied by small local plants.



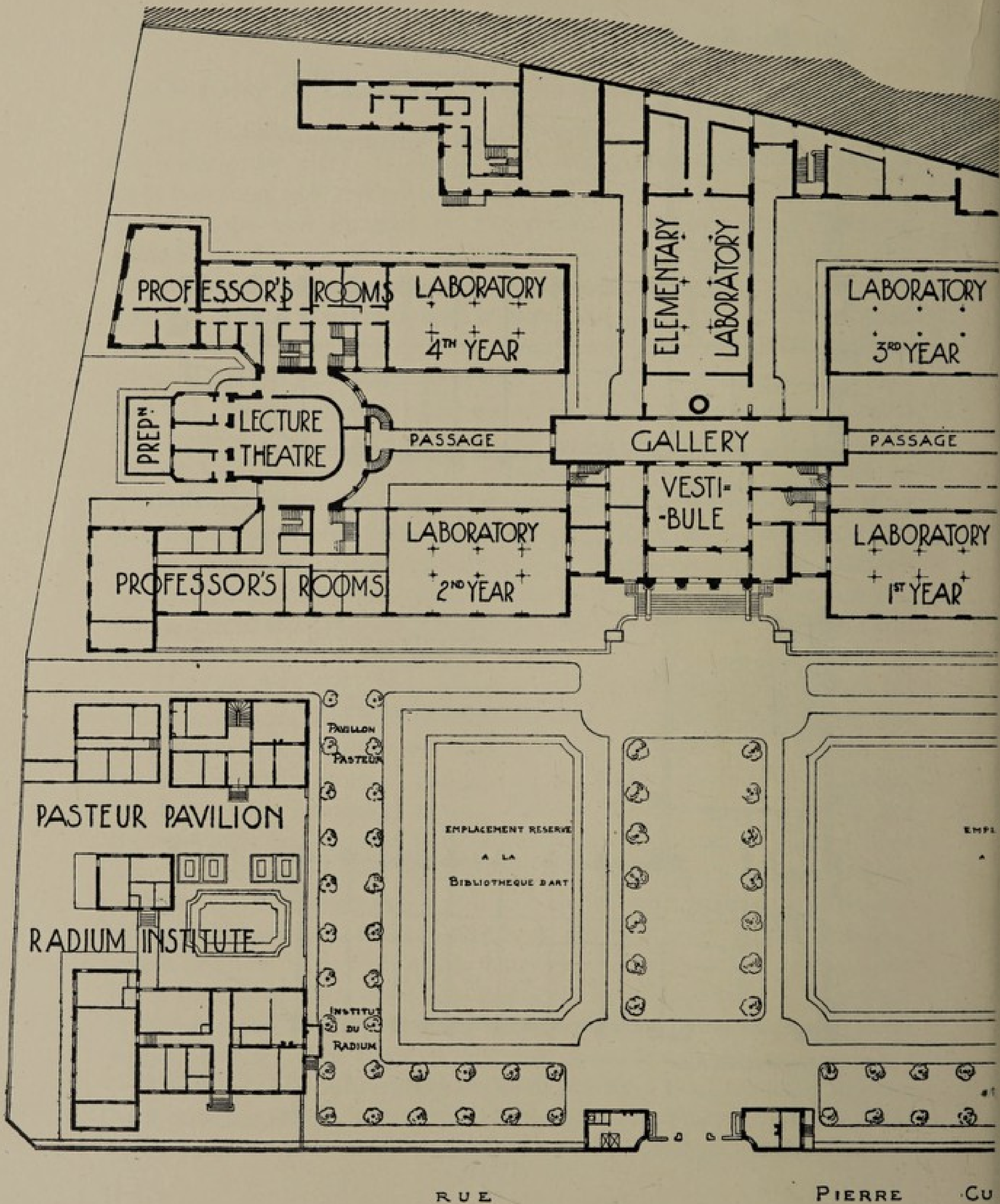
[*Messrs. Oatley and Lawrence, F.F.R.I.B.A., Architects.*

FIG. 108.—Ground Floor Plan, University of Bristol.



[*Messrs. Oatley and Lawrence, F.F.R.I.B.A., Architects.*

FIG. 109.—First Floor Plan, University of Bristol.


PROFESSOR'S ROOMS
LABORATORY
4TH YEAR
ELEMENTARY
LABORATORY
LABORATORY
3RD YEAR
PREPN.
LECTURE
THEATRE
PASSAGE
GALLERY
PASSAGE
VESTI-
-BULE
LABORATORY
2ND YEAR
LABORATORY
1ST YEAR
PROFESSOR'S ROOMS
PAVILLON
PASTEUR
PASTEUR PAVILION
EMPLACEMENT RESERVE
A LA
BIBLIOTHEQUE D'ART
RADIUM INSTITUTE
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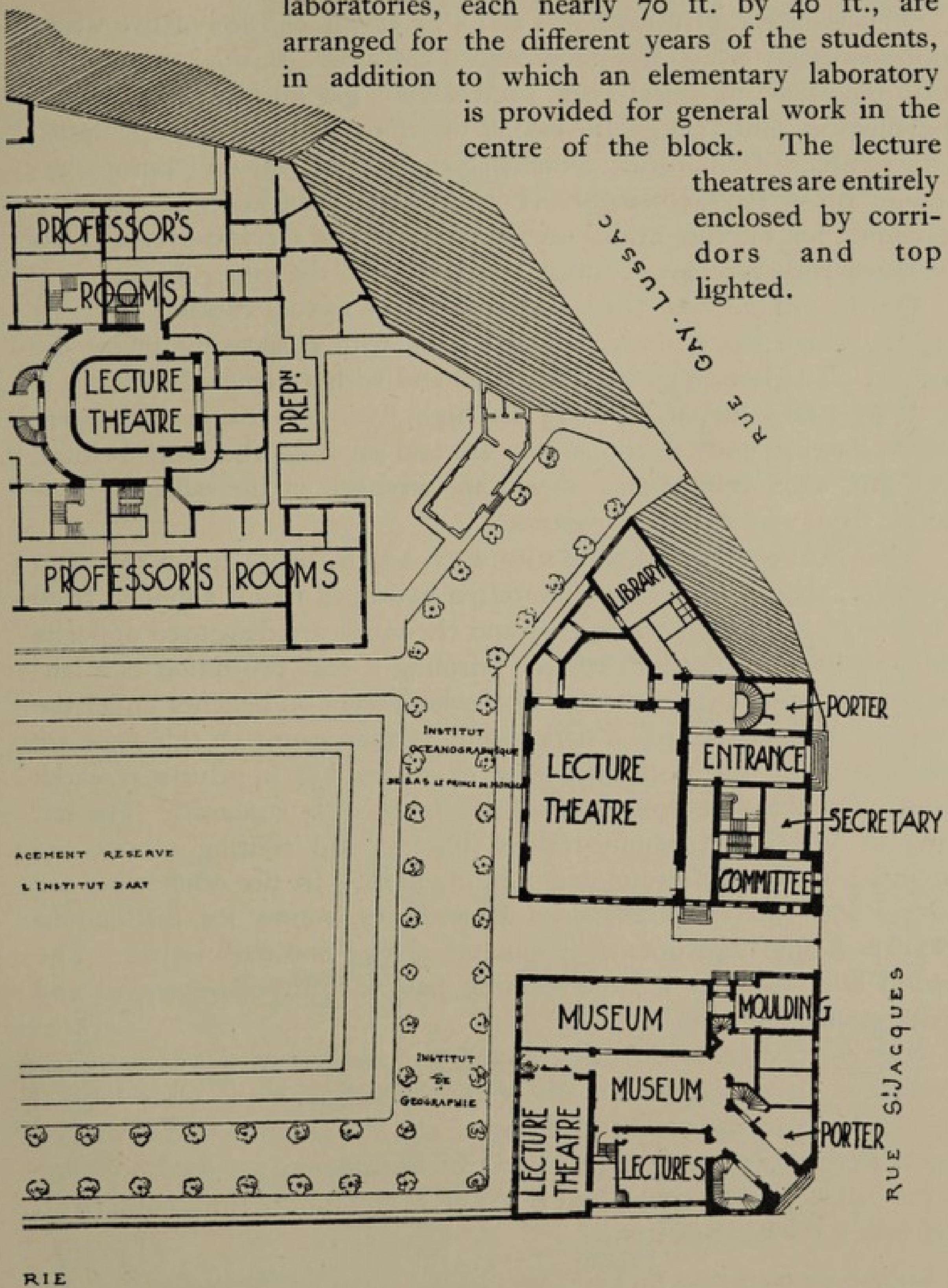
DU
RADIUM
RUE DULM
RUE PIERRE CU

FIG. 110.

The ground plan of the Institute of Chemistry, Paris, with the adjoining Pasteur and Oceanography Institutes, is shown in Fig. 110. The laboratories, each nearly 70 ft. by 40 ft., are arranged for the different years of the students, in addition to which an elementary laboratory is provided for general work in the centre of the block. The lecture theatres are entirely enclosed by corridors and top lighted.



Chemical Laboratories, Leipzig University[1]

This building, of three floors and a basement, consists of two wings with rooms on either side of a central corridor. In the basement are small rooms for technical work, bacteriology, gas analysis, distillations, and furnace work, also for the sale of materials, and cleaning apparatus. The technical laboratories contain steam supply, vacuum pump, hydraulic press (600 atmospheres), centrifugal, shaking and grinding machines, hot filtering arrangements, and gas and electric ovens. Lifts for goods and passengers connect this level with the upper stories.

On the ground floor (Fig. 111) is the large lecture theatre, 52 ft. by 43½ ft., which has an independent access, with cloakrooms below the staging. The lecture table, partly tiled and with a flap in the centre, is 37 ft. by 3 ft. 3 ins. and 3 ft. 1½ ins. high, hydrogen, oxygen, nitrogen, carbon dioxide, and electric supply are laid on from the room behind. Two ⅝-in. thick framed glass sheets are arranged in the table for protection from explosion experiments.

There are two large laboratories, each 20½ ft. by 54 ft. on the main frontages, and off each are sulphuretted hydrogen rooms supplied from a basement gasometer, while glass and chemicals are dispensed opposite the laboratory in the right wing. Forming a rear projection is a laboratory for 30 medical students, 16 of whom work on benches under the windows, and adjoining is a dark room. Other rooms on this floor are subsidiary, and for assistants, each of whom has a private research room. On the first floor is a theatre to hold 82 students. The left wing is devoted to administration, library, and waiting rooms, the director's suite, professors' and minor rooms. In the other wing are a large and two small advanced laboratories, rooms for distillations and closed tube experiments, assistants', service and dark rooms. The second floor includes a large meeting hall and physico-chemical and photographic laboratories.

The ventilation is on the grouped fan system, except that in the medical students' laboratory, the fume hoods on every table have a separate exhaust fan on the roof above, and the sulphuretted hydrogen rooms have also separate fans. Red tiles on concrete are used on many of the benches where much heat is required, and for the fume cupboards, and teak for other benches.

[1] Particulars are taken from Dr. Beckmann's account of this building, published in 1908.

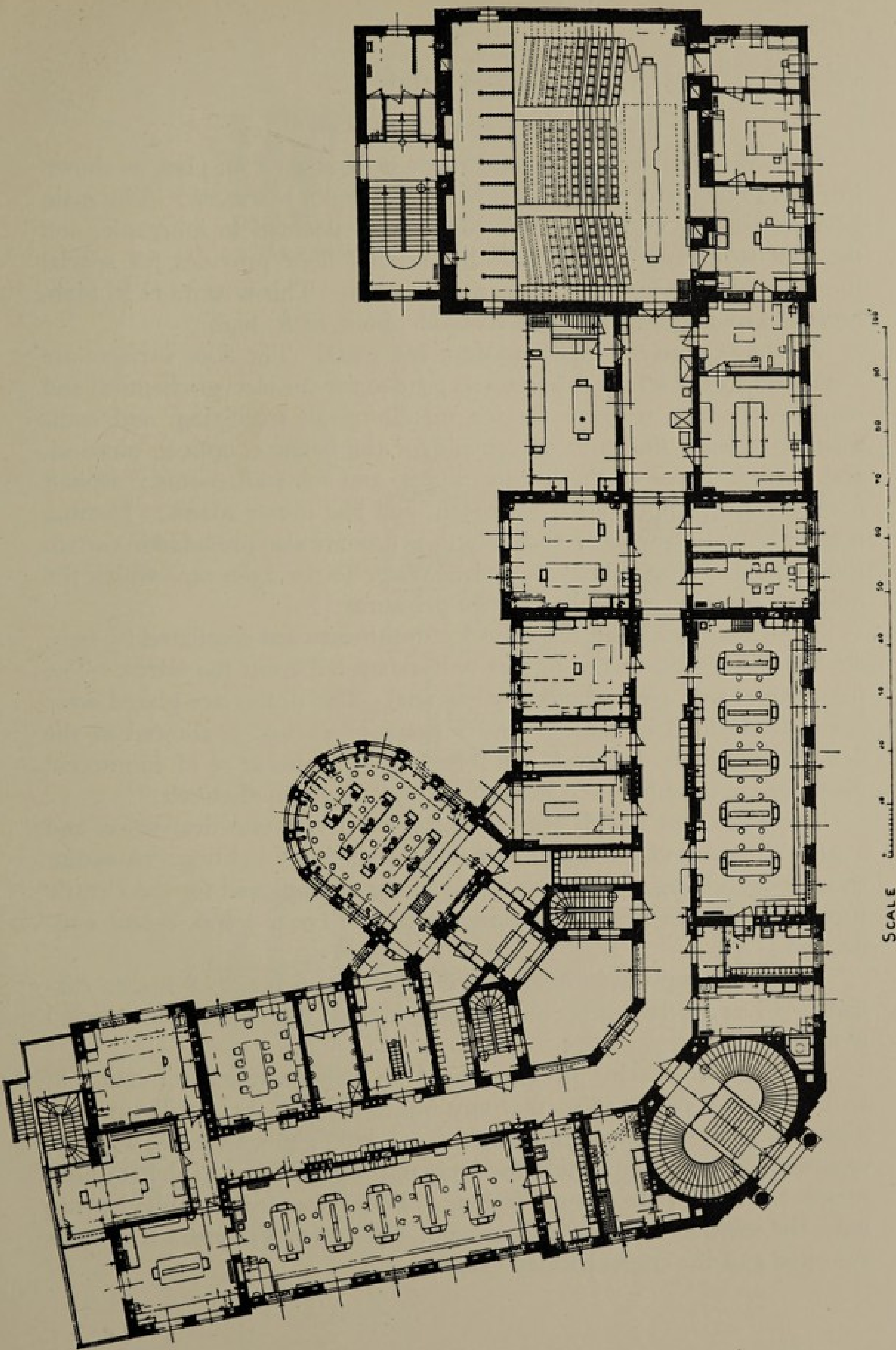


FIG. 111.—Ground Plan of Leipzig University, Chemical Department.

Berlin Chemical Institute

This building, erected about 1900, is H-shaped on plan, as shown in Figs. 112-13, and comprises three stories and a basement. The main laboratories face N.N.W. The top floor is devoted to inorganic, and the first to organic work, while the ground floor provides for special branches of chemistry and for administration. This is some 12 ft. high, but the first and second floors are each about 17 ft. high.

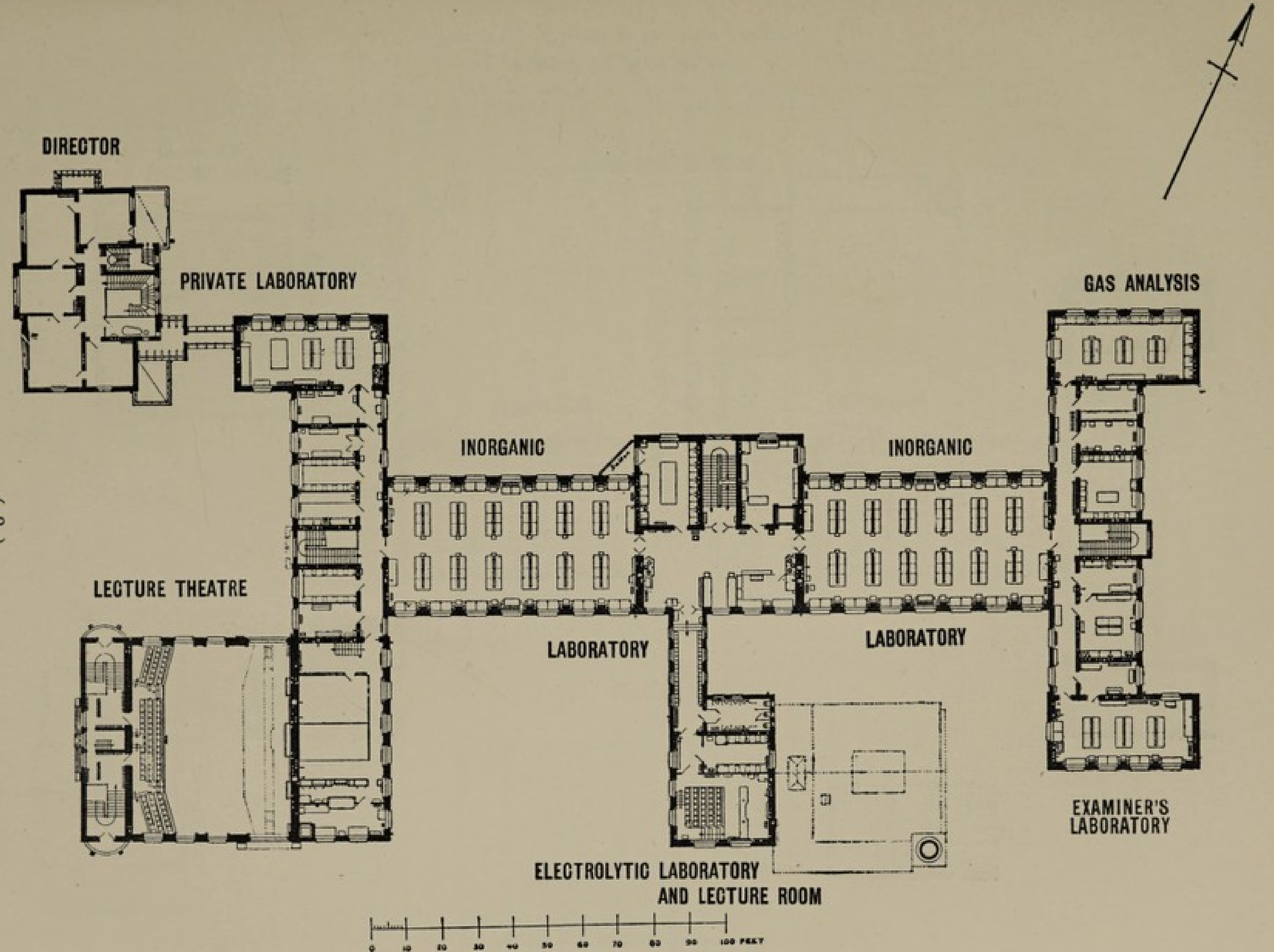
All doors open out and are 3 ft. 3 ins. wide. The floor surfaces are —oak blocks for all the laboratories; stone for the electro-chemical and machine-rooms; terrazzo for the metallurgical, sterilizing, and combustion rooms; linoleum on cement for the balance, optical, physical, and students' area of the lecture rooms, and for staff rooms; asphalt for the stores, sulphuretted hydrogen, and like minor rooms. Heating is effected by low-pressure steam, but gas fires are also provided in certain rooms used during holiday periods. Water to the 2380 taps which the building contains is supplied at two pressures.

The laboratories and the main lecture theatre are ventilated by fans, air being supplied to the former and exhausted from the latter. The fume cupboards are operated by gas jets. The drains are glazed ware channels, bedded in cement, and a space of 12 ins. is allowed in the floors to obtain the necessary fall; lead wastes 1 in. or $1\frac{1}{4}$ in. in internal diameter are used between the fittings and the drain channels.

There are two 10-cell accumulators for electro-chemical work, and a 240-cell accumulator was originally installed for lighting. A motor transformer giving 1000 amperes at 50 volts is employed for the electric furnaces. All the general working benches have a $\frac{1}{2}$ h.p. motor connection.

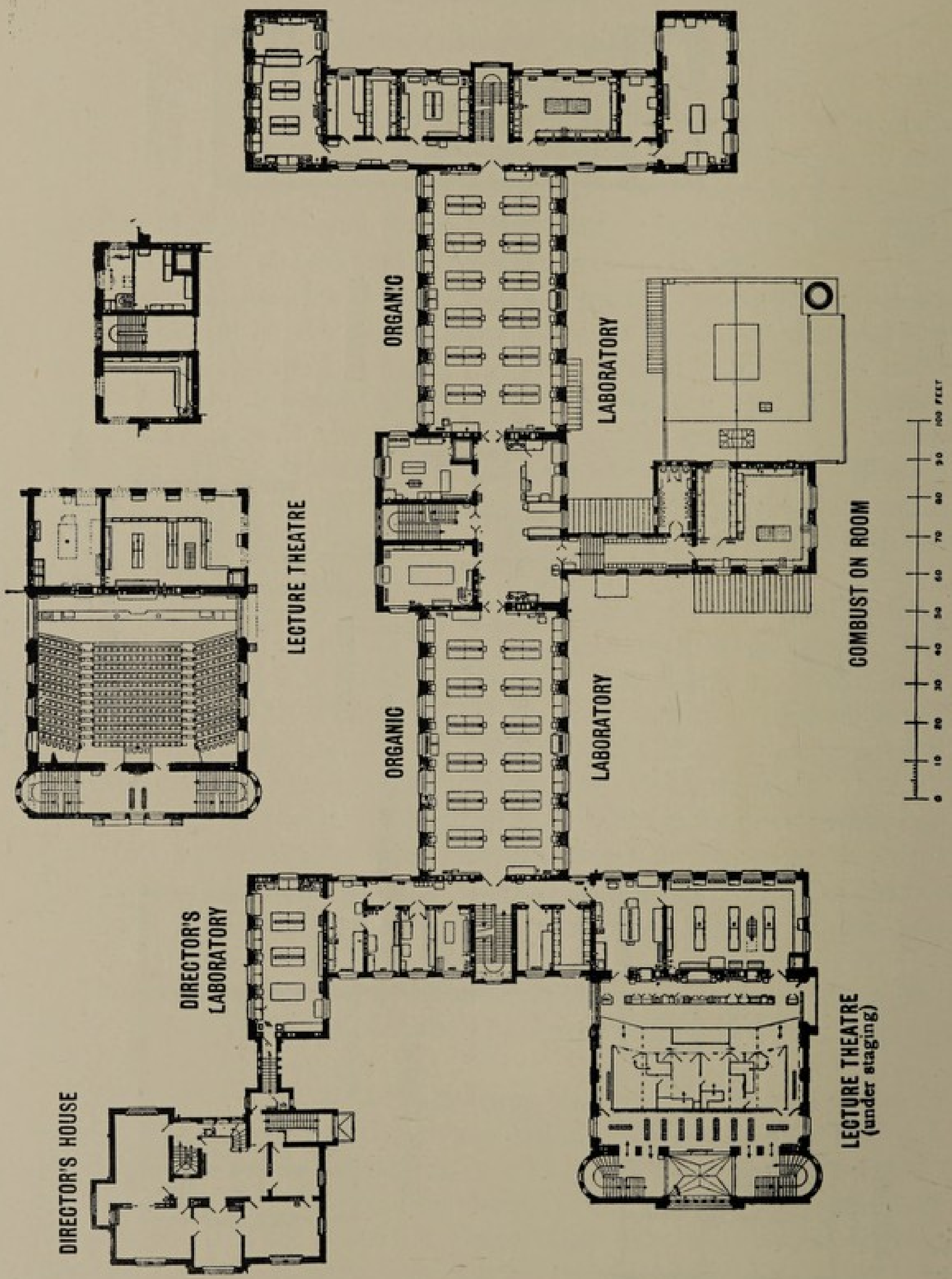
The fume cupboards have glazed pipe flues 6 ins. to 8 ins. in diameter. The special outlet chimney pots to these flues have been referred to and figured on page 144.

The double working benches stand on cement, raised a fraction of an inch above the floor so that any liquid spilt in them will run out. These benches are throughout 10 ft. 6 ins. long and 5 ft. 6 ins. wide for organic and 4 ft. 7 ins. wide for inorganic work except in the research rooms where they are about 8 ft. long. Both sides are movable, leaving only the central drainage and reagent shelves as fixtures. The tops are oiled and the fronts painted grey.



SECOND FLOOR PLAN

FIG. 112.—Chemical Institute, Berlin.



FIRST FLOOR PLAN

FIG. 113.—Chemical Institute, Berlin.

Balance tables are of $1\frac{1}{4}$ in. oak, 24 ins. wide, and are 32 ins. above the floors.

The combustion benches have sandstone tops $37\frac{1}{2}$ ins. high and $21\frac{1}{2}$ ins. wide, near which are wooden lead-lined sinks 31 ins. by 18 ins. by 5 ins. deep. Each bench has a vent opening connected to a flue in the walls. The wrought-iron hoods, which are hinged, project 24 ins. from the wall, and are 43 ins. above the benches.

Turning to the arrangements of the different floors, the second floor (Fig. 112) is divided into two approximately equal parts, with certain central rooms in common, each half being under the direction of a professor. The two large inorganic laboratories, each 79 ft. by 37 ft., accommodate 72 students each, at benches with hard wood tops which are 4 ft. 7 ins. wide, and allow 3 ft. 6 ins. to each place, below which space are two sets of drawers and cupboards.[1] The room connecting the two main laboratories is used for ether distillations and grinding. The rooms adjoining the central stairs are preparation and sulphuretted hydrogen rooms ; the latter has 14 wall cupboards, and off it is a balcony for experiments with noxious gases. The wing of this central portion contains an electrolytic laboratory, and a small lecture room for 34 students. In the west wing the small rooms near the centre are balance, optical, oven, and similar rooms. At the north end of this wing is a private laboratory, and at the south a lecture room for 110 students with preparation room attached. In the east wing, the small central rooms are for balances, glass blowing, and other uses, the larger laboratory on the north for gas analysis, and that on the south for examination purposes.

The general arrangement of the first floor (Fig. 113) is similar to that above. The two large organic laboratories are of the same size, and contain the same number of benches as those for inorganic work, but each bench is devoted to four, in place of six students, the bench length per head being 5 ft. 3 ins. Each room holds 48 students.[2] A general room for special operations connects the two laboratories, and a small library and apparatus store and dispensary adjoin the central staircase. The central wing contains a balance room, and at the extreme end, a combustion room. In the west wing, on the north, is the director's laboratory adjoining his house. The other small rooms near the staircase, are balance, optical, closed tube, and interview rooms, while

[1] $39\frac{1}{2}$ sq. ft. of floor area per head. [2] $59\frac{1}{2}$ sq. ft. per head.

on the south two rooms for preparation and erection of apparatus give access to the large lecture theatre, approached by a separate students' staircase at the other end. This lecture theatre, 60 ft. by 49 ft. and 31 ft. high normally, seats 352, but a further 138 can be accommodated in gangway and gallery seats. The lecture table in this theatre has been referred to on page 37. The ceiling and most of the walls are wood

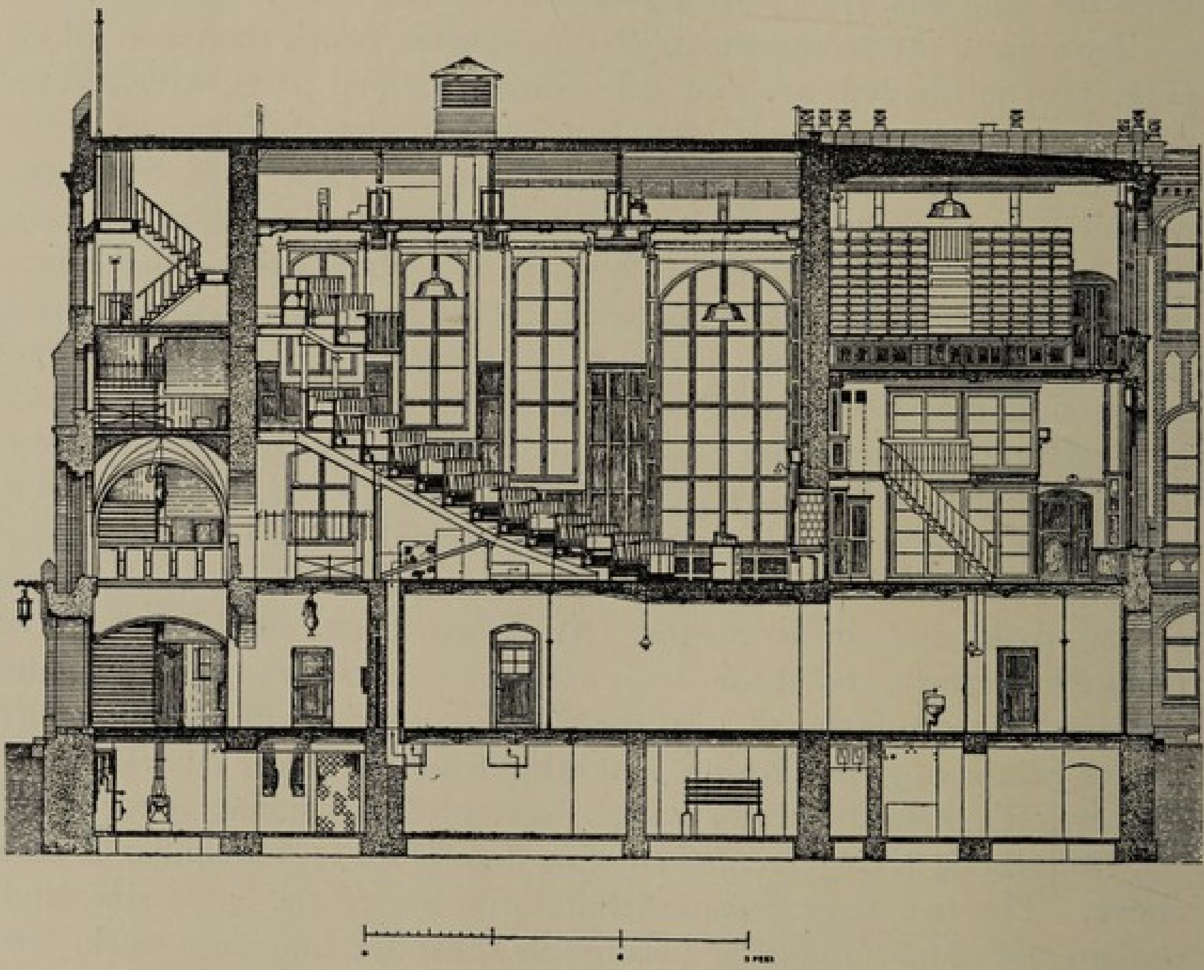


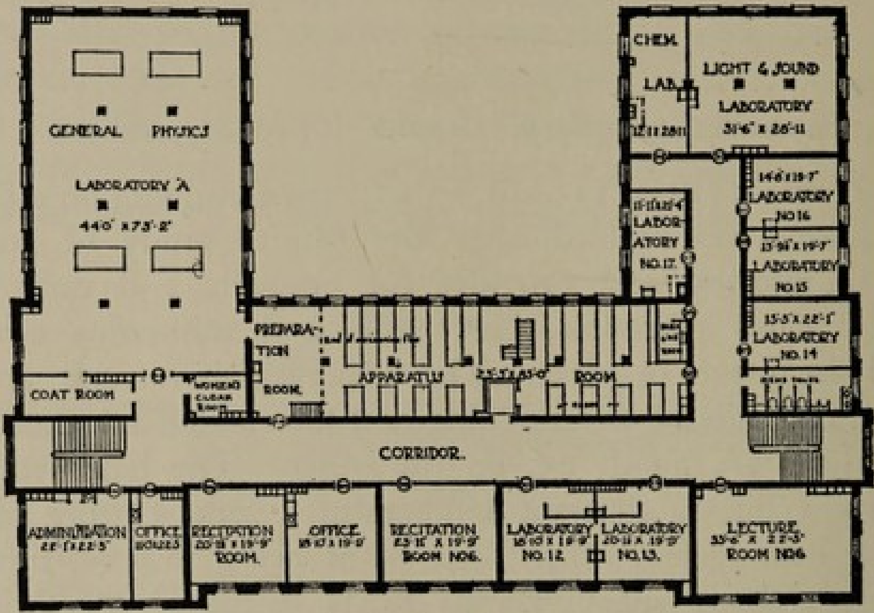
FIG. 114.—Section Through Main Lecture Theatre, Chemical Institute, Berlin.

panelled to assist acoustic qualities. The east wing on this floor contains at the ends two special laboratories, one for physical work, and a large combustion room, a balance, closed tube, assistants' and smaller physical rooms. The ground floor is devoted to special rooms, stores, and workshops. The central block forms a laboratory for work on a commercial scale, where large operations involving 100 litres (22 gallons) of liquids can be dealt with. The basement is chiefly devoted to service plant.

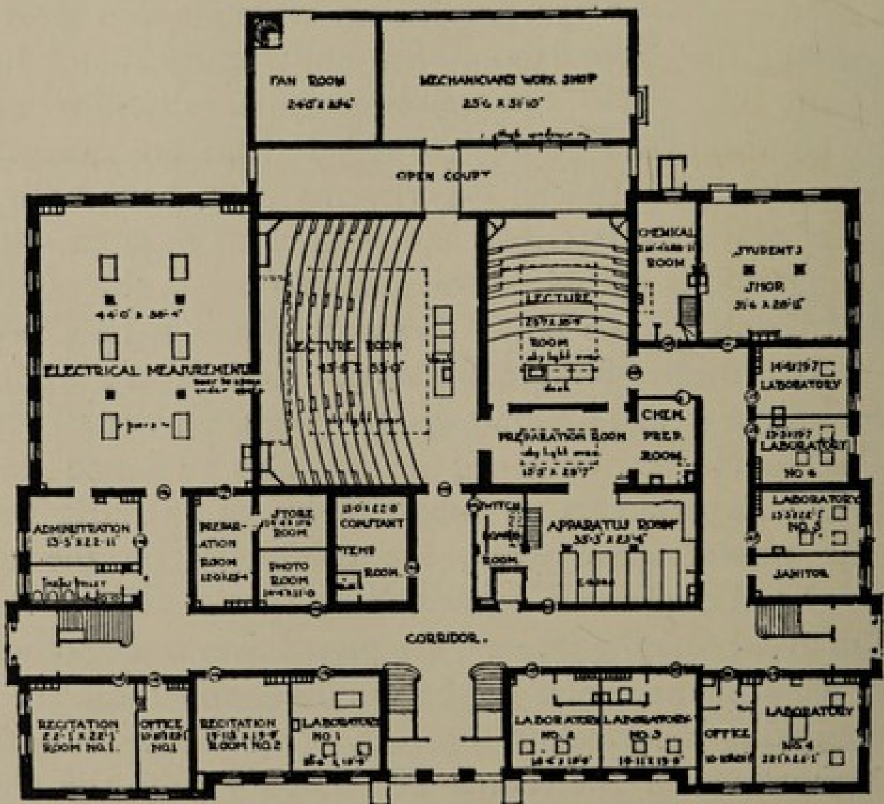
Physical Laboratory, Urbana University, Illinois

This laboratory (Figs. 115-16), an extensive building on a site about 250 ft. square, was erected after the careful study of 20 leading physical laboratories, and provides for graduate and undergraduate work. To avoid vibration thick walls and numerous cross walls were used in place of steel. The general laboratories are placed together on one side of the building and the smaller advanced rooms, of which there are about 25, on the other. The basement is used for ventilation ducts, constant temperature work, battery room and storage, the heating and other large plant being in a separate building, but such rotary machinery as exists is placed together at one corner on a reinforced concrete floor, upon 18 ins. of sand, clear of the walls, which scheme for preventing vibration has proved satisfactory. All the first floor laboratories and lecture rooms have piers carried down to the ground, but wall brackets have been found equally good, even on the higher floors, provided these are near cross wall intersections. For very special experiments piers have been built on special beds of gravel as described and figured on page 72. The large theatre, seating 265, is placed on the ground floor in the middle of the building and is top lighted only. Separated from it by a preparation room is a second theatre for 120 students. Each laboratory has rooms attached for minor repairs, administrative uses, and one or two dark rooms. The rooms are darkened by curtains mounted on vertical spring rollers. Experiments on sound, light, and electric waves, and most of the photographic work, are conducted on the top floor. Stores with glazed cupboards connected by special stairs and by a lift (hydraulic to avoid rotating motors) are placed over one another, and on mezzanine floors in the centre of the building, and these are in touch with the unpacking room below.

The arrangement of the rooms will be seen from the plans upon which their uses are indicated.

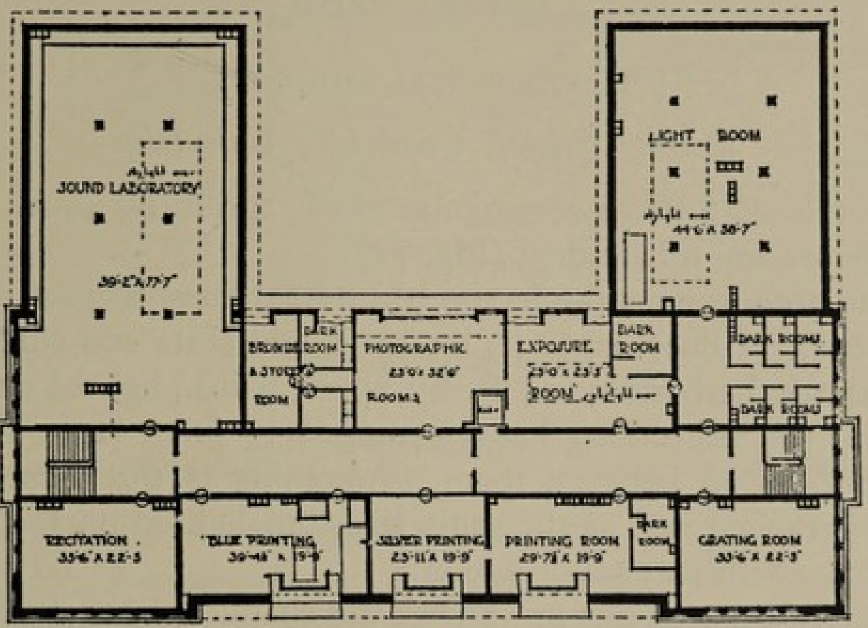


SECOND FLOOR

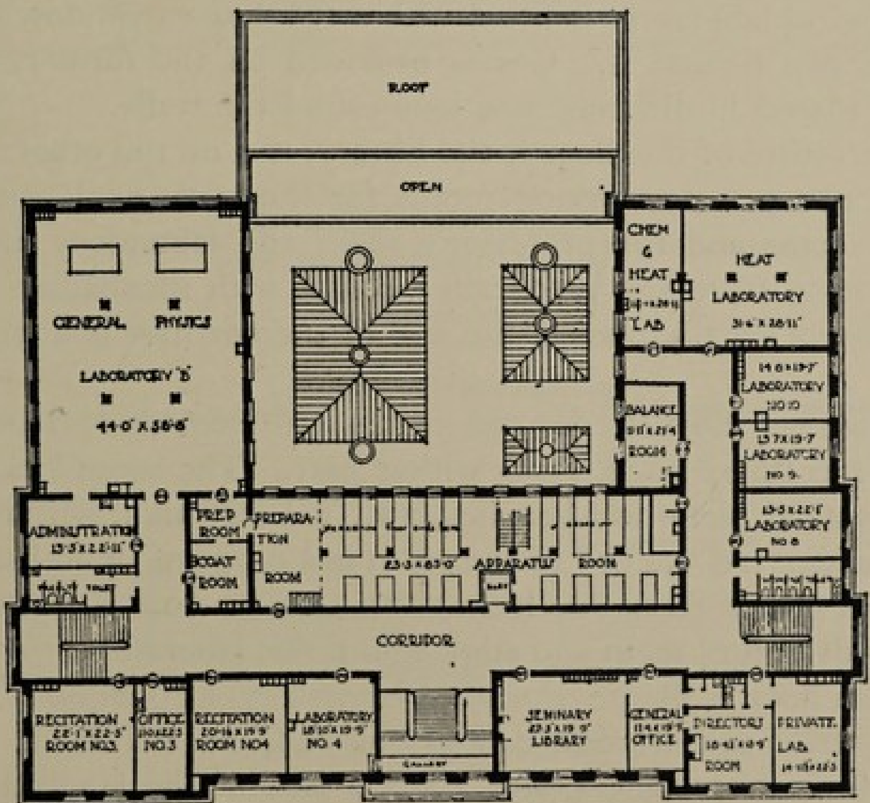


GROUND FLOOR

FIG. 115.—Physics Laboratory, Urbana University, Illinois, U.S.A.



THIRD FLOOR



FIRST FLOOR

FIG. 116.—Physics Laboratory, Urbana University, Illinois, U.S.A.

II. BIOLOGICAL SUBJECTS

Botany School, Cambridge University

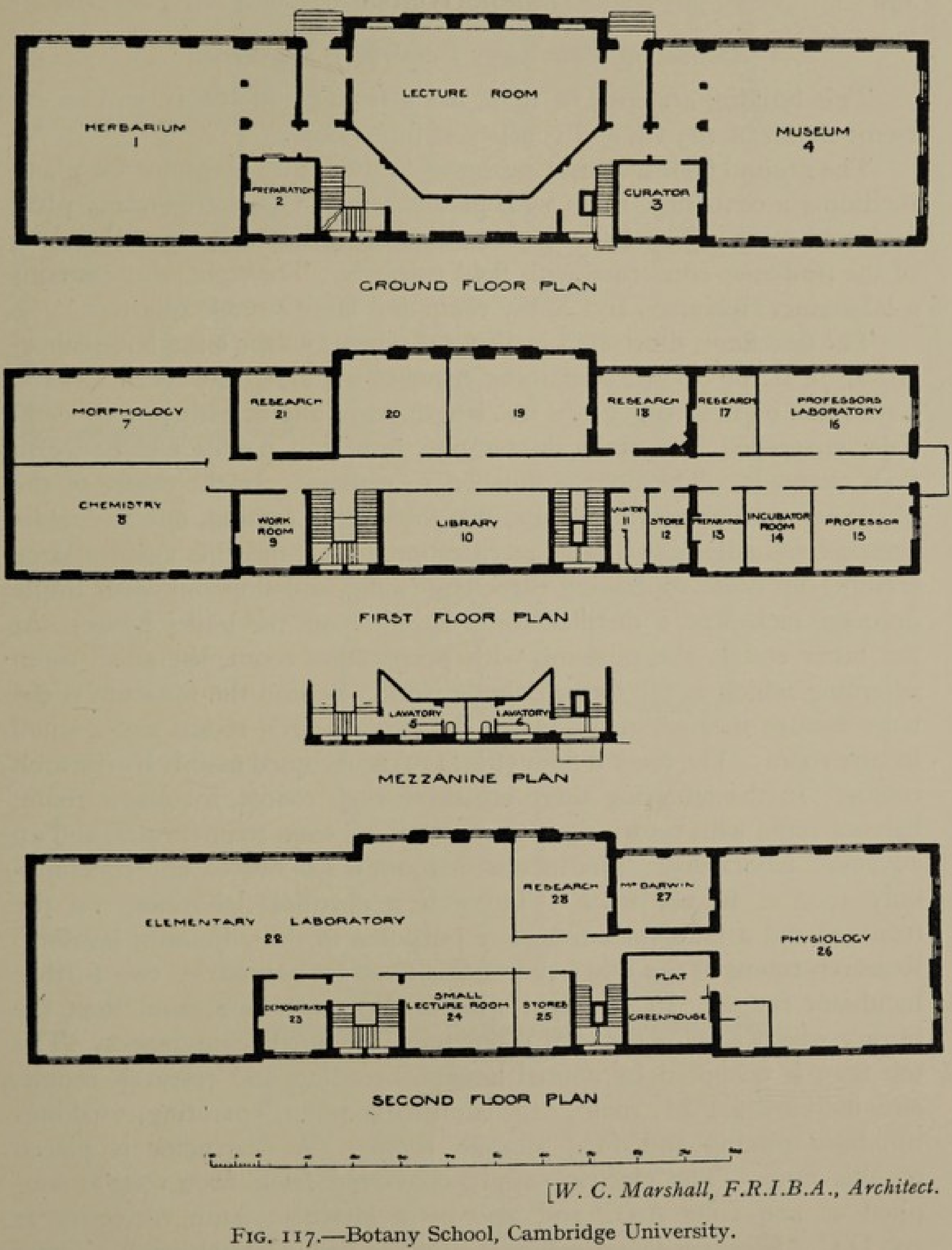
This building forms a rectangular block, 200 ft. by 40 ft., consisting of three floors and a basement (Fig. 117).

On the ground floor the lecture theatre, the lowest part of which is on the basement floor, is 52 ft. by 35 ft. and seats 200 students. On the left is the herbarium, 45 ft. by 39 ft. 6 ins., lighted on the north and south, the collections being arranged to form bays, with tables for reference work between them. Adjoining is the curator's room. Similarly arranged and of the same size, but lighted on three sides, is the museum, with its curator's room.

The first floor contains on the left the chemical laboratory equipped with ordinary double benches with drawers but without lockers. The morphological laboratory is fitted with a continuous window bench and a parallel one behind it. Gas is provided on the former, and three sinks are placed in different positions round the walls.

In the centre of this floor is the library, and on the other side of the corridor, two private working rooms for the staff, while on the right research rooms and the professor's room and laboratory find a place in addition to store and preparation rooms with incubator. The projection shown on the plan at the end of the corridor is a small greenhouse.

The second floor is devoted to a large elementary laboratory on the left, 100 ft. by 40 ft. at its widest part. The room has places for 150 students at plain deal benches, 2 ft. 10½ ins. high, without drawers or cupboards. At the end of the room is a range of small lockers. An illustration of this room has been given on page 80. A demonstrator's room, small lecture room and store adjoin this laboratory. At the other end of this floor is the physiological laboratory, a room 40 ft. by 46 ft., which contains deal window benches, also 2 ft. 10½ ins. high. Provision is made for galvanometers, and a small part of the laboratory is partitioned off as a dark room. Both high and low-pressure water are supplied to this room, and off the flat adjoining it is a greenhouse, sunk to this floor level so that it is not exposed to the sun. On the roof is another greenhouse and a large flat for open-air work.



[*W. C. Marshall, F.R.I.B.A., Architect.*

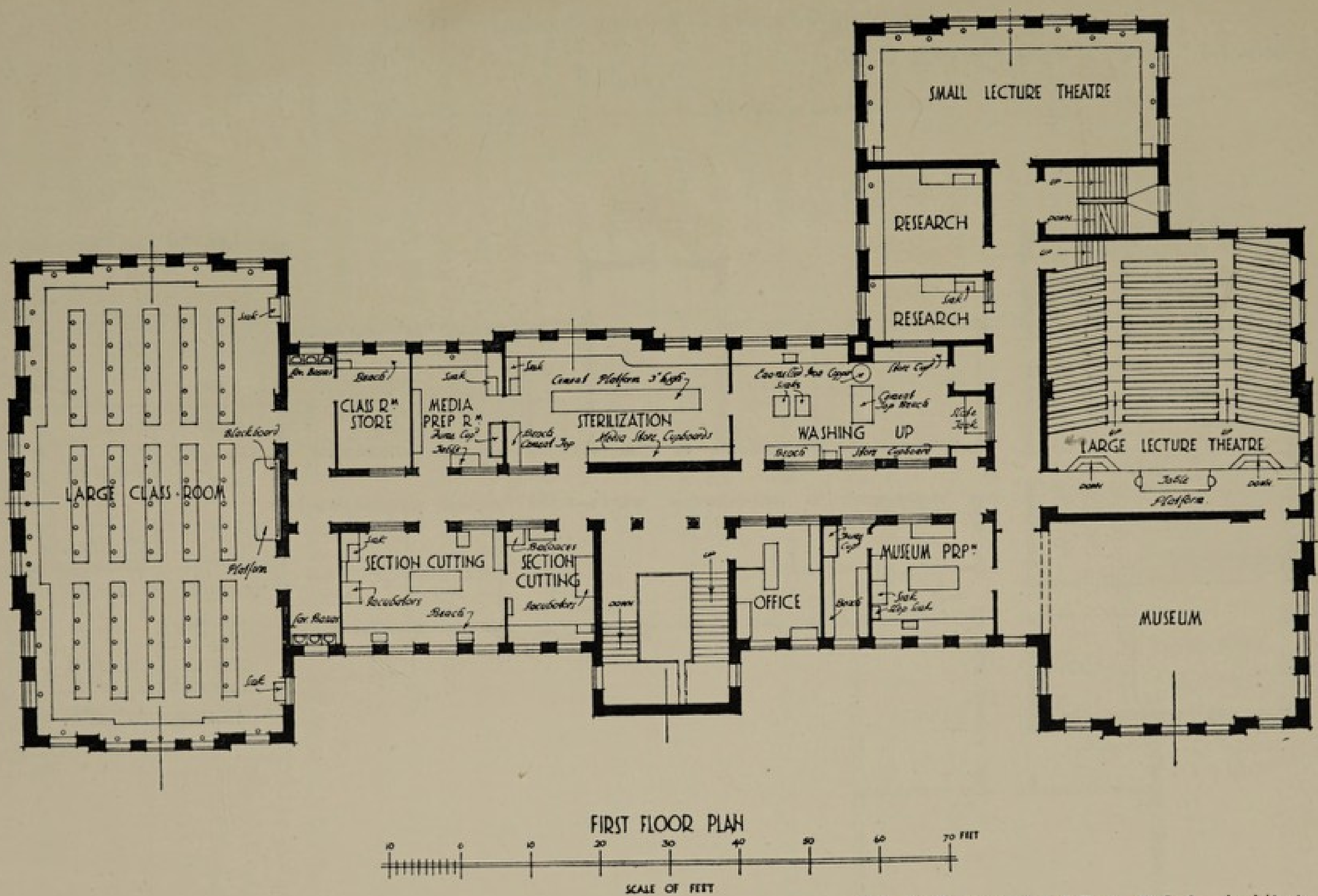
FIG. 117.—Botany School, Cambridge University.

School of Pathology, Cambridge University

This building, opened in 1928, has a frontage of 186 ft. and an extreme depth of 103 ft., and consists of four floors.

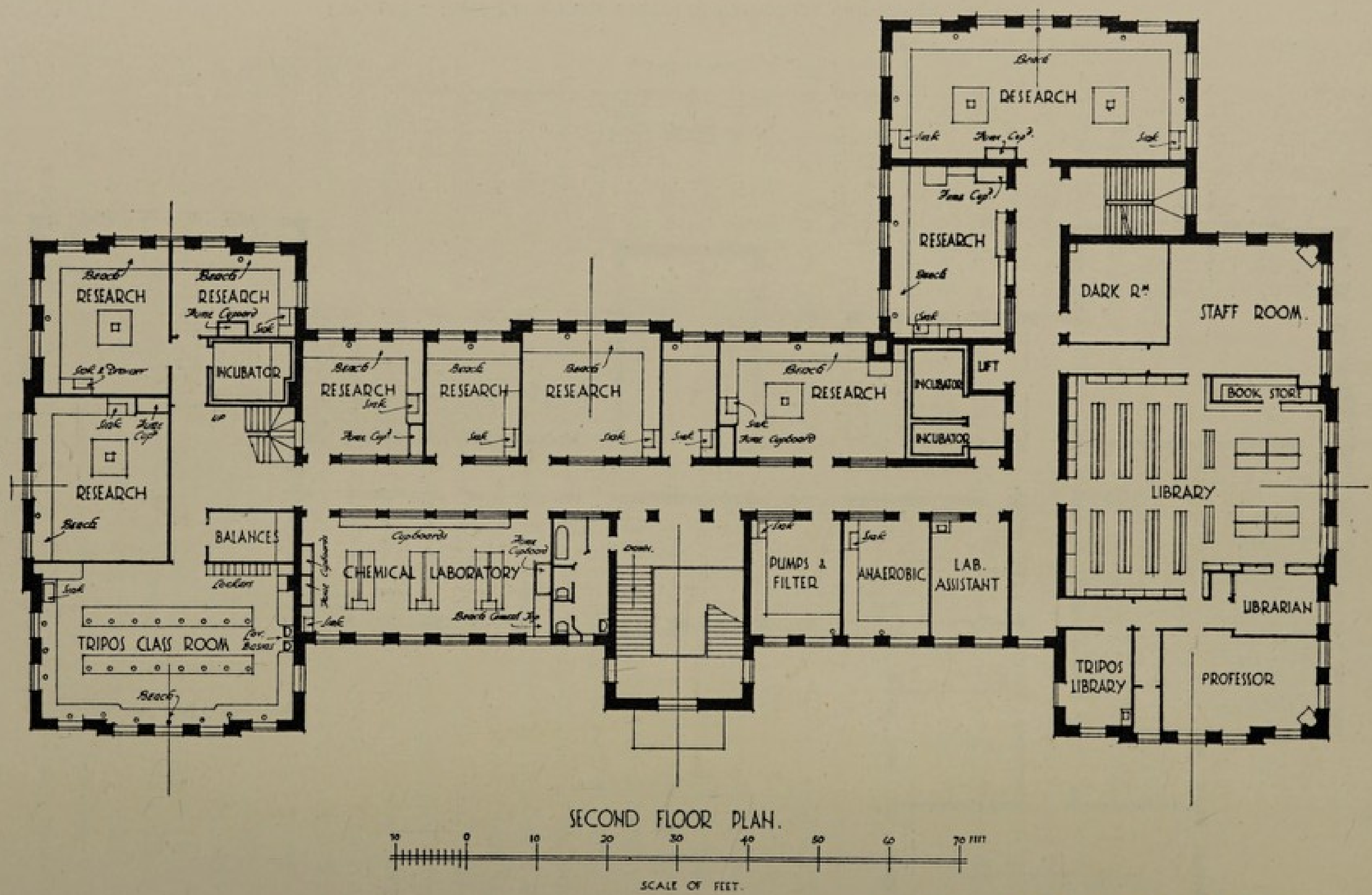
The ground floor is mainly occupied in the centre by rooms for plant, including a centrifuge room with pit for safety, CO_2 refrigerating plant and cold store. The left wing contains the offices and research rooms of the professor concerned with field research. The right wing contains a laboratory, research, and X-ray room and large storage quarters.

The first floor, illustrated in Fig. 118, shows on the left a large laboratory, 78 ft. by 36 ft., containing benches without drawers or lockers, 2 ft. 6 ins. high, giving 3 ft. 4 ins. length per student, with round, movable, enamelled iron sinks discharging into iron wastes and hence to floor channels. The floor is finished in cement. In the centre of the block are various service rooms, two for section cutting, one for media preparations adjoining a large sterilization room, and this again a large washing-up room containing three large sinks and slop sink with ample drainage racks and a distilled water supply from the boiler house. At the other end is the museum with preparation room, the small room adjoining which is for formaldehyde work. Behind the museum is the large lecture theatre, 39 ft. by 36 ft., two research rooms and a small lecture room. The second floor (Fig. 119) is occupied mainly by research rooms. In the left wing there are three such rooms, incubator room, balance room with no window, to maintain an even temperature, and an advanced laboratory. The incubator room is gas heated and consumes only 1000 c. ft. per week. There is a chemical laboratory on the frontage and a bath for emergency purposes in the adjoining lavatory. Research rooms at the other end of this floor are served by two further incubator rooms. In the right wing is the professor's room next the library which adjoins the staff room used for small conferences. The top floor is occupied by animal houses, breeding and research rooms, and includes a P.M. room, cage sterilizing room, operating, washing-up, food mixing and food storage rooms. A destructor is placed on this floor. The electric supply converted from 2000 volts is supplied at 200 volts A.C., and also by a Hewittic lamp converter at 200 D.C. Steam at low pressure is supplied to the laboratories. There is no general ventilation system, fume cupboard flues being operated by such natural draught as hot gases can give.



[E. P. Warren, F.R.I.B.A., F.S.A., Architect.

FIG. 118.—First Floor Plan, School of Pathology, Cambridge University.



[E. P. Warren, F.R.I.B.A., F.S.A., Architect.

FIG. 119.—Pathology Laboratory, Cambridge University.

Biology Block, University College of North Wales

This single story building, some 140 ft. by 100 ft., provides for botany and zoology, and consists of two similar wing blocks with larger central rooms between them, lighted by gables and windows over the corridor flats. The botanical wing on the N.W. at the top of the plan, Fig. 120, provides a small professor's room and research laboratory, which latter adjoins the physiological laboratory, 22 ft. by 26 ft., off which on the right is another research room, next a dark room entered from the corridor. A small museum and herbarium, 15 ft. by 26 ft., separates the above from an advanced laboratory which adjoins the elementary room, 32 ft. by 26 ft., with long tables facing the window wall. Two further research rooms complete the wing accommodation. In the centre is a well side-lighted, though internal lecture room, 25 ft. by 33 ft., with preparation and store room attached. The small top-lighted library is common to both departments.

The provision for zoology on the road frontage consists of two research rooms, one being off the general laboratory, 25 ft. by 26 ft., beyond which a passage, separating the professor's room from a small vivarium, leads to a small advanced laboratory, giving access again to the lecture room 26 ft. square. The museum occupying the rest of the centre block is 33 ft. by 65 ft., and has a long ridge lantern and external entrance. This room has been illustrated on page 94.

Over the lavatory flat on the S.W. is a botany greenhouse approached externally, and supplied with electric radiators to meet the shutting down of the hot-water heating system to this house and the building. External provision in the grounds is made for potting work and also for zoology in the matter of special dissecting.

Services are carried in trenches under the corridors and thence to rooms on either side, the maximum electric power amperage for botany being 40. Structurally the building is of the simplest character on the score of economy, the walls of 9-in. brick rendered in white cement externally, the floors of the laboratories in cement, wood blocks being confined to the large central and private rooms. The fittings are generally simple in design though providing for adequate storage. Tanks are provided on the roofs to give a supply of rain-water.

The cost per cubic foot of this one-story block was about 1s. 1d., and the fittings and services cost, in addition, about £2500.

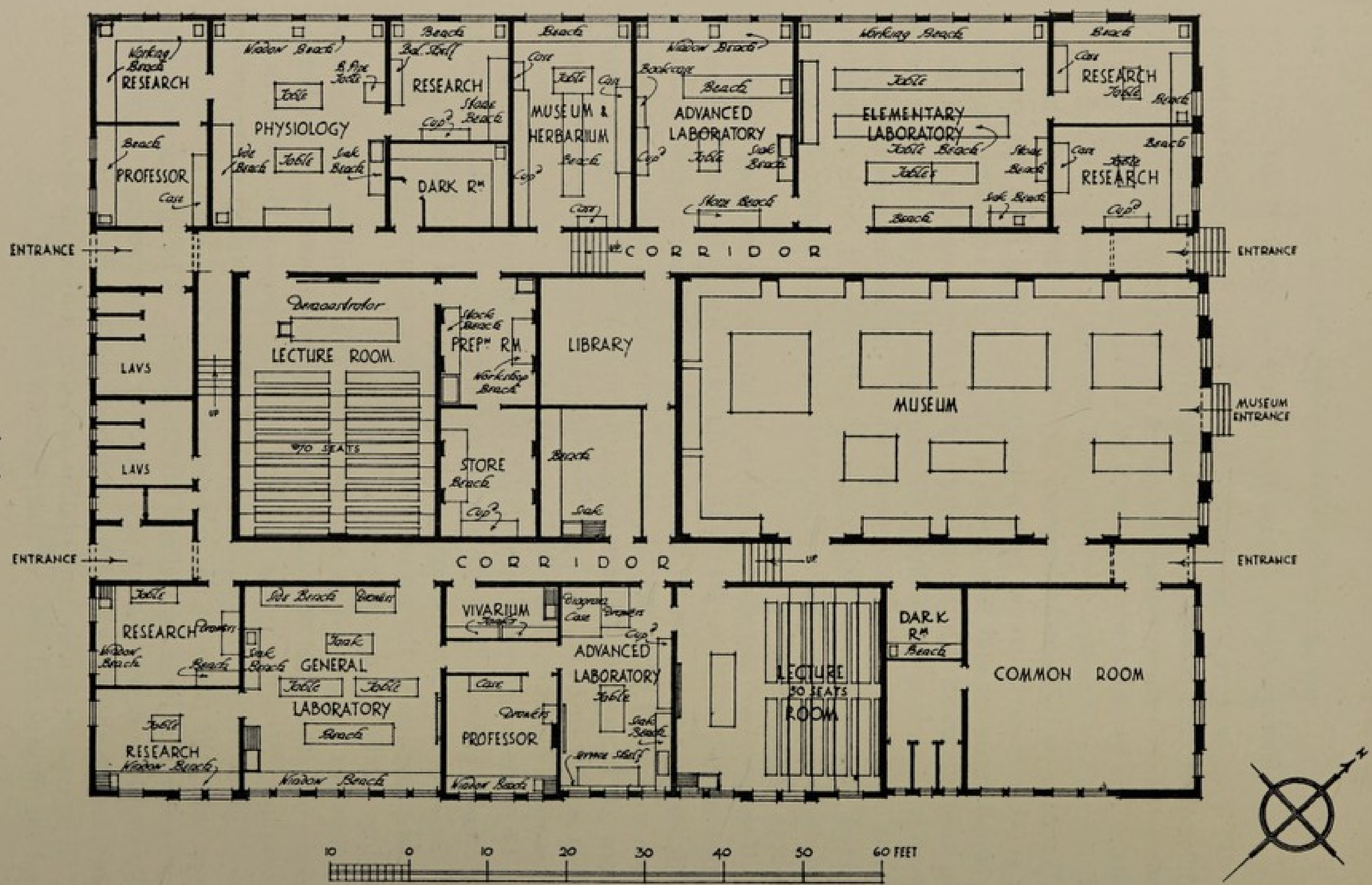


FIG. 120.—Biology Department, University College, North Wales.

Botany and Zoology Departments, Agricultural Block, University College, North Wales

This building, with a frontage of 187 ft. and a central depth of 47 ft., provides for the biological sciences applied to agriculture. It consists of two stories, the ground floor is devoted to administration, a library and a lecture room, and museum at the ends of the building. The first floor, shown in Fig. 121, is occupied by zoology on the left, general botany on the right, and plant pathology in the rear rooms. The zoological laboratory, 45 ft. by 26 ft., is used both for practical work and demonstrations. A preparation room separates this from the lecturers' private laboratory. Beyond an adjoining research room is a lecture and preparation room, used generally by this floor. For botany the arrangements are similar, with, however, three research rooms in place of two. At the back a general plant pathology laboratory gives access to a culture room, while on the other side of the staircase are a lecturer's room, research room, and a smaller one for examinations. The rooms at the bottom of the figure on the left belong to the veterinary department. On the flat roof are a series of greenhouses with means of controlling temperatures. The fittings, in teak and Douglas fir, include special sinks for plant soakage and storage, and large wire-covered enclosures on the roof for plant growth.

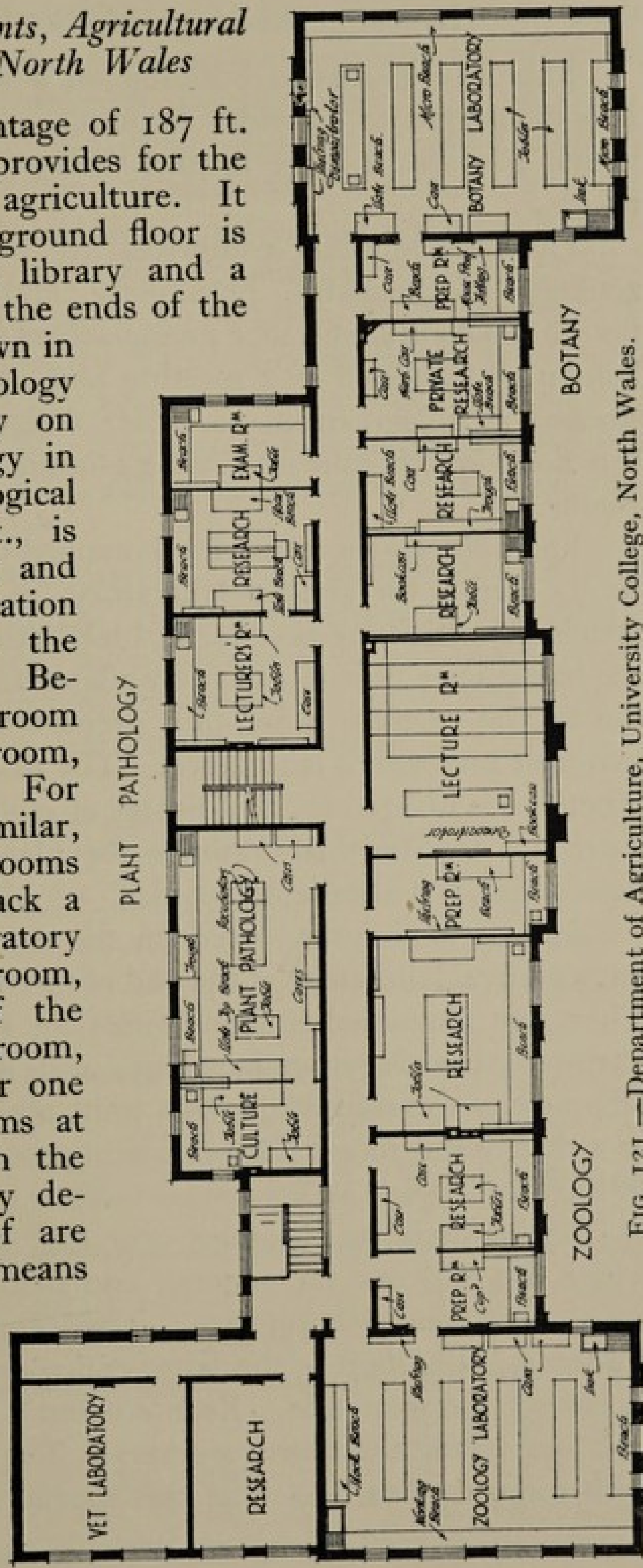


Fig. 121.—Department of Agriculture, University College, North Wales.

Biological Building, McGill University, Montreal

This is a T-shaped building on a site sloping from west to east. It is connected to an older building, shown broken off on the plans, which provides a large lecture theatre, laboratories, and some minor rooms.

The new building comprises five floors, and provides for botany, zoology, biochemistry, physiology, and pharmacology. The ground floor has a central entrance giving access to a large hall under the general laboratory designed as a meeting place for staff and students, and also stocked as an aquarium—a rather unusual arrangement. The rest of this floor, which runs into rising ground, is occupied by plant and toilet rooms.

The floor above forms the botanical department shown in Fig. 122. At the end is the general laboratory, 30 ft. by 80 ft., with greenhouse attached,[1] with fungus cellar and laboratory below. The smaller rooms are based on a unit to outside walls of 10 ft. by 22 ft. On one side of the central corridor a one-unit preparation room adjoins an office and two-unit professor's laboratory. The museum and reading room at the other end is utilized for the display of students' work. On the other side there are two-unit laboratories for plant morphology and mycology, next which is a sterilizing room.

Zoology is accommodated on the next floor (Fig. 123) with again a large general laboratory at the end of the block which holds 120 students. There are four smaller laboratories for advanced work in comparative anatomy, osteology, embryology, and like subjects and also private laboratories for research. Two units are given to an aquarium and one to a thermostat room. A macerating room is provided on the top floor of the building.

Biochemistry on the floor over Fig. 124, comprises 33 units, 13 of which are laid out for general, and 6 for special laboratories. There are three general laboratories. These hold respectively 96, 24, and 16 students. The first is the large end room while the other two are adjacent on the west side. Each student's place has two sets of drawers and lockers for alternative workers. The laboratories are well supplied with fume cupboards. The two special laboratories on the other side

[1] The detached greenhouses for this department have been described and illustrated on page 84.

of the corridor comprise six units and are used for advanced or research work in metabolism and bio-organic synthesis; one unit each is devoted to photography, nitrogen determination, balance work, store and preparation requirements and demonstrators' room. An office, library, and reading room, the private office and professor's laboratory, and the private laboratory and room of the assistant professor are two-unit rooms.

The fourth floor is devoted to physiology, and has the same general plan as the floors below. The large laboratories, however, are here in the old adjoining building, the new building being mainly concerned with research, the library and professors' rooms are placed over the laboratories at the head of the T. The animal operating suite consists of five rooms, about 10 ft. by 12 ft., adjoining a private corridor parallel to the main corridor.

The fifth floor, occupied by the pharmacology department, is confined to the central part of the building. It contains a general laboratory, nearly 70 ft. long, for 60 students for physiological and chemical work. The tables each possess kymographs operated by independent motors. The animal room in this department occupies two units.

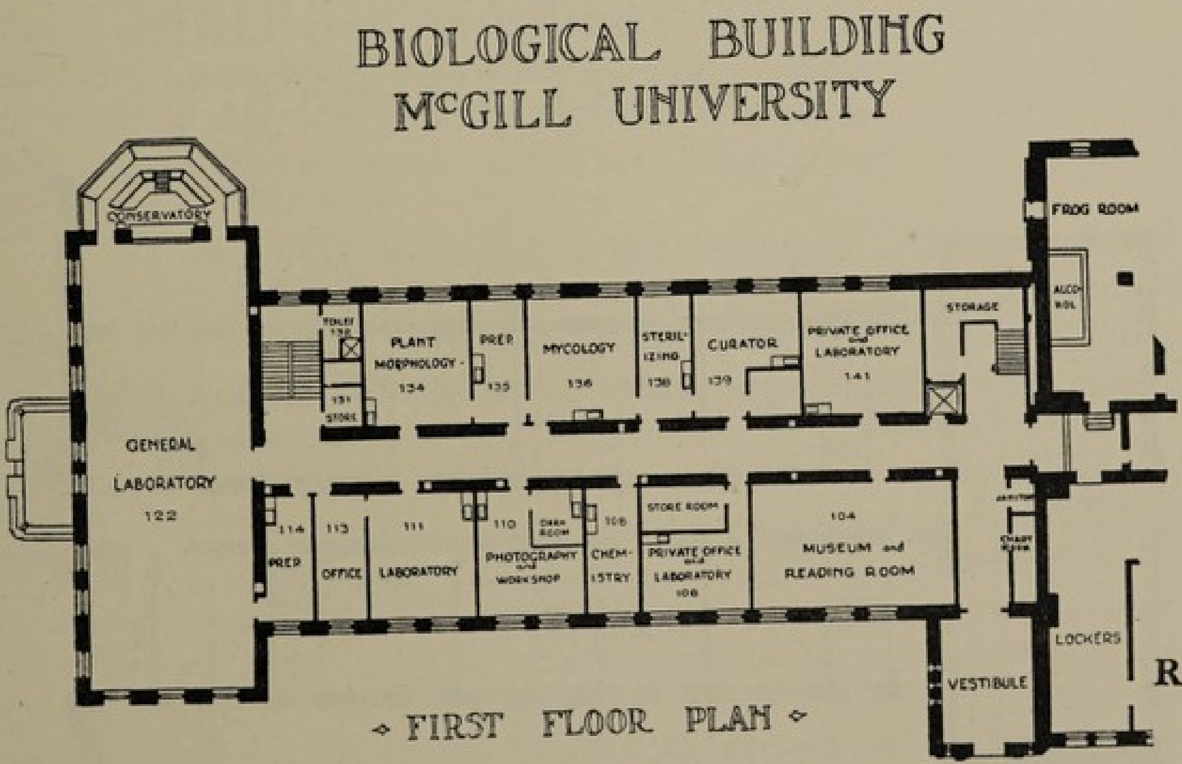


FIG. 122.—First Floor Plan, Botanical Department, McGill University.

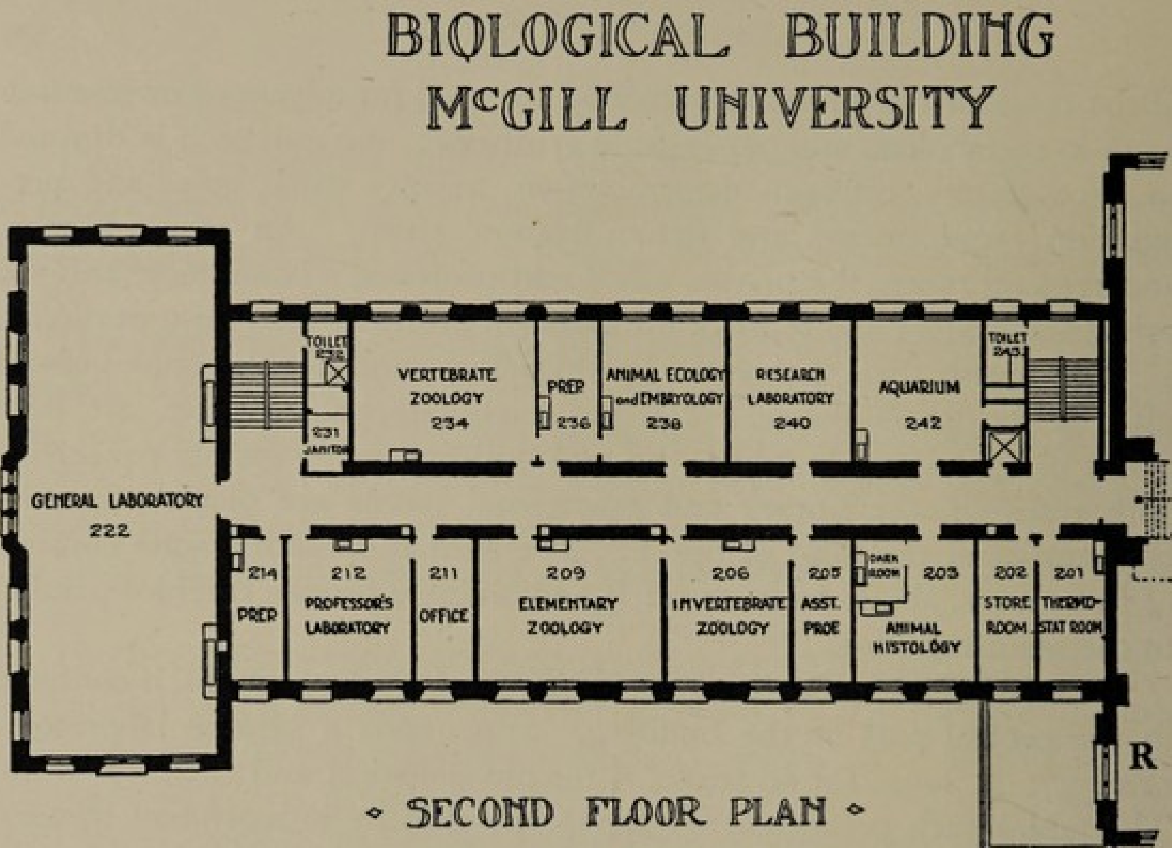


FIG. 123.—Second Floor Plan, Zoological Department, McGill University.

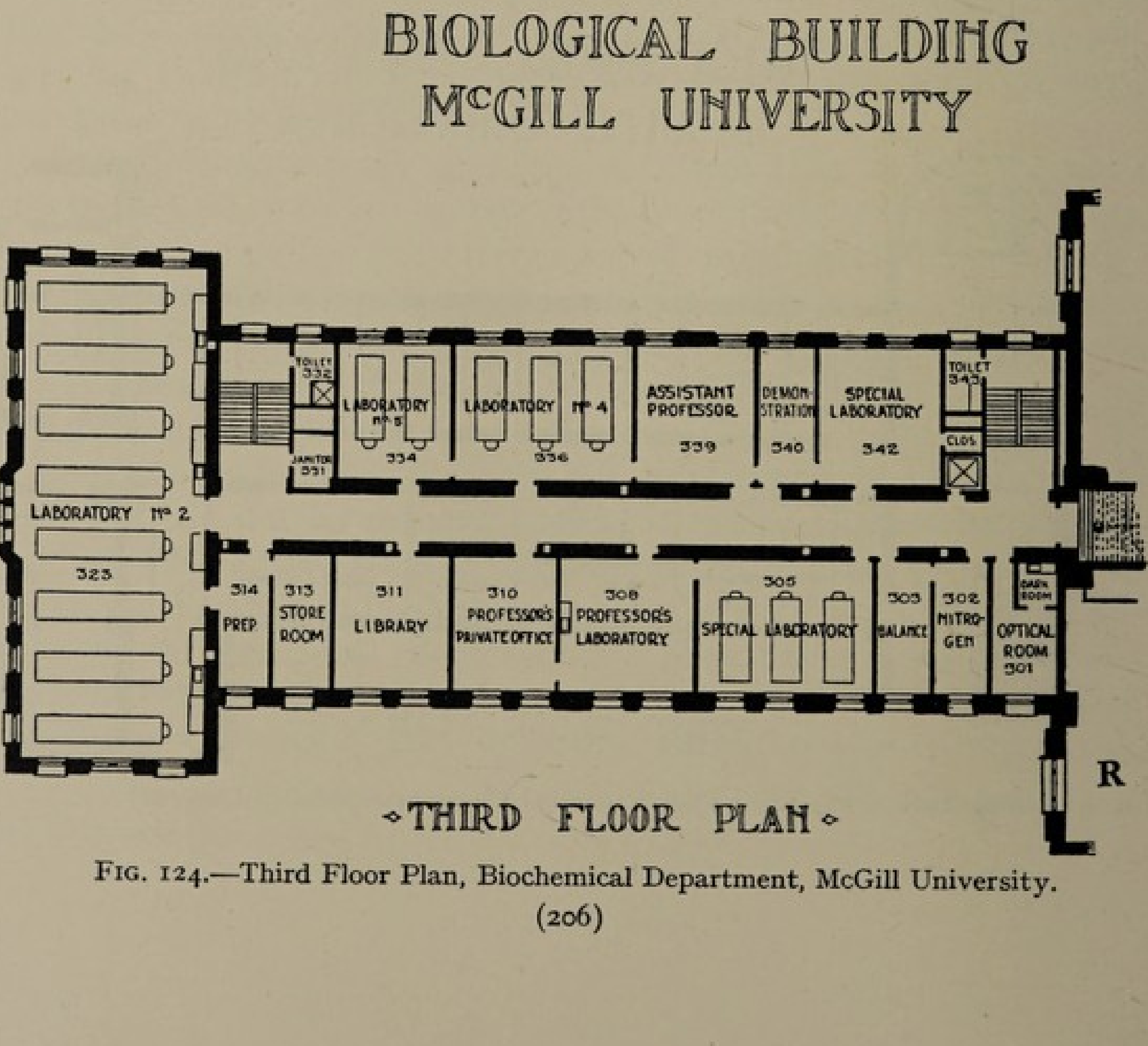


FIG. 124.—Third Floor Plan, Biochemical Department, McGill University.

Yale University, Sterling Hall of Medicine

Occupying a corner site, with frontages each about 220 ft., this building consists of four floors. It is planned on a unit system with eccentral corridor, units having 11 ft. frontage, with 16 ft. depth to front and 22 ft depth to rear rooms.

The department of physiology here described occupies the two lowest floors shown in Figs. 125-6. The basement floor, which is at ground level at the back, contains in the centre a receiving office giving access to a very large stock room beyond which are the students' cloakrooms. Next these on the right is a dark room for spectroscope and other optical work, a special room for the distillation of inflammable liquids with hoods and alberene tables round the walls, a research room (No. 27) possessing an electric autoclave and large dialysing sink. Other adjoining rooms are for food preparation with Grinnell dryer, powerful centrifuge, meat grinders, presses and stock bins. The nutrition room at the end is 36 ft. by 35 ft. and provides for some 400 small cages for mice and rats on alberene shelves with cement floor, and can be kept at 80° C. The adjoining room (No. 19) is used for food preparation, cleaning, and sterilizing, with live steam. The large laboratory at the rear is 90 ft. by 22 ft. and holds 100 students. Here there are nine central tables for 8 students, each with a sink 2 ft. by 6 ft. and tables round the walls. Room 9 possesses a large refrigerator, and is used for preparation and assistants' research.

In the other wing are found on the frontage a machine shop and aquarium (each two units), animal room, one, and dark rooms of three units. The end laboratory is 47 ft. by 24 ft., and adjoins a slightly larger laboratory at the rear with access to a technician's room next to a lecture room, 34 ft. by 22 ft.

The floor above (Fig. 126) is largely devoted to research and administration. An entrance loggia opens upon a spacious foyer beyond which is the main lecture hall, some 50 ft. by 40 ft., with stage, anteroom and passage behind adjoining external approach or escape stairs. The cinematograph room is centrally placed between the entrances from the foyer. Over the lecture hall (not shown on the plans) are reference and reading rooms used by this department but on the floor devoted to anatomy.

In the right wing a large seminar is followed on the frontage by the professor of physiological chemistry and secretary's offices, professor's laboratory and staff research rooms, while at the end of the corridor the advanced laboratory is for graduate students with some knowledge of physiological chemistry. This room is 50 ft. by 25 ft. and holds 20 students. Twelve steam baths, and a centrifuge are provided. The metabolism room adjoining, 25 ft. square, contains dog and rabbit cages and a large sink for washing animals.

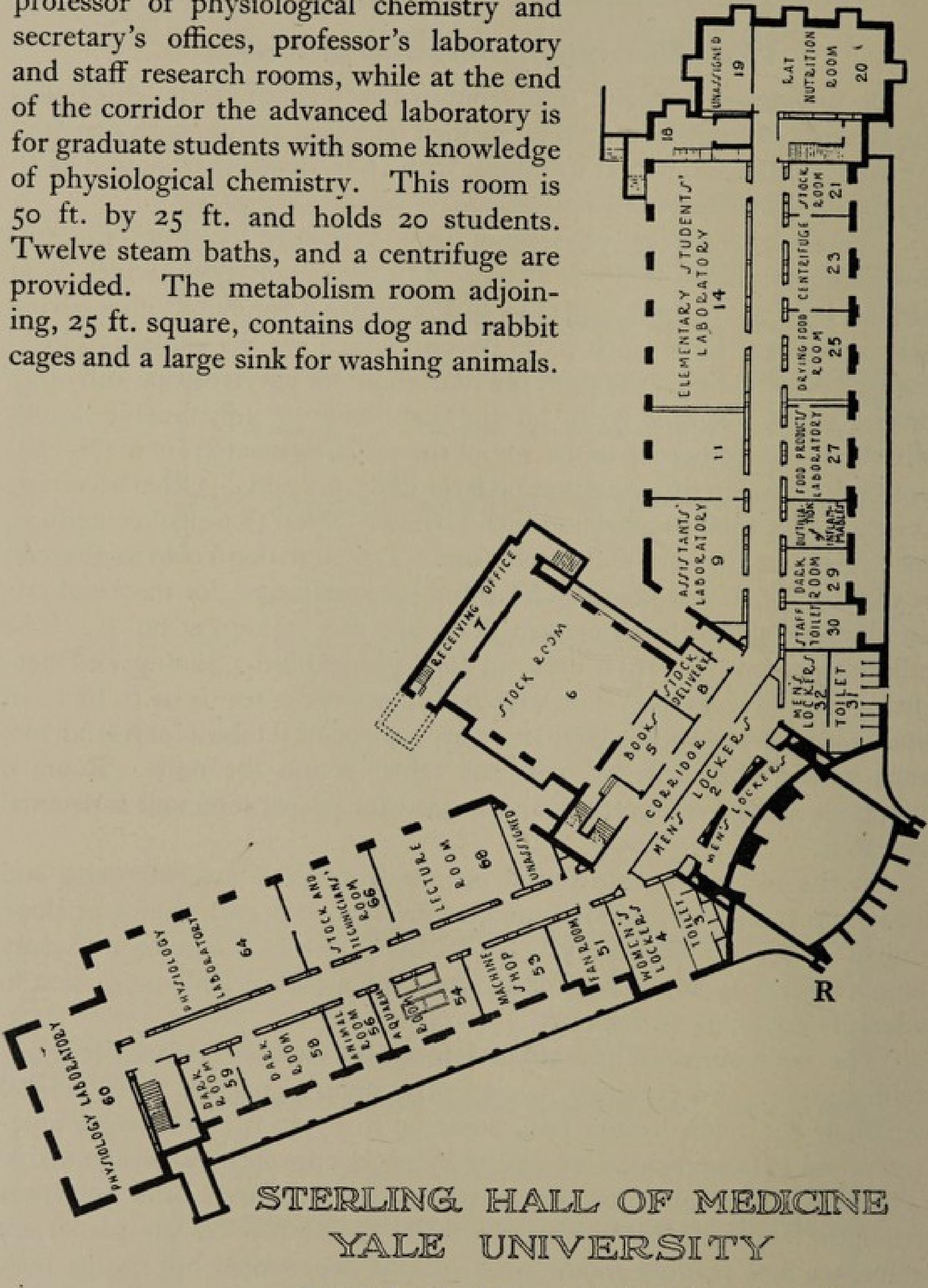


FIG. 125.—Physiology Department, Sterling Hall of Medicine, Yale University.

The operating room next this, 13 ft. by 35 ft., has two tables with cluster lights. The physical chemistry room contains a large refrigerator and hydrogen-ion apparatus. Rooms in the other wing are devoted as shown largely to administration, research, and special uses.

All the laboratories are served with hot and cold water, gas, steam water baths, compressed air, vacuum, electric power extraction hoods, and electric ovens.

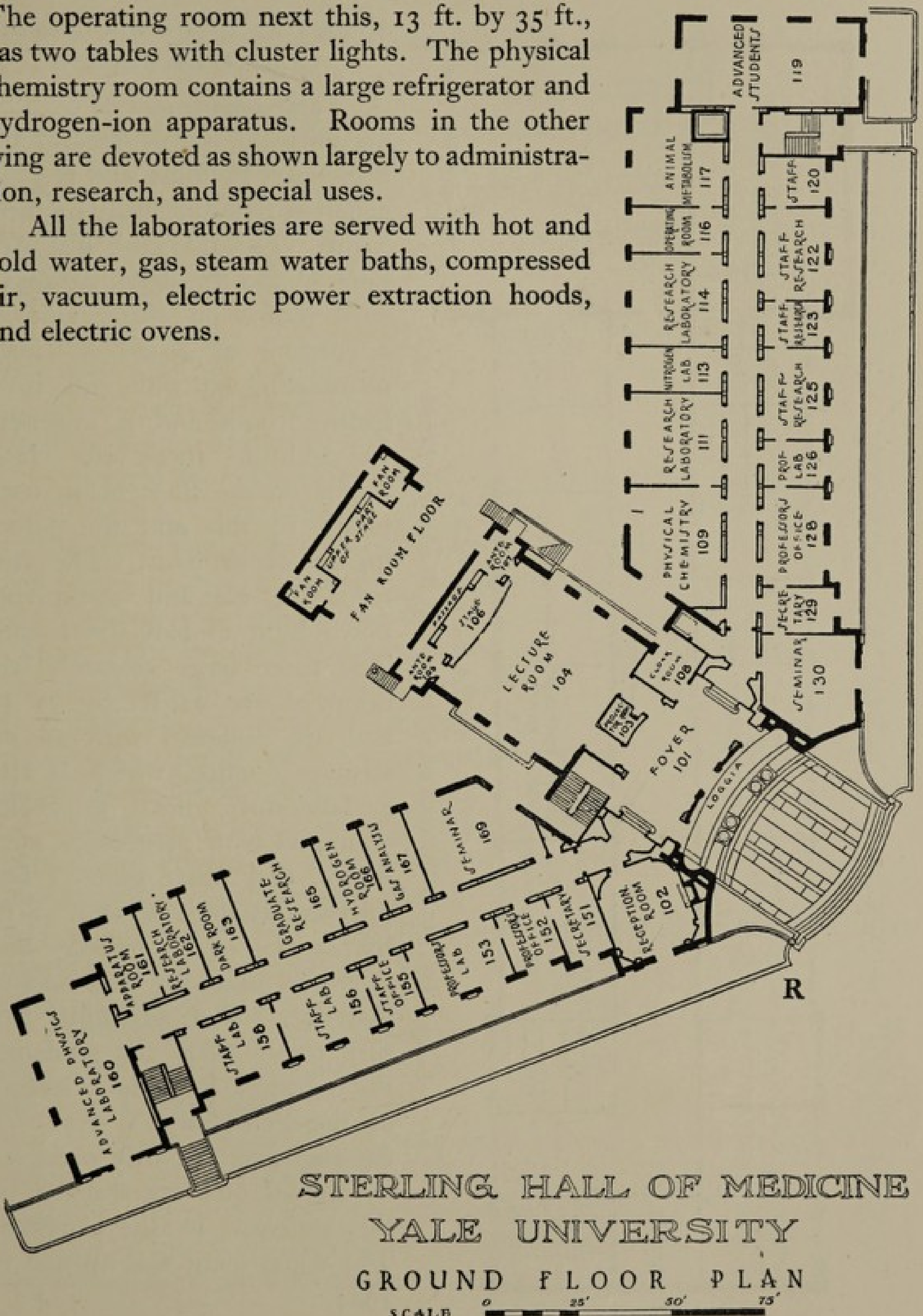


FIG. 126.—Physiology Department, Sterling Hall of Medicine, Yale University.

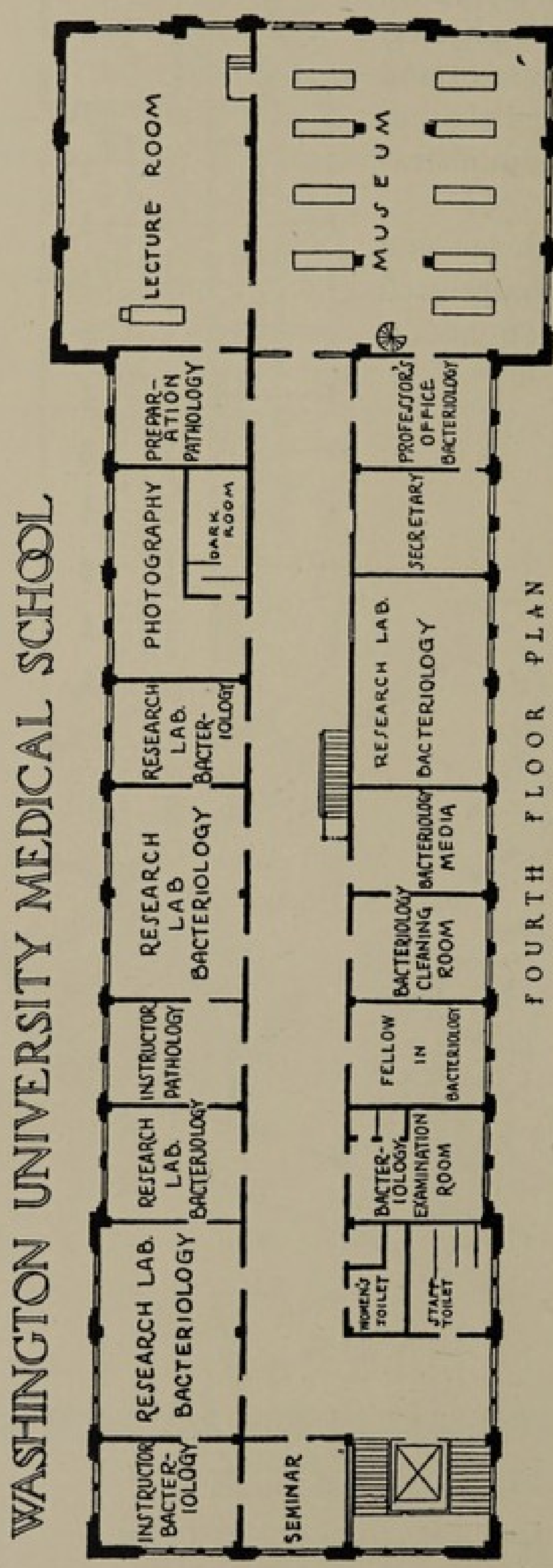


FIG. 127.—Bacteriological Department, Washington University.

Washington University, Department of Bacteriology

This department (Fig. 127) occupies the fourth floor of the dispensary building and is associated with public health requirements. The suite is about 235 ft. long by 60 ft. deep, arranged with rooms on either side of a corridor of generous width, terminating at one end in a lecture room and a museum. In addition there are classrooms on the floor below used jointly by this and the pathological department. The corridor runs east and west, giving north light to half the rooms. The three large research laboratories are 21 ft. by 31 ft. and are designed with an instructor's office, which is also a laboratory next to them, equipped with incubators, sterilizers, and other plant. The museum at the east end, 48 ft. by 43 ft., has a gallery, and is chiefly used for pathological material. The adjoining lecture room holds 102 students. Photography is made a feature of the department's work. A flat roof over is partly occupied by animal quarters reached by the staircase in the corridor. The department was opened in 1924.

Western Reserve University School of Medicine

This large building, with a frontage of 307 ft. and two wings, 174 ft. and 159 ft. long, provides on five floors departments for the study of all the biological sciences, botany excepted.

The sunk ground and the floor above are devoted to anatomy and pathology, the second floor to hygiene, bacteriology, histology, and embryology, the third to experimental medicine and pharmacology, and the fourth to physiology and biochemistry.

Plans are shown of the two top floors (Figs. 128-9). Plans of other floors are similar, presenting a central corridor 10 ft. wide, running round the building with rooms each side, based on a unit of 15 ft. frontage, with a depth of 25 ft.

The third floor plan (Fig. 128) shows the department of experimental medicine and pharmacology, the former being on the east side. In the centre five units are devoted to experimental surgery. The west half of the centre is occupied by teaching rooms generally for this floor, and the west wing houses the staff and research quarters for pharmacology. The teaching rooms are a two-unit lecture room with preparation room attached next the chemical laboratory, while across the corridor is an experimental laboratory some 80 ft. by 25 ft. Animal and stock rooms adjoin this laboratory, the two small rooms at the corner (unnamed) being hot and cold rooms.

The rooms in the west wing are special to pharmacology. A three-unit library adjoins the director's study next to which is his laboratory. Beyond this the suite shown consists of staff rooms for chemical and frog work with an end room for physical chemistry. Rooms on the other side of the corridor are for mammalian and metabolism experiments separated by a workshop.

On the east side of the central block the experimental medicine rooms are chiefly devoted to research on the frontage, and for stock and shop work at the back. In the wing the library and director's quarters are arranged much as for pharmacology. A small operating room with sterilizing room attached is provided at the end of the block. A one-unit room for small animals is provided in this wing.

All the rooms are excellently lighted, the glass area being as much as two-thirds of the floor area. The height of the rooms is 13 ft.

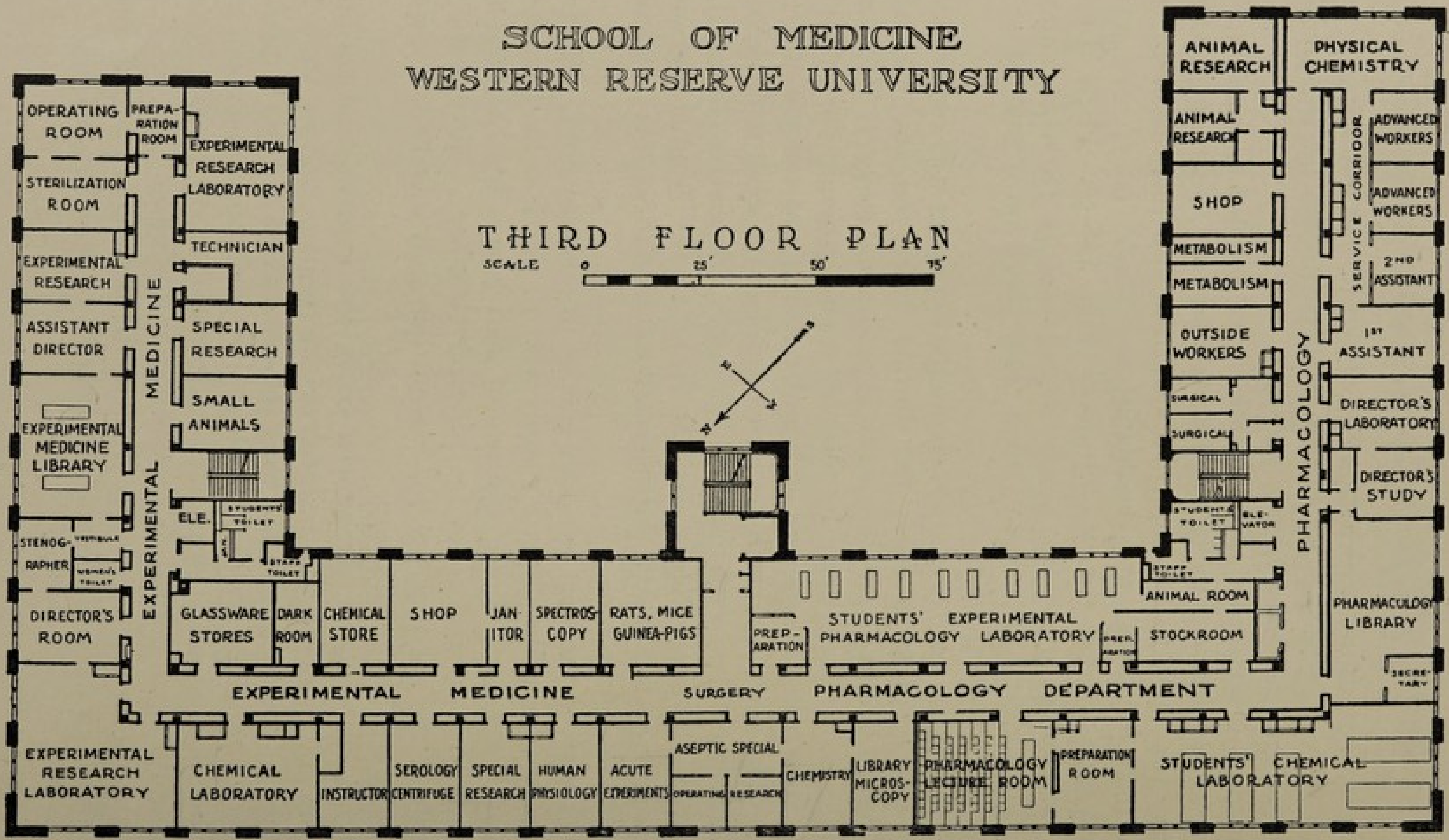


FIG. 128.—Experimental Medicine and Pharmacology Departments, Western Reserve University.

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Departments of Physiology and Biochemistry—The former of these departments occupies the eastern half of the top floor. Of the 14,356 sq. ft. of floor space, 4500 are assigned to students, 7936 to research, and 1920 to corridors and offices. At the extreme end of the wing is the main laboratory of 2464 sq. ft. for 80 students (30½ sq. ft. a head). This room has 26 windows, 15 reflecting lights, and 36 bench lamps with plugs to floor sockets. Benches are arranged for 4 students and contain 2 lockers; they have tops which overhang about half the width of the working place; the lockers are approached from the ends and are movable. Experiments requiring services are carried out on fixed wall benches. Clockwork kymographs are used, as great importance is attached to the mobility of the furniture. The floor is of asphalt and contains ample trenches for service pipes. Off the laboratory is a store room adjoining the demonstration room, the table of which is supplied with gas, water, compressed air, vacuum, 110 D.C., and 2·25 volt battery currents. The central section of the table is movable. Large classes meet in the biochemical lecture room (see plan). The chemical laboratory occupies the corner of the block. The library, shared with biochemistry, is 42 ft. by 22 ft. An interesting feature is the optical dark room, used both for photographic development and optical work, 29 ft. long; the room contains a series of stalls for ophthalmoscope work. The constant temperature room is controlled by cooled brine and steam coils, and is used for calorimeter work, gas analysis, and the like.

The biochemical department, occupying the western half of this floor, has on the main frontage a general laboratory, 45 ft. by 23 ft. (three units), with half-unit balance room. The external corner is occupied by administrative rooms and the professor's laboratory. The rear centre rooms provide a half-unit constant temperature room next the staircase, and one unit rooms for combustions, ammonia work, metabolism, steam baths, and physical measurements.

The wing block contains at the extreme end a large teaching laboratory, 57 ft. by 52 ft., with preparation and two stock rooms directly accessible from it on one side, and on the other a balance room, workshop, and further stock room.

The building is one of the largest recently erected for the study of biological subjects.

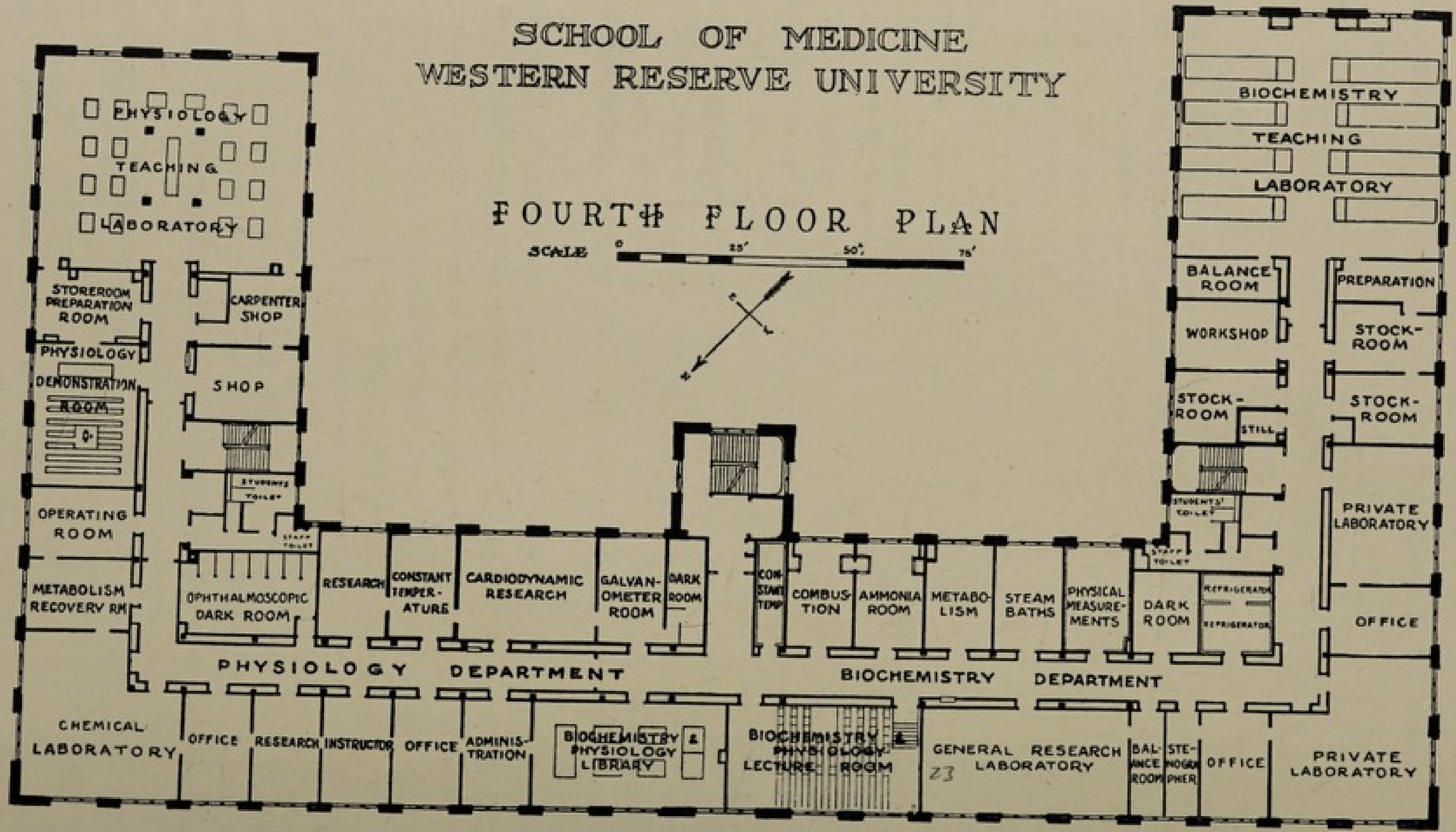


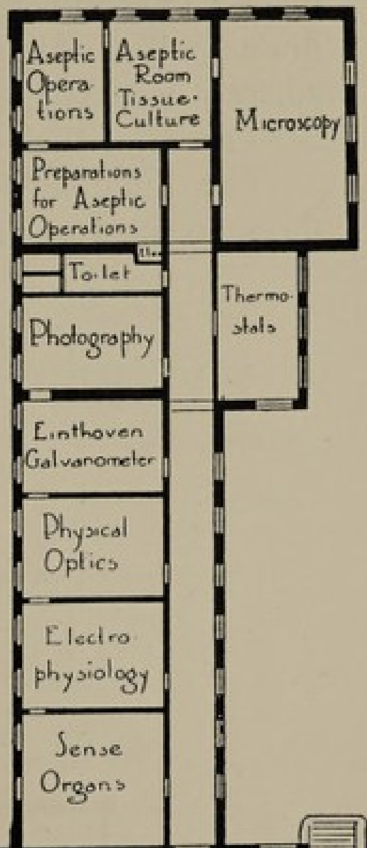
FIG. 129.—Physiology and Biochemistry Departments, Western Reserve University.

R

Institute of Physiology, Milan

This building, opened in 1927, is associated with that for biochemistry, which department has a similar plan reversed, the whole forming three sides of a square. The ground plan (Fig. 130) contains the large lecture room, some 49 ft. square, in the centre of the frontage with external entrance. A small classroom and laboratory flank this room, while at the corner is the porter's flat, a rather unusual position. The rooms in the wing, about 18 ft. wide by 23 ft. deep, are devoted to physical subjects, those at the end being reserved for aseptic operations, preparations, and microscope work.

On the basement floor (not shown) the frontage is occupied by materials and storage, while the wing provides three rooms for metabolism, three for observations on animals operated on, a small laboratory and offices.



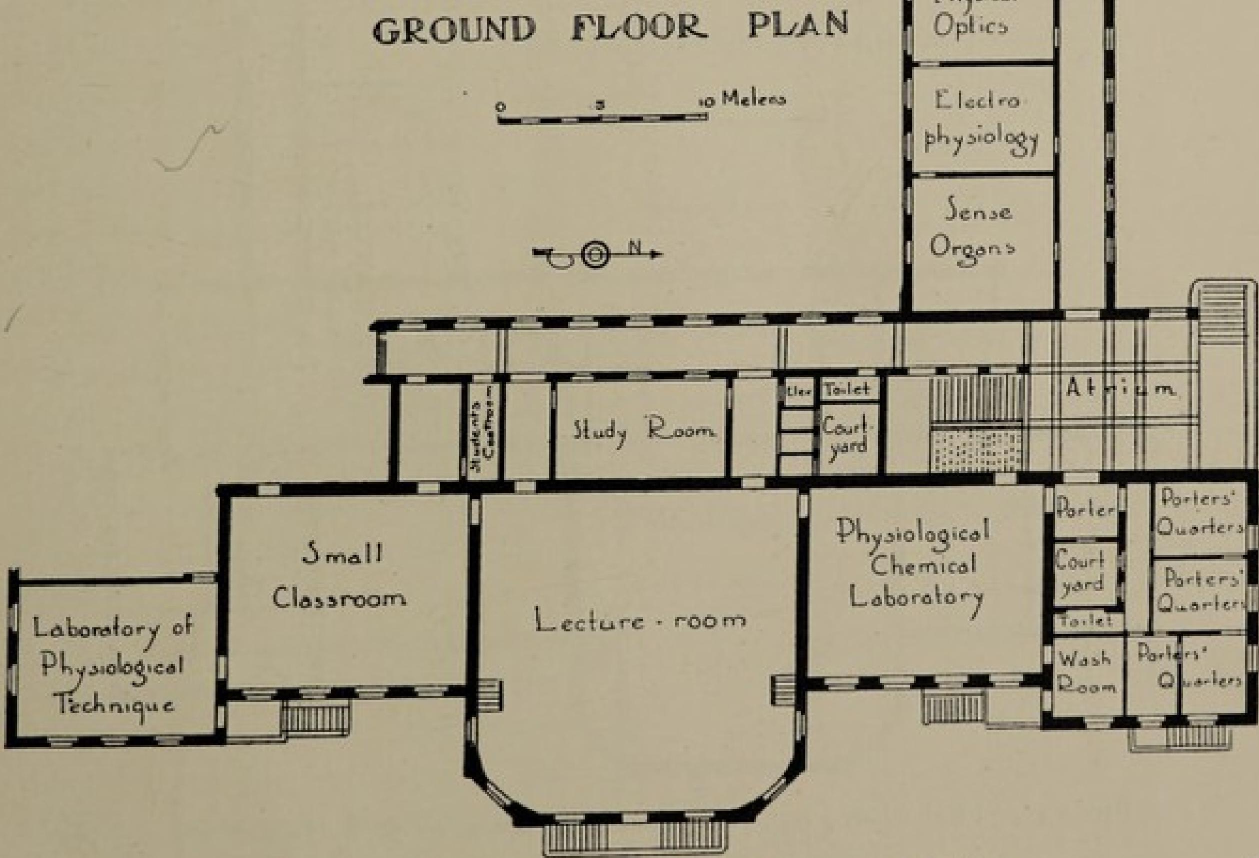


Fig. 130.—Institute of Physiology, University of Milan.

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The first floor (Fig. 131) besides a room for physical chemistry and a library on the frontage, provides the professor's and reading room at the corner. The wing is concerned with chemistry, and with experimental physiology in the end rooms. This wing enjoys a south aspect to the court, hence the external corridor. An animal lift is provided from the basement. Paved floors are provided with floor drains which admit of hosing out from adjacent water taps. Considerable use has been made of shelves composed of cement.

The building is mainly occupied by those engaged in medical training.

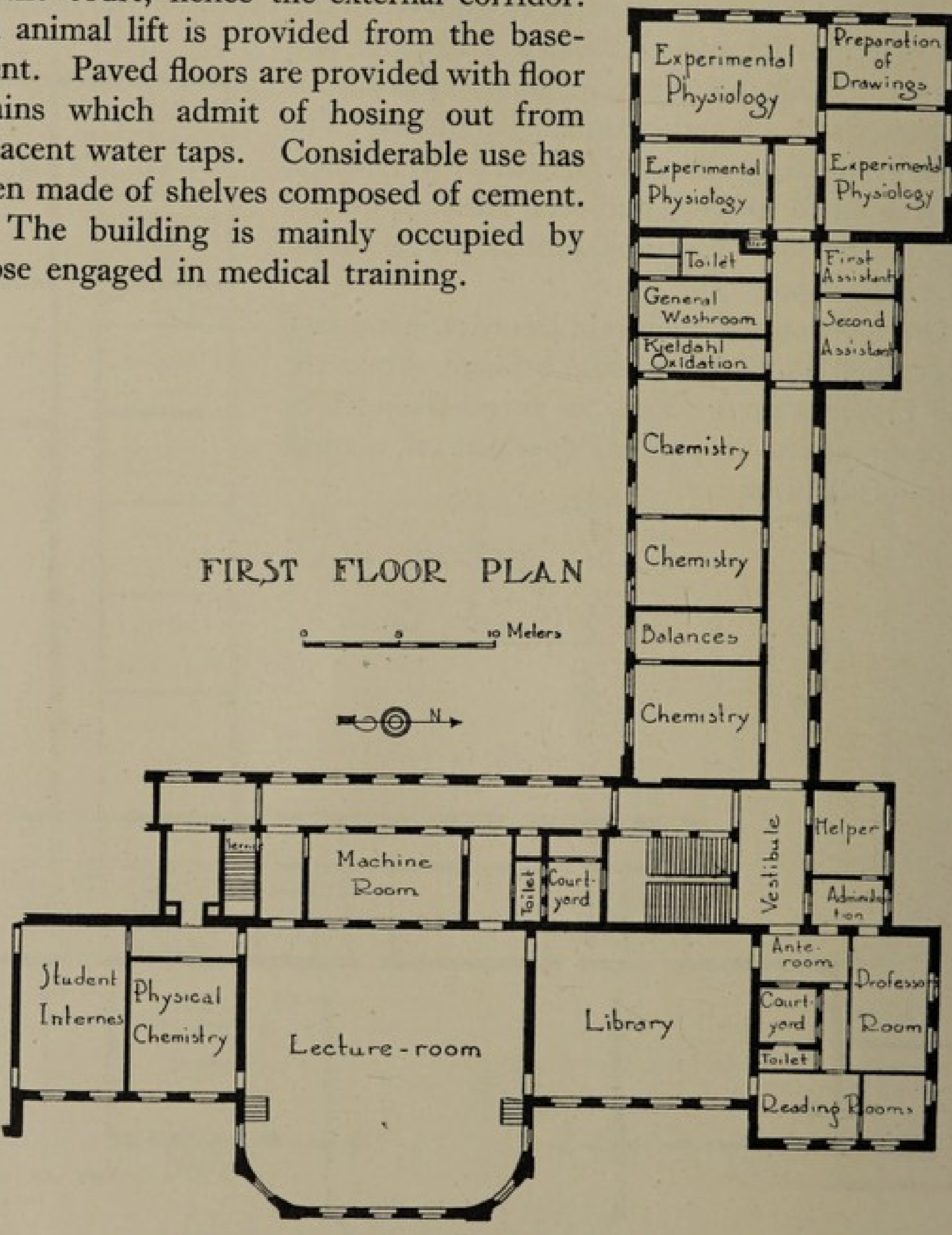

FIG. 131.—First Floor Plan, Institute of Physiology, University of Milan.

R

Animal Building, School of Pathology, Oxford University

This detached building, of two stories, is connected by a long enclosed corridor to the new school of pathology, and has a frontage of some 140 ft., with a verandah on both floors to the central rooms. On the left, on the ground floor (Fig. 132), are two stalls, 11 ft. by 12 ft., for horses, and two rather smaller, for cows, with a large P.M. room and garage at the back. Next there are two stalls for calves and six pens for goats. On either side of the staircase are rooms for small animals, beyond which are a laboratory and another small animal room, each some 14 ft. square, while in the wing are two further animal rooms, some 16 ft. square. At the back is the heating plant and incinerator. The first floor is occupied on the left by fruit, corn, and hay stores over the stalls, in the centre by more small animal rooms with food kitchen and stores over the heating plant, the wing on the right being a resident caretaker's flat. The small animals are kept partly in tiers of cages and partly in floor pens made up of detachable metal sheets, which enables them to be taken apart for cleaning. The building possesses a small steam plant for sterilizing purposes.

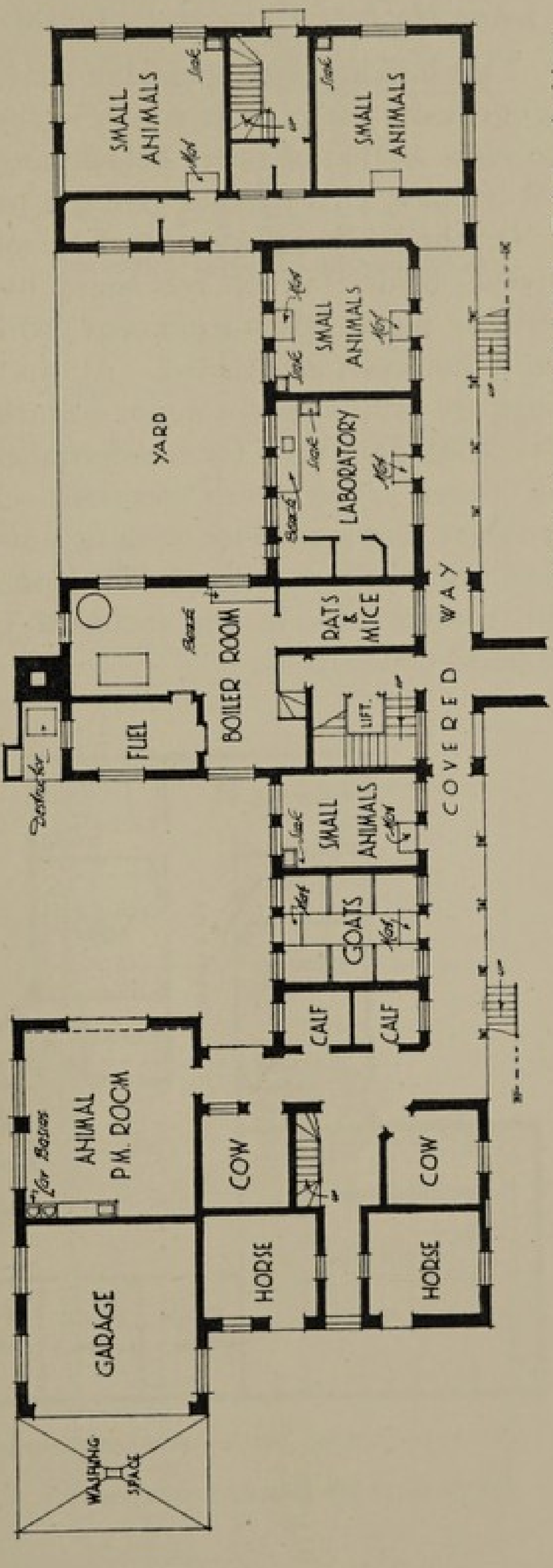

Fig. 132.—Animal Building, School of Pathology, Oxford University. [E. P. Warren, F.R.I.B.A., F.S.A., Architect.

Johns Hopkins University, Animal Houses, Pathological Laboratory

This building was opened in 1923, and the animal quarters form the eighth floor, the plan of which is shown in Fig. 133. The contour is the same as that of floors below, but the outer walls are set back about 6 ft. from a 4 ft. parapet giving a passage way right round the block.

On the left is an open court surrounded by a wall containing glazed screens, behind which are cages used for dogs. These cages have alberene floors but no drainage, which is found a disadvantage; the court, however, is drained. At the other end, adjoining the smaller court, are two rooms for larger animals, *e.g.* sheep. The rooms between these courts are used for small animals, fitted with cages, clear of walls and floors. The room near the elevator is equipped with steam sterilizers, and is used for washing animals and cleansing cages. On the other side of the corridor is the food kitchen and ventilating fan room. The conservatory is not included in the suite, but belongs to the botanical department.

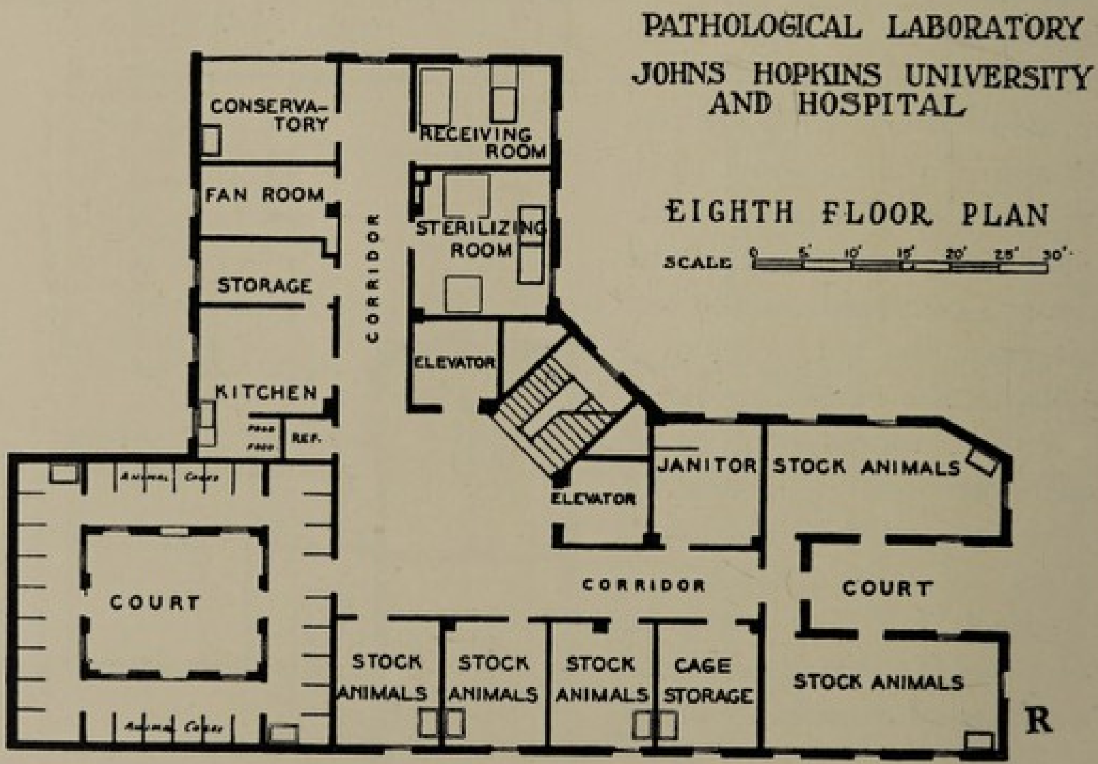

FIG. 133.—Animal Suite, Pathological Laboratory, Johns Hopkins University.

Animal Suite, Research Laboratory, Illinois University, Chicago

This department, which forms the fifth (top) floor of the above building, is shown in Fig. 134. This is one of a large number of hospital buildings grouped together on a ten-acre site adjoining the County Hospital, the lower floors of which are devoted to pharmacology, pathology, bacteriology, physiology, and anatomy. The operating section comprises three operating rooms, sterilizing and recovery rooms, bath and robing room. The animal quarters contain a bath room where animals arriving are cleaned, three isolation rooms, small animal stock rooms, food rooms, office and toilet rooms, and a series of observation pens with access to open-air runs and from these to a common runway. Corridor space is liberal. Sterile surgery is kept apart from non-sterile operations. The food room, used as a kitchen, is supplied with a refrigerator and grinding machine. The floors are cement on asphalt and copper, the walls glazed brick. Ventilation is provided by a powerful fan system.

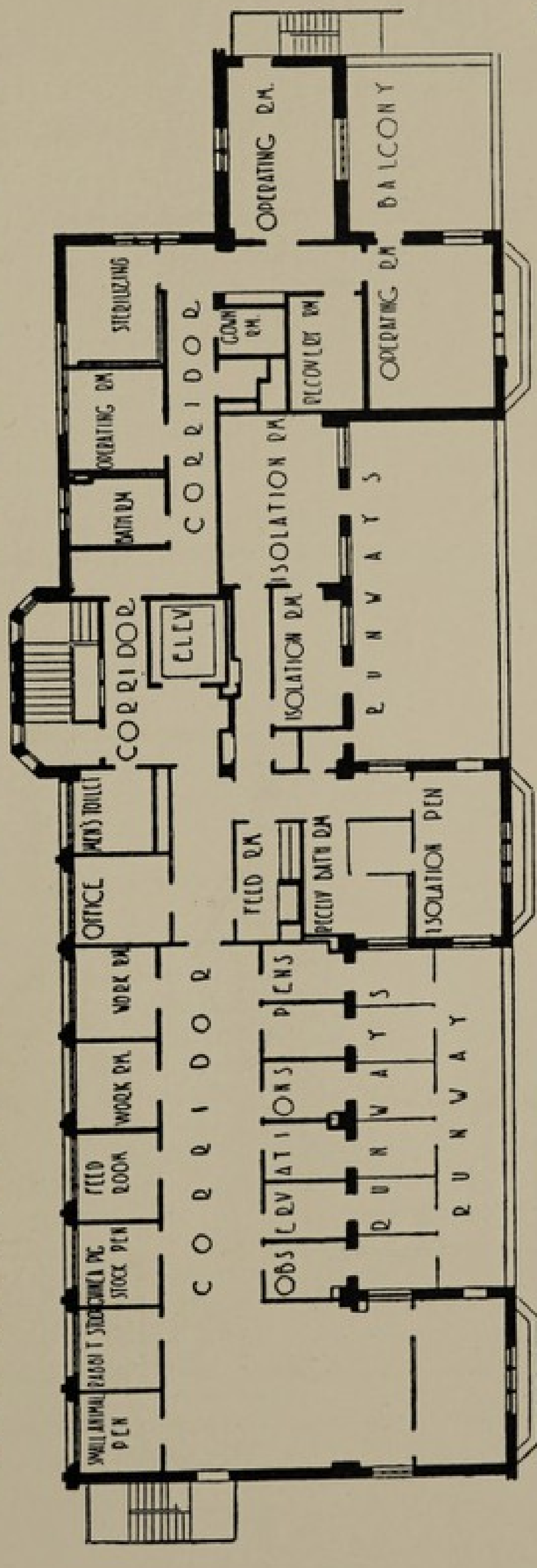

Fig. 134.—Animal Suite, University of Illinois, Chicago.

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