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ABSTRACT

Information and recommendations are presented to assist school planners in designing facilities for physics. Emphasis is given to design features related to the conduct of laboratory experiments by students, television teaching of physics, new physics courses, classroom demonstrations, equipment storage and preparation areas, and combined classroom-laboratory facilities. Factors such as location, size, shape, utilities, and flexibility are considered in relation to preparing functional specifications for space to be used by physics classes. Some examples of high school physics rooms are included along with schematics and photographs. (FS)

Laboratories & Classrooms For High School Physics

Reprinted from
Modern Physics Design and Function

A Report of the American Institute of Physics' Project on Design of Physics Buildings

A REPORT
FROM
EDUCATIONAL
FACILITIES
LABORATORIES

is a nonprofit corporation established by the Ford Foundation to help American schools and colleges with their physical problems by the encouragement of research and experimentation and the dissemination of knowledge regarding educational facilities.

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CASE STUDIES OF EDUCATIONAL FACILITIES

Laboratories & Classrooms For High School Physics

A Report of the American Institute of Physics' Project on Design of Physics Buildings

by R. Ronald Palmer and William Maxwell Rice

With a Preface

by W. C. Kelly

This report constitutes Chapter 12 of the book, Modern Physics Buildings—Design and Function, *published by Reinhold Publishing Corporation. This chapter is the only one which is devoted solely to secondary school physics facilities; nevertheless, many topics of interest to high school planners are covered in other chapters. Anyone seriously involved in the planning of high school physics facilities would be well advised to study the book as a whole.*

We would like to acknowledge the cooperation of Reinhold and the American Institute of Physics in permitting us to reprint this chapter.

EDUCATIONAL FACILITIES LABORATORIES

Preface

New school buildings are rising throughout the nation. In cities and towns, building committees are at work over floor plans, allotting dollars and checking drawings. School activities are being reviewed, too. There is an increasing awareness that these are times of educational change. Old patterns are giving way to new ones—in buildings as well as courses.

Laboratories and classrooms for physics—the subject of this booklet—pose particularly complex problems for building planners. Physics, like the other sciences studied in schools, is changing rapidly. There is a new insistence that high school physics courses must reflect these changes: new physics programs are the order of the day. Furthermore, increased enrollments in school physics, straining laboratory facilities, lie ahead as students and their parents come to realize the importance of physics as a preparation for college studies and for citizenship in a technological age. Finally, the many special requirements of good physics teaching—laboratory electrical services, storage space for apparatus, the demonstration bench, and project areas, to name a few—which have always made special demands upon school design, present greater problems these days for the architect and the school staff as the emphasis increases in physics courses on laboratory work, teacher demonstrations, and opportunities for individual learning.

This booklet contains information and recommendations to assist school planners in designing physics rooms. It is a product of the Project on the Design of Physics Buildings, an eighteen-month study of physics building facilities sponsored by the American Association of Physics Teachers and the American Institute of Physics under a grant from the Educational Facilities Laboratories, Inc. Professor R. Ronald Palmer of Beloit College directed the project, and William Maxwell Rice, A.I.A., acted as staff architect. The project was carried out within the Education Department of the American Institute of Physics.

The contents of this booklet constitute Chapter 12 of the final report of the project, entitled *Modern Physics Buildings—Design and Function* and published by Reinhold Publishing Corporation of New York City. Although the report is concerned mainly with the design of physics facilities in colleges and universities, it contains in addition to Chapter 12 much material that would be helpful in the design of school physics laboratories. The reader is referred to it with confidence that he will find it a useful book.

Many have contributed to the success of the Project on the Design of Physics Buildings. Space will not permit me to name them all here. The reader will find their names recorded in the preface to *Modern Physics Buildings—Design and Function*, the parent volume of this booklet. Educational Facilities Laboratories, Inc. provided support for the project and, by an extension of the original grant, the means of distributing this booklet to schools. It is a pleasure to acknowledge this support.

W. C. Kelly
Director of Education
American Institute of Physics

INTRODUCTION

This chapter contains suggestions for planners of facilities for physics in secondary schools. Although it comes at the end of the book, the discussion of high school physics is not an afterthought. From the beginning of the physics buildings project, we have been interested in new designs for school laboratories and in ways of providing school planners with as much helpful information as possible.

The Role of High School Physics

High school physics has strong claims for consideration in a book on physics facilities. The first systematic treatment of physics for many students occurs in the eleventh or twelfth grade. A successful experience with a good high school physics course carries the student of science and engineering into his higher education with an interest in the exact sciences and a readiness to engage in precise, quantitative, sequential reasoning about the physical world. For the student preparing for a career in other fields, a good physics course provides an insight into the scientific enterprise and a basis for judgment on numerous public problems in a technological age. In 1960, approximately one quarter of high school graduates had taken a one-year course in physics. The number of physics students and the percentage of students studying physics are both on the rise, and it seems evident that physics teaching and learning will be increasingly important activities in schools.

Because the nation needs well-informed citizens and well-qualified scientists and engineers in ever increasing numbers, facilities for teaching physics effectively in high schools are an appropriate concern not only of school planners, but of all who want to see the quality of American education raised. Provision for higher-quality instruction in physics and for greater numbers of physics students in the future cannot be overlooked in designing new schools.

School laboratories and classrooms are interesting for another reason, however. Many innovations have been made in high school physics facilities, perhaps more than in classrooms for colleges and universities. Combination classroom-laboratories and project rooms, for example, have developed rapidly in schools. College building planners will find in the plans of some schools valuable suggestions for the design of introductory college physics laboratories.

Changes in Educational Programs

Educational programs are undergoing a steady evolution these days under the triple pressures of growing enrollments, technological change in educational tools, and expanding knowledge in all fields of study. Ample documentation of the growing problems of the schools in providing educational opportunities is available.[1,2] Here we will describe a few of the proposed solutions that will eventually affect the teaching of many subjects, including physics, and that will be reflected in building design. *Team teaching* is being successfully used in some schools to meet the shortage of expert teachers by more efficient use of the teacher's time. As developed at Wayland (Massachusetts) Senior High School, for example, a teaching team for a subject includes the subject's leading teacher, a person of considerable experience and depth of preparation who acts as team leader; several other teachers; several interns or student teachers; and several clerks.[3] Interns engaged in apprentice teaching are supervised by the teachers. Clerks and other assistants relieve the teachers of many of the routine clerical and supervisory duties that nibble away at the teacher's time. *Classes of varying sizes* permit a more flexible educational program at Wayland and other schools following this plan. Lecture groups, taught by the team leader, are several times as large as the ordinary high-school class and are brought together for the initial presentation of subject matter or for demonstrations that can be effectively given to large groups.[1,3] Recitation classes and seminars are medium-sized groups.

Educational television is being tested in a variety of school situations ranging from complete instruction in several subjects to occasional programs that supplement instruction by the classroom teacher.[1,4] Although the extent to which television teaching will be depended upon for basic instruction has not been established, it seems clear that both broadcast and closed-circuit television will be a valuable adjunct to classroom teaching in the future by permitting the teacher to introduce to his class persons, events, and phenomena that would otherwise be inaccessible to them. Special building facilities can be installed to permit television to be used efficiently and flexibly as a classroom tool.[4]

Teaching machines are under study in schools as a means of furthering learning, of developing better teaching methods, and of freeing teachers from the supervision of rote learning.[1] Some of these machines provide drill exercises for the student and enable him to test himself on his grasp of rote elements of his studies; others provide playback exercises in pronunciation as aids in learning modern foreign languages.

Changes in Physics Teaching

Physics teaching, too, is changing. Foremost is a renewed insistence on *laboratory experiments by students.* Laboratory work is of prime importance in teaching introductory physics. Many schools are emerging from a period in which the student laboratory had fallen into disuse into one in which laboratory teaching is given equal billing with teacher demonstrations and classroom discussion. Adequate time, space, and equipment are needed for student experiments. *Television teaching of physics* is being tested; the Harvey White film-television course in high-school physics, and the Continental Classroom refresher course in physics for high-school teachers have been developed to provide physics courses in schools where a qualified physics teacher is not available and to assist physics teachers in service to keep up to date in their preparation in physics. *New physics courses* are evolving. The Physical Science Study Committee is developing a modern course in physics for high schools and is preparing materials for such a course. Space is not available here for a review of the content and the objectives of high school physics courses or of new physics programs. See *Physics in Your High School,* prepared by the American Institute of Physics, for a discussion of these topics and for comprehensive recommendations for the improvement of physics teaching.[5]

Changes in School Buildings

Although this chapter will concentrate on the problems of planning physics facilities in schools, it should be noted that the school buildings being constructed these days house a variety of activities and do this with increasing effectiveness. Physics instruction shares in the total resources—including building space and facilities—of the entire school. Just as physics contributes greatly toward the objectives of a sound educational program, it needs the support of the other subject and service fields—the other natural sciences, English, mathematics, and counseling, to name a few. Exciting progress is being made these days in developing more suitable "packages" for all of these activities—school buildings that nurture educational activities without smothering them, that encourage learning, and that permit necessary change. The Hillsdale (California) High School, for example, employs the flexible subdivision of large open spaces in a so-called "loft plan" to permit the coalescing of space around work centers as the educational activities demand.[6] Newton (Massachusetts) South High School, when completed, will follow a "house" plan (Figure 1). Students at this school will be divided among three houses located in three separate buildings each with its own teaching staff.[7] A science building, gymnasium, auditorium, and library will complete the campus plan which promises to combine the superior facilities of a large school with the closer student-teacher contacts of the small one. Watch for the development of other solutions to the problem of finding a suitable building envelope for school activities. Gradually but to an increasing extent, the teaching of physics and the other high-school subjects will take place in a different setting from the familiar "four-square" school building.

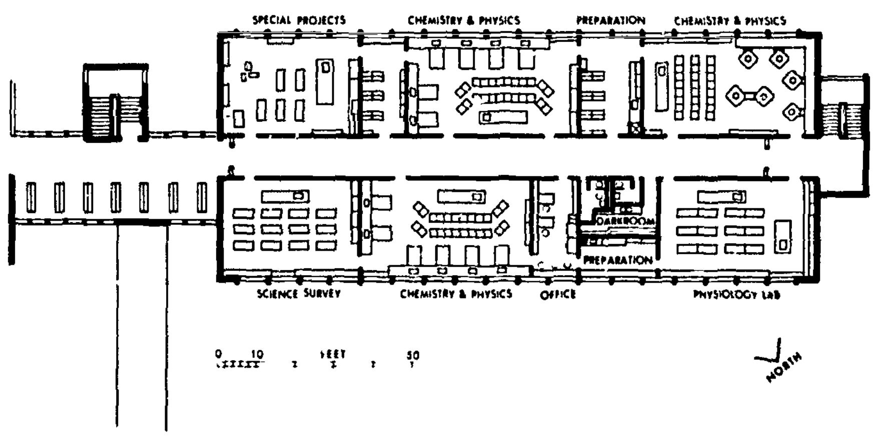
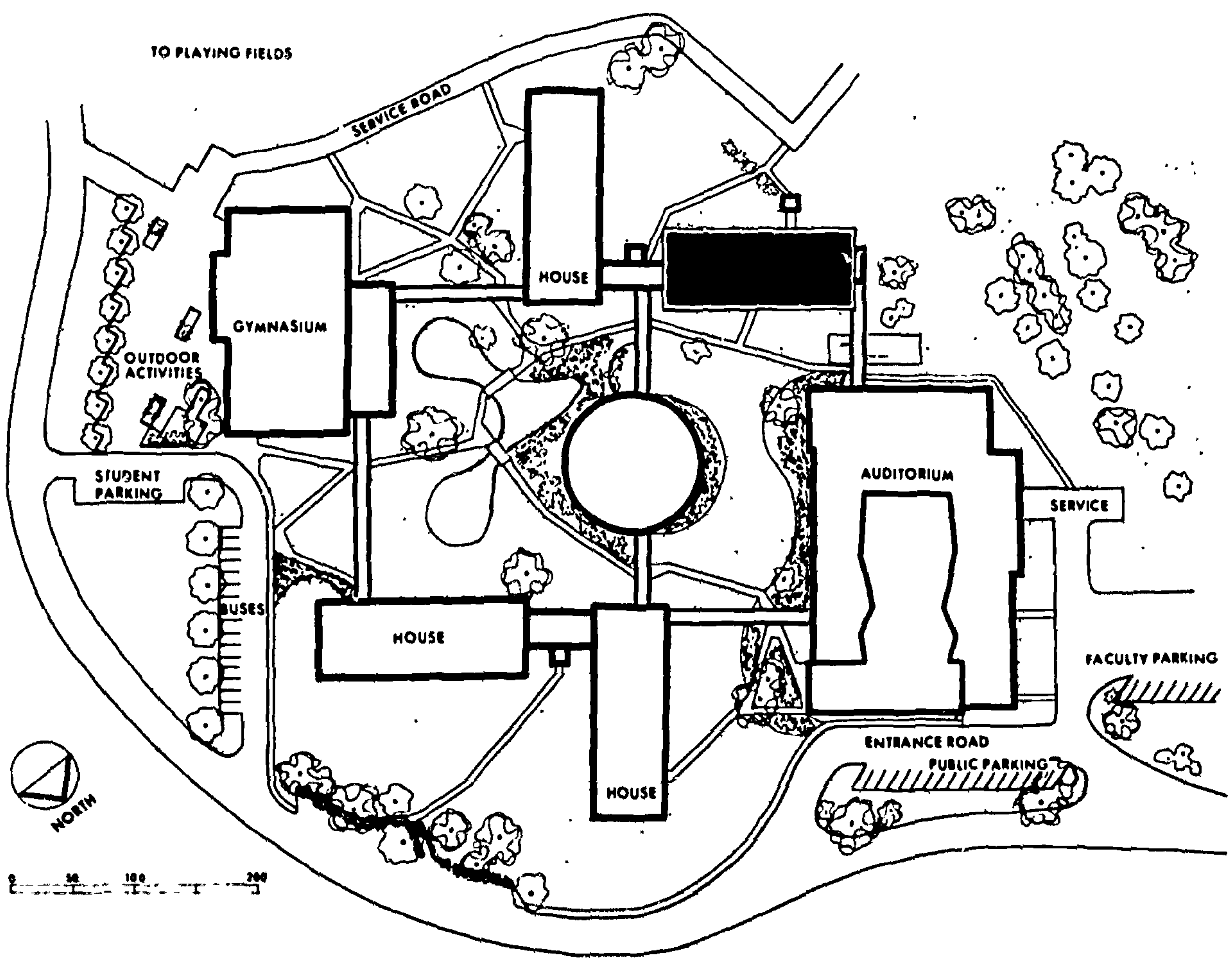


Figure 1. "House" plan of Newton (Massachusetts) South High School. Second-floor plan, above right.



ACTIVITIES IN HIGH SCHOOL PHYSICS

Before planning physics laboratories and classrooms, one should have a clear notion of what activities physics students and teachers will engage in. Naturally the physics course at one school will differ from that at another. Moreover, a school may offer more than one physics course or may offer additional courses in subjects related to physics, such as electronics and other vocational subjects. The activities—although not the subject matter and objectives—in all of these courses, however, are enough alike and their space requirements are similar enough that it makes sense to discuss here both the activities in a composite physics course and the building facilities that these activities require. We shall then offer some suggestions for planning physics facilities and some examples of how several schools of different sizes have designed rooms to house physics activities. At the end of this chapter we shall provide a check list of design requirements with references to helpful information to be found elsewhere in this book.

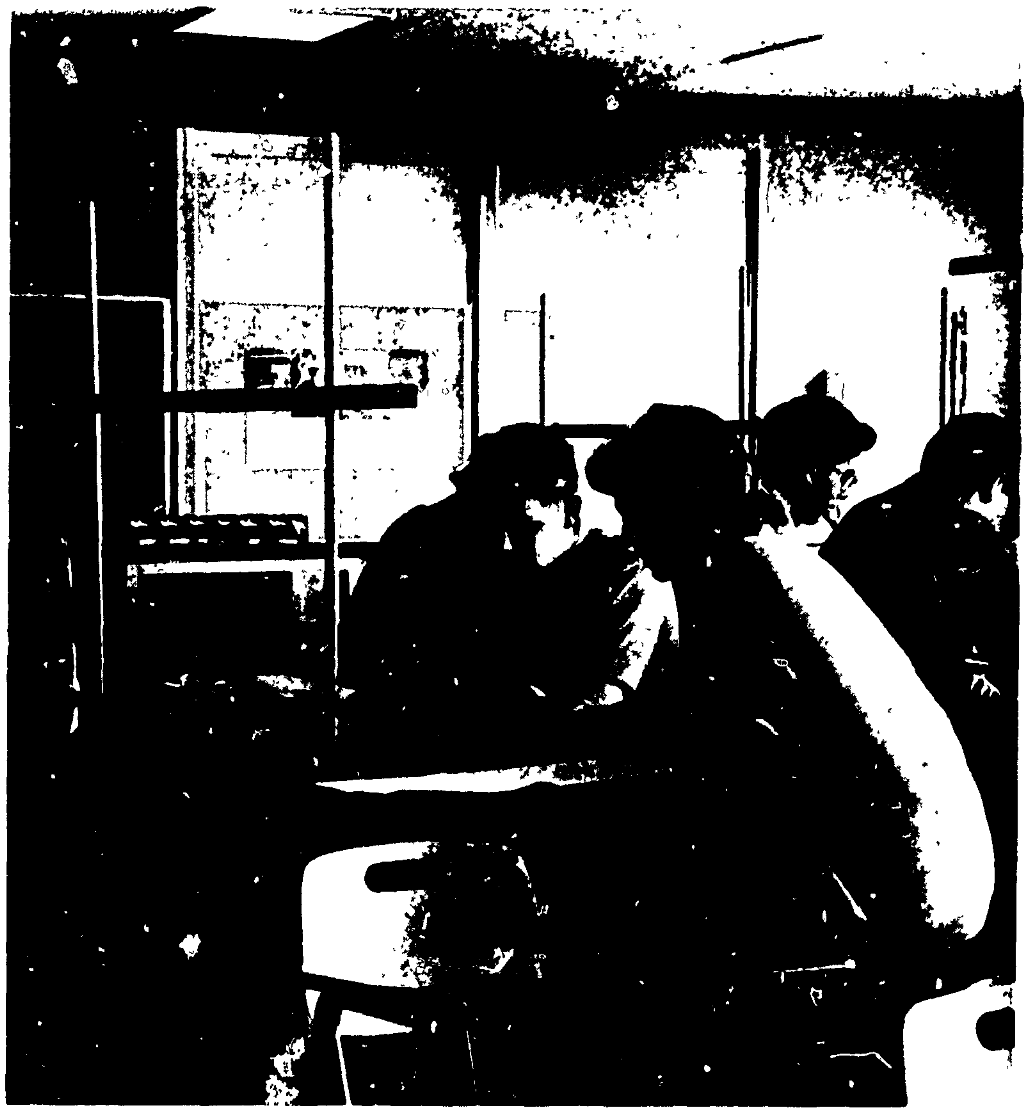


Figure 2. Students in the physics laboratory of Garden City (New York) High School. Note booths with vertically sliding doors for apparatus used in student projects (shown in background).

Experiments by students

In strong physics courses, the teachers place considerable *emphasis on student experiments.* Students work individually or in pairs, or—less desirably—in groups of more than two. They use physics apparatus, exploring the physical world in a variety of experiments in the sub-areas of physics such as mechanics, wave motion, sound, heat, electricity and magnetism, light, and atomic and nuclear physics. Students may investigate wave phenomena, measure the velocity of light, or count particles from a radioactive source. Direct contact with the apparatus and opportunities for the student to show initiative, ingenuity, and persistence in his experimental work are most important (Figure 2). The laboratory class—usually a group of about 24 students—ideally meets once or twice a week for a double period. Although single-period laboratory sessions are prevalent, many schools at present are attempting to replace them by double-period laboratory sessions. A 40- or 45-minute span of time is just not long enough for the class to set up its apparatus, carry on reasonably coherent experimental work, and put the laboratory in order for the next class. Laboratory classes with more than 24 students are feasible. To conduct them effectively, however, the physics teacher needs a qualified laboratory assistant, and the school must, of course, make a greater investment in laboratory equipment.

Experiments by the physics class are carried out on broad sturdy *laboratory tables,* or wall benches, provided with durable surfaces

Figure 3. Laboratory tables for elementary physics at the Bronx High School of Science. Stopcocks on the table tops provide gas, compressed air, and rough vacuum. Electrical panels on the sides provide 120 volts ac, 0–120 volts ac, and 0–120 volts dc as well as switches and a pilot light.

and supplied with the necessary services (Figure 3). Some physics equipment is heavy, and much of it requires a stable support so that shaking or jarring the table will not disturb the adjustment of the apparatus. For both reasons, laboratory tables must be strongly built with adequate cross-bracing. Table drawers are usually not wanted since they are seldom used for apparatus storage and often become depositories for broken wires, waste paper, and dust. Physics students sometimes stand, sometimes sit, at their laboratory work depending upon the task of the moment. Hence a convenient table height—usually about 30 inches—is necessary for standing without excessive bending and for sitting on chairs with knees clearing the lower edge of the table.

Overhang of the table top of not less than 2½ inches provides needed room for table clamps that support rods and apparatus. Tapered or threaded sockets for rods are also often provided in the table top. Wood is the preferred material for physics tables: it is non-magnetic, electrically non-conducting, more quiet than metal, does not dent readily, and resists thermal shock. Solid maple table tops sealed with clear lacquer provide good service. Corrosive chemicals, apart from battery liquids, are seldom used in physics classes. A variety of non-corrosive liquids can be spilled on the table during experiments, however, and the table top should be designed accordingly. The handling of mercury by students is not recommended except under extremely careful supervision because spillage creates an accumulating health hazard and is expensive. Heat experiments in schools seldom require raising the temperature of objects beyond the boiling point of water. Hence, an asbestos pad placed underneath burners, heaters, and containers of hot water usually provides sufficient thermal protection for the table top.

About 7 square feet of table top should be provided for each experimenter. Physics experiments often involve apparatus that spreads out over the table such as tracks, trays, electrical meters and their connecting wires, supporting rods, and swinging pendulums. Ample apparatus room and elbow room should be provided. The top of the table should be kept as free of obstructions as possible. Gas cocks and electrical terminals might well be mounted on the side of the table or, if this is not possible, in compact groups near the center of the table. Incidentally, provide ample storage space against one wall of the laboratory for notebooks and textbooks that are not needed during the laboratory work so that they will not add to the clutter on the table. Hooks in the ceiling above the tables are used in some schools for mounting student apparatus.

The *services* most often required at student tables are gas and alternating current at 120 volts. Currents required at each outlet seldom exceed 5 amperes. At least four convenience outlets for ac and at least one gas connection should be provided for each pair of students. Taps for hot and cold water should be provided at sinks with suitable splashboards, at least two sinks to a laboratory. Direct-current services at several voltages—usually 6, 30, and 120—are needed to varying extents depending upon the level of the physics course. Small direct currents are provided by dry cells, and steady direct current at 6 volts by batteries placed on or near the tables. The higher direct voltages, depending upon the degree of regulation and the power required, are usually supplied by motor-generator sets or rectifier banks. The outputs of these central installations are distributed by panel boards controlled by the teacher or by smaller local power supplies at the students' tables. Central power systems (Figure 4), properly designed and installed,

Figure 4. Central power installation using rectifiers for physics laboratory at St. Charles (Illinois) High School. Above the radio receiver is a typical bench outlet.

are versatile, are centrally controllable by the teacher, and generally require a sizable initial investment. However, some teachers prefer local power supplies. While considering the installation of a central switchboard, school planners should look very carefully at the requirements of the school and at the relative advantages and disadvantages to the school of central versus local power supplies with reference to regulation under load, initial costs and maintenance costs, versatility, and student and teacher acceptance of the devices. Some other laboratory services provided in more advanced physics laboratories or project areas in the larger high schools are 6.3 volt ac, rough vacuum lines, and compressed air lines. A good electrical connection to wet ground is useful within the laboratory. If the school has a radio club, conduits from the classroom to the roof will be required for antenna wires. Chemical hoods with exhaust fans are seldom needed in physics laboratories. Students who need them occasionally for projects can usually obtain access to them in chemistry laboratories.

Tables or wall benches should be far enough apart so that students will not bump into each other excessively and so that the teacher can make his usual rounds easily or can quickly get to the scene of an emergency. Clearances where students work back to back should not be less than 5 feet. Sturdy chairs of conventional seat height or sturdy stools about 24 inches high should be provided; rugged construction is called for because students occasionally stand on them to adjust apparatus. Stools whose heights can easily be adjusted are now commercially available. It should be possible to darken the room during experiments on light: opaque window shades sliding in grooves mounted at the edges of the windows or fully-closing venetian blinds are usually employed. Glass panels in doors may require shades. Note that the darkening provided by badly fitted shades or incompletely closed venetian blinds is not sufficient, but on the other hand, the degree of light control required in photographic darkrooms is seldom needed in the physics laboratory. Commercial suppliers of furniture and other fittings for the laboratory can be helpful in providing suggestions and information about their company products. A detached and critical evaluation of their recommendations will enable school planners to obtain maximum educational benefits from expenditures.

So far, we have discussed principally the space requirements for experiments by the entire class. *"Free" laboratory experiments and project work* by smaller groups of students are also important in physics and require, in addition to most of the facilities already discussed, some special facilities. "Free" laboratory experiments require the students to develop their own experimental attack on a problem and in some instances to construct the equipment themselves. The teacher in the free laboratory provides a minimum of detailed instructions and encourages independent thinking and ingenuity on the part of the students. In project work, the emphasis again is upon independent and occasionally original experimentation—the high school counterpart of research. The distinction between free laboratory and project is that the former generally involves shorter experiments performed by teams of two or three students, and the latter involves more ambitious experiments by individuals. Both require more or less secluded space so that equipment can be safely stored or once set up can be left undisturbed until worked upon again. At Garden City (New York) High School, five project booths were built in each physics laboratory. The booths are similar to the fume hoods used in the chemistry laboratory. Each booth is 42 inches wide and 30 inches deep with a lockable door that slides down to the table top. Each booth has two ac electrical outlets, two variable-voltage outlets, and a light. One booth has a gas outlet, and there is a panel of safety glass between adjacent booths. The Bronx High School of Science has separate projects rooms (Figure 5) with lockers for shop equipment and for experimental equipment in physics and chemistry. Rotatable storage cabinets, developed at the Navy Pier

Figure 5. Table for physics projects and for shop work at the Bronx High School of Science. Note the lockers under the work bench at right. Nest of open boxes (in background) provides space for books and notebooks.

Branch of the University of Illinois and now commercially available, offer an ingenious solution to the problem of storing project apparatus (Figure 24 in Chapter 7). In addition to a certain amount of seclusion and a good stock of basic physics equipment, free laboratory areas and project areas require a student work bench with bench tools and simple power tools, a supply of stock materials and parts, and—very important—a reading corner with physics books and journals.

Physics experiments performed in schools are not intrinsically dangerous, but adequate *attention to reasonable safety precautions* in the student laboratory is wise. Electrical fuses or circuit breakers, easily located and replaced or reset, should be placed in supply lines and on delicate experimental equipment. Conservative fuse ratings are recommended to give maximum protection against overload of the lines and of instruments. A central switch to turn off the electrical power at all outlets in the laboratory and a master gas valve to turn off the gas at all stopcocks will provide a certain amount of peace of mind for the physics teacher when he closes the laboratory for the day. By the same token, handles are preferable to knobs on gas stopcocks so that the teacher can see at a glance whether the stopcock is turned on or off. One school has installed a relay switch and "panic" button which the physics teacher can use at his desk to turn off all electric power in the project area in a laboratory emergency. A fire extinguisher of the carbon dioxide type and a fire blanket might be recommended by the local fire marshall. Radioactive materials are handled in such small quantities in school physics laboratories that they do not require special handling other than safe storage. Proper instruction of the students in safe procedures for handling electrical equipment, tools, laboratory burners, and laboratory materials is, of course, the best safety precaution.

Classroom Demonstrations by the Teacher

Demonstrations, in which the teacher performs experiments or illustrates principles with apparatus, are effective in teaching physics. They are not a satisfactory substitute for laboratory experiments by students. However, demonstrations enable the teacher "to present phenomena which lead to principles, to show applications of principles that have already been discussed, to explain the mathematical solution to a problem in physics, to arouse the curiosity of the student, to surprise the superior student and shake his complacency that he knows all there is to know about physics, to inject a humorous note into the discussion, to illustrate how a physicist goes about the solution of a problem, or to summarize and recapitulate a discussion. In their demonstrations, physics teachers should use measuring devices large enough to be seen by the entire class, optical projectors, scale models, standard laboratory apparatus, specially made demonstration devices, and simple home-made equipment."[5]

At present physics demonstrations are rarely given in schools to classes larger than 30 or 40 students. *Larger demonstration classes* can be taught in this way. Colleges have done this routinely for many years. Some schools, as we have noted earlier in the chapter, are now experimenting with lecture sections of over 100 students to whom demonstrations are presented by the most experienced teachers. If the demonstrations can be seen and heard by the entire class—and this requires careful planning—large demonstration lecture classes are feasible. Movable, sound-proof partitions, now under development, will enable schools to provide large rooms for lecture demonstrations and to subdivide this space at another time in the school schedule into smaller rooms for discussion classes and seminars.[8] Inevitably, student-teacher contacts are not as effective in classes of 100 or more as in classes of 30. The give-and-take of discussion between student and teacher is important in physics teaching in probing the student's understanding and in clearing up misconceptions. Provision should be made elsewhere in the school program for these contacts, perhaps in recitation classes or in the laboratory sessions, if demonstration classes are large.

Whatever the size of the class, the physics teacher needs a number of *special facilities* for demonstrations, facilities that are not required in classrooms used for teaching English or American history, for example. The physics demonstrator is a kind of showman and he requires a suitably equipped platform for his demonstrations. The room must be arranged so that the students can see and hear clearly, and various services must be provided for the performance of experiments. Finally, if the room is to be used efficiently, convenient arrangements must be made to move the demonstration apparatus quickly into it from the storage room, to set up the apparatus before the class begins, and to remove the equipment afterwards.

During a class period, a physics teacher who likes to give demonstrations to his students may perform four or five demonstrations, some requiring the use of long tracks, wires stretched between the ends of the demonstration table, and so on. Hence, the *demonstrations table* should be large—about 12 feet long, 3 or 4 feet wide, and approximately 3 feet high (Figure 6). It should be sturdily built of seasoned wood to support heavy equipment and to serve as a firm base for experiments. The table is usually enclosed in front and on the sides. Cabinets and drawers are provided at the back—the teacher's side of the table—for storage of vacuum pumps and other accessory apparatus used in demonstrations. The top of the table is painted with a corrosion-resistant paint and overhangs the sides by 2½ inches or more to permit the use of clamps. Four or five flush plates—sockets for tapered or threaded table rods—are set into the table top for mounting apparatus. A small sink with hot and cold water taps and a drain should be installed near one end of the table, recessed and provided with a cover that fits flush with the table top. Two or three gas cocks with hose nozzles should be distributed along the back of the table, preferably under the overhang or in some other unobtrusive place so that the teacher and students will not bump into them. Convenience outlets for 120-volt ac should be provided in generous numbers, at least a half dozen at the back, two on each side, and two on the front of the table. If a central direct-

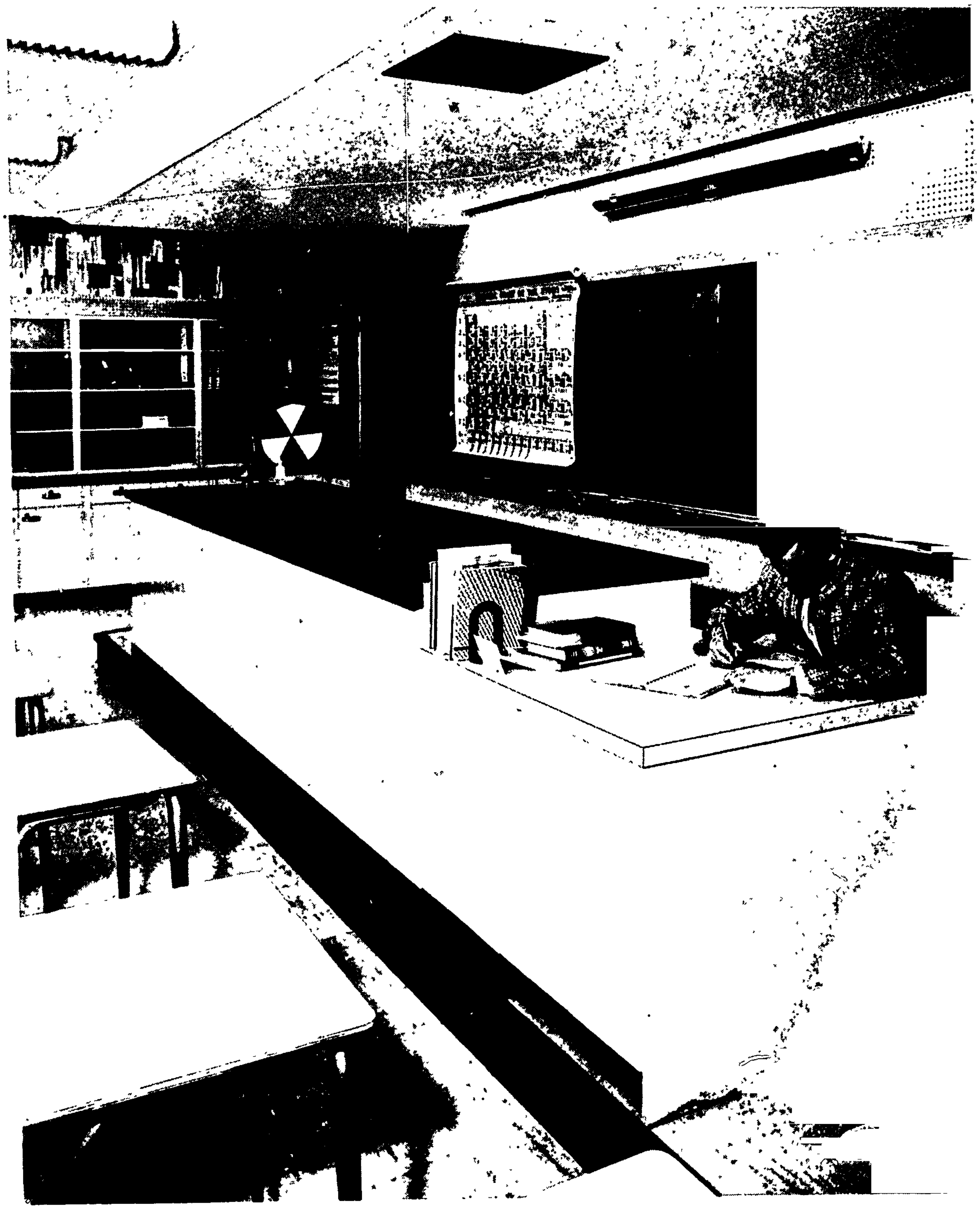


Figure 6. Demonstration table and teacher's desk at St. Charles (Illinois) High School.

current supply is planned for, several lines from the dc switchboard to the demonstrations table should be provided. If not, the teacher will use local dc power supplies or batteries, which can be conveniently installed in the demonstration table. Compressed-air service is a convenience, but not essential. Shielded cables connecting the lecture table to a loud speaker or to a mirror galvanometer mounted at the ceiling near the middle of the room are wanted by some teachers. Large "station meters," ammeters and voltmeters mounted on the wall, are provided in some schools as demonstration equipment. Lines connect the meters to the lecture bench so that the demonstrator can select the right ranges and insert the meters into circuits at will.

The *surroundings of the demonstrations table* will have much to do with whether it is effectively used. The students sit in front of the table, separated from it by a clear space 4 or 5 feet in depth. This cleared area allows the teacher to walk around to the front of the table in performing some experiments and to suspend apparatus occasionally—pendulums, long springs, and so on—from the ceiling in front of the table. Tablet-arm chairs of sturdy

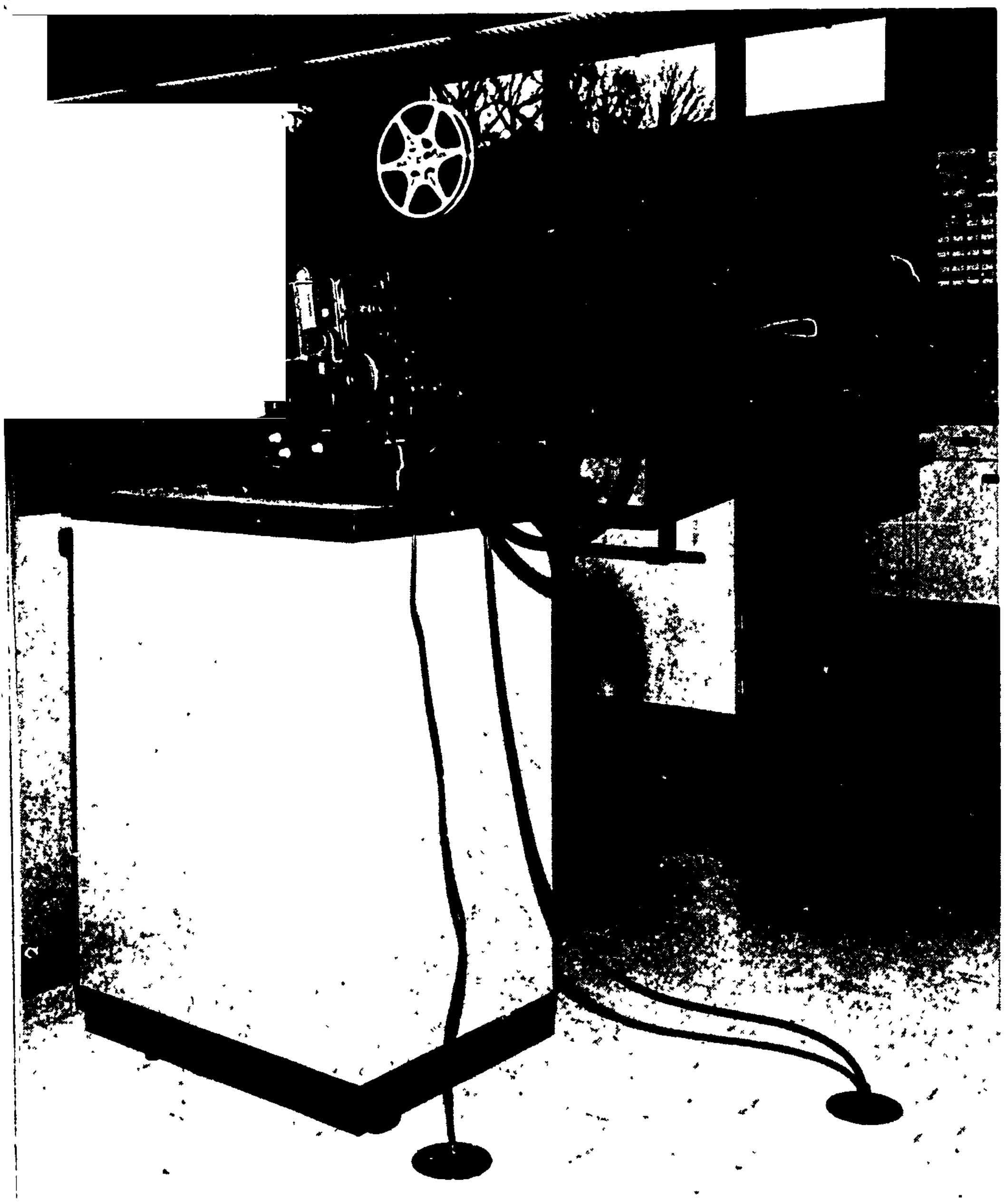


Figure 7. Projection table and floor outlets at St. Charles (Illinois) High School. Note laboratory tables in background.

construction with ledges for books under the seat are ordinarily provided for the students. Chairs with both seats and backs of Fiberglas, which has been color-impregnated, have proven to be completely serviceable at St. Charles (Illinois) High School; maintenance costs are lower because scratches do not show so readily. Some schools have the students sit at laboratory tables, but this causes difficulties if apparatus for laboratory experiments has been set up. Hooks or a rail on the ceiling over the demonstration table or over the space in front of it and channels inserted into the walls will permit the mounting of apparatus.

Ensuring that the demonstrations can be seen and heard by *every* student is extremely important (see Chapter 5), particularly as class sizes grow. Clear sight lines, provision of adequate supplementary illumination at the demonstration table and chalkboard, and the avoidance of glare must be carefully considered by the building planners. In addition, the physics teacher must review every demonstration from the viewpoint of his students and make a deliberate attempt to see that apparatus is large enough, that scales are visible, that contrasting colors are used in painting apparatus, and so on. Approximately 12 lineal feet of chalkboard behind the demonstration table is required. Slate chalkboards are preferable as a writing surface, but the more colorful steel-base chalkboards have the advantage of being magnetic so that pointers, cardboard and plastic aids to visualization, and other light objects can be attached to them with small alnico magnets during demonstrations. A projection screen for audio-visual aids and for the shadow projection of apparatus should be provided over the chalkboard or on a side wall. Electrical connections for projectors should be provided—a shielded cable under the floor with appropriate outlets at the front and back of the room for sound and ac convenience outlets at the back of the room for the projector (Figure 7). Charts are occasionally used during physics classes and means should be provided for mounting them at the front of the room—a chart rail or tack strip over the chalkboard. Peg boards are being installed increasingly in physics classrooms and laboratories for mounting booklets, posters, tools, and apparatus inexpensively and attractively.

Light control is important in many physics demonstrations and for audio-visual aids. The room should be provided with light-tight shades, and at least one set of switches for the room lights should be within easy reach of the demonstrator, preferably at the back of the demonstration bench, so that the teacher can easily darken the room.

Television will be used increasingly as an adjunct to teacher demonstration in physics in the future. Difficult or dangerous experiments, interviews with famous physicists, and activities within physics research laboratories will be witnessed by physics classes by television either in live programs or by videotape, in broadcast programs or by closed circuit. How to equip central television studios in schools and provide lines for distributing the video and audio signals to classrooms falls outside the scope of this book. Here we will merely note that the television receiver may well be accessory apparatus in the physics demonstration room of the future. Sight lines for viewing the receiver in a variety of classroom situations have been studied, and considerable information about ways of mounting receivers is available for school planners.[4]

We close these notes about demonstrations in physics by pointing to the possibilities of *corridor exhibits*—"demonstrations to individuals." Some of the larger high schools (Figure 8) are finding corridor exhibits valuable as a means of reinforcing student understanding of certain of the ideas of physics and arousing interest in physics among students in the earlier grades. The corridor exhibits contain apparatus, materials, charts, clippings, and explanatory labels. They are displayed in locked cabinets built into the corridor wall near the physics laboratory and are replaced periodically by the physics teacher.

Figure 8. A physics display cabinet in the corridor wall at Bronx High School of Science.

Discussion and Recitation

Discussion and recitation in physics courses have already been mentioned as providing the give-and-take exchanges between student and teacher that clear up difficulties and lead to greater understanding of the breadth and the subtlety of physics concepts. The demands upon the skill and knowledge of the teacher are large, but the facilities required are rather modest—tablet-arm chairs for the students, around 20 lineal feet of chalkboard so that the class can be sent to the board in two "shifts" to solve physics problems, a table and chair for the teacher, and a bulletin board for posting classroom notices (Figure 9).

Figure 9. Medium-size classroom (40 seats) for discussion sections in physics at Bronx High School of Science. Note coatracks and tack boards at back of room. The demonstration table was added at front to permit demonstrations if desired.

Figure 10. Office adjacent to the science project area at Evanston (Illinois) High School has additional space for storage of apparatus and a small research area for the teacher. Equipment at left is a closed-circuit television system used with a microscope as a microprojector in biology. Note the "panic" button and cord on desk used for turning off power in project area in an emergency.

Office Work

Grading, planning, conferences with students, and running the laboratory in the physics course require that the physics teacher have a quiet and comfortable place to work when he is not instructing students (Figure 10). A desk and comfortable chair of his own and a book shelf or bookcase would seem to be an absolute minimum of equipment. In addition, a four-drawer filing cabinet with a lock is recommended for storing the innumerable papers, booklets, catalogs, and leaflets that any science teacher needs to conduct the laboratory and to keep up with his field. The teacher's desk should be as close to the physics classroom and laboratory as possible. In some schools, teachers with physics teaching assignments may have their desks in the preparations-storage area or in a room used as the departmental office. A desk for the teacher in the classroom-laboratory is more common. Every effort should be made to provide a reasonably quiet and private place so that the physics teacher can grade papers and reports, plan lessons and laboratory work, confer with students about difficulties or about special projects, and carry on the ordering of laboratory equipment and supplies.

Storage of Apparatus

The storage and maintenance of apparatus and supplies in physics deserve the careful attention of school planners if the physics program is to be fully effective. Physics teaching, as we have emphasized in the foregoing discussion, requires apparatus, laboratory materials, small parts, and stock materials in fairly large quantities and in great variety. As contrasted with chemistry and biology, physics relies heavily on what is essentially capital equipment—meters, oscilloscopes, timers, calorimeters, and so on—rather than on consumable supplies. Consumables are needed in physics, but generally the physics teacher can use equipment for year after year. If the equipment is originally of good quality and is carefully maintained, the school's investment can be protected and the stock of equipment built up by yearly additions.

The problem of *storing equipment* includes providing enough shelf and cabinet space, locating the storage space conveniently near the places where the apparatus will be used, protecting the stored apparatus against damage or loss by suitable covers and locks, and providing a convenient organizational scheme so that the physics teacher can find apparatus and materials quickly (Figure 11). Approximately 150 square feet of shelf space are needed for storing most of the student laboratory equipment in schools where there are 24 students in a physics laboratory class; locked cabinets along the walls of the laboratory serve well for this purpose. The preparation room should have an *additional* 300 square feet of shelf space as well as numerous drawers for apparatus and supplies. All cabinets should have doors, locks, and adjustable shelves; narrow shelves should be avoided, particularly in cabinets equipped

Figure 11. Storage for electronics parts and equipment, and work area at St. Charles (Illinois) High School.

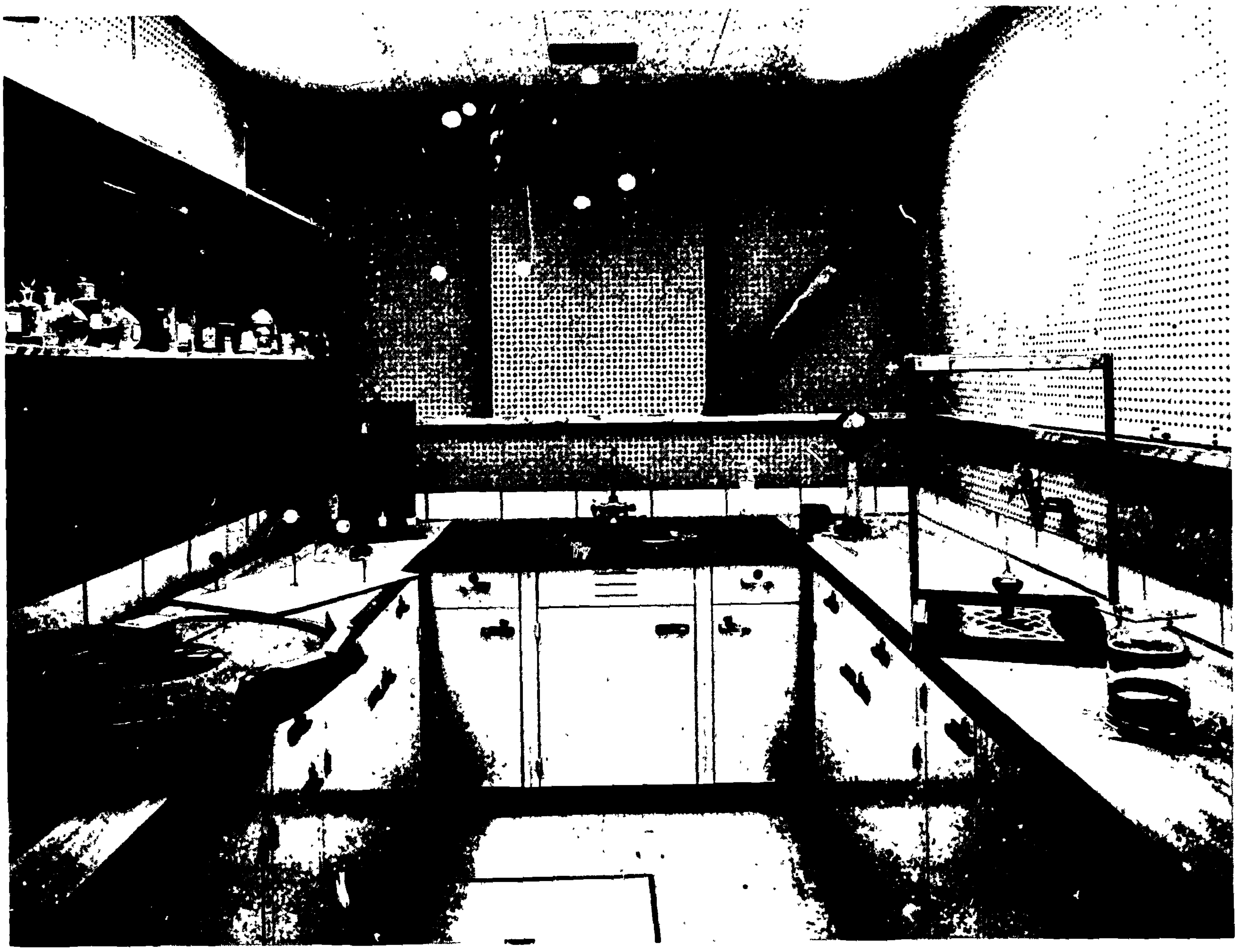


Figure 12. Physics preparation area at St. Charles (Illinois) High School.

with sliding doors. Chemicals and batteries should be stored at a distance from the other materials in a well-ventilated place from which corrosive fumes will not reach apparatus. In one school, the door that leads from the storage area to the classroom-laboratory is a Dutch door with a counter mounted on the lower half so that equipment can be checked out at the door. Audio-visual equipment preferably should be stored on the spot where it will be used. We have already remarked that the cabinets in the base of the demonstration table can be used for storing some equipment accessory to the demonstrations—vacuum pumps, power supplies, clamps, and so on. Many physics teachers follow the scheme of organizing their storage space according to the subdivisions of the physics course, assigning some cabinets to mechanics equipment, some to light, some to electricity and magnetism, and so on. A card file of equipment and supplies, kept up to date, is essential.

The *preparation area* is usually combined with the storage room. Preparations include the preliminary setting up of apparatus to be used in demonstrations and student laboratory experiments, repair and maintenance of apparatus, construction of new apparatus, and occasionally photographic development. The preparation area should be equipped at least with a strong table and may well contain a table or bench fully equipped with a sink and the services supplied to the laboratory tables (Figure 12). If a workbench is not conveniently nearby in the student laboratory, the preparation area should have a workbench. Some schools provide means of darkening the preparation-storage room so that it can be used as a photographic darkroom. (Large schools that have photography clubs provide separate darkrooms that can be used by the science departments.) To facilitate the setting up of demonstrations in the classroom and their removal after class, rolling tables of the same height as the demonstration table are used in many schools: the apparatus is set up in the preparation area and the tables are wheeled into the classroom shortly before the class begins. The tables on wheels are not a complete answer to the problem of full utilization of the demonstrations classroom, however. Many demonstrations require on-the-spot setting up, so that the classroom must be free during the period before the demonstrations are to be given.

FOR EARLY CONSIDERATION

Programming

Preparing functional specifications for the space to be used by physics classes will of course be only a part of the problem of programming the entire school building. (See Chapter 2 on Programming.) Nevertheless, early in these discussions the architect, who often devotes half of his design effort to programming, will want the views of the school administration and the teaching staff concerning the science facilities. We cannot stress too strongly the importance of consulting the physics teacher. He has had the experience of working in the present physics laboratory, and he is in direct contact with the problems of teaching physics within the complex of conditions represented by the school, the students, and the community. The viewpoint of the teacher cannot be dispensed with if the physics rooms are to be properly designed for the school. Involve him early and often in the planning process. Physicists at nearby colleges, universities, and industrial laboratories, who have had experience in planning laboratory facilities, can also be helpful and should be called in as consultants. Visits to successfully functioning physics laboratories in other nearby schools are also very much in order.

An excellent introduction to the problems of school construction and valuable background information on costs, planning, and structural details will be found in *The Cost of a Schoolhouse,* published by the Educational Facilities Laboratories, Inc.[8]

Location

The location of the physics space is not critical. If the school is to have a science wing, physics classrooms naturally will be in it and can share certain facilities with the other sciences—a shop, project room, science library, and photographic dark room. However, a southerly location on the ground floor, once recommended for physics laboratories, is no longer essential. Physics laboratory sessions are occasionally noisy, however, and it is well to keep this in mind in assigning academic neighbors. It would be convenient, but not essential, for the physics area to be located near the school shop.

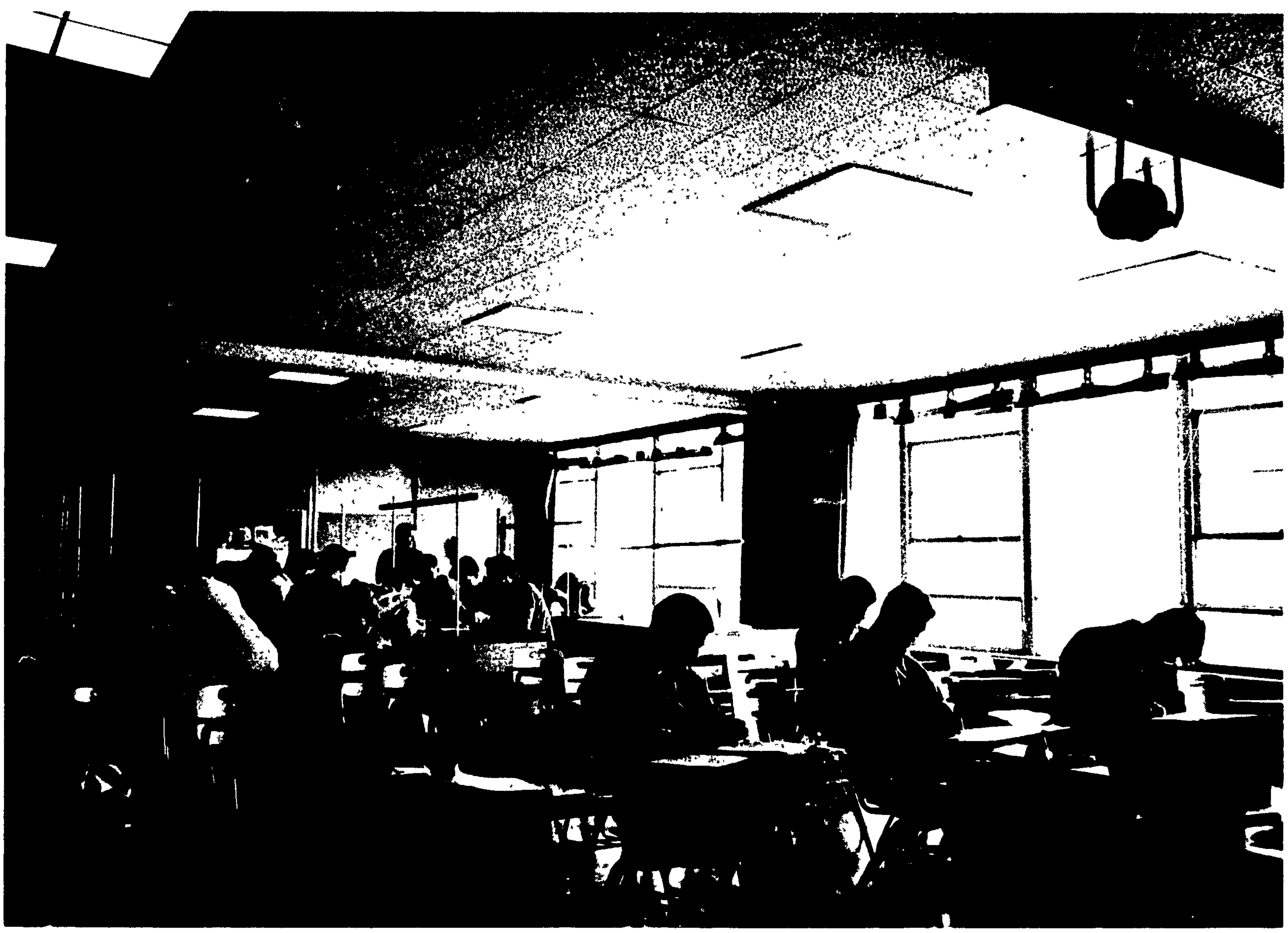
Combination Rooms

Combinations of physics areas with those used for other subjects have to be considered in the smaller schools. Physics and chemistry are the two subjects most often combined in this way although physics and general science sometimes share a laboratory-classroom. The severe requirements of construction economy and full utilization of space often understandably necessitate such arrangements. However, the growing enrollments in all of the sciences, including physics, make it imperative that the possibility of the future need for separate laboratories for the different sciences not be overlooked in planning new schools. Moreover, the kinds of activities described here as characteristic of physics classes—and this is also true of chemistry and the other sciences—can be best carried out in a room devoted to physics, a room that is a headquarters and a home for physics students and teachers. However well planned, arrangements for sharing a classroom tend to destroy the characteristic "atmosphere" that develops in a room long used for hard and serious study of a science. Less important, but still something to consider, are the practical difficulties of sharing—extra moving of apparatus by teachers to make way for incoming classes in the other subjects and the effect of fumes from the chemistry experiments upon stored physics apparatus. Nevertheless, the sharing of classrooms by several sciences is thought to be desirable or necessary by many schools, and we shall give examples of such arrangements later in this chapter. Another kind of combination is the use of the same room for both laboratory work and demonstration-discussion classes—the laboratory-classroom. This is a common and advantageous arrangement in small and medium-size schools (Figure 13) because it allows the teacher to plan a flexible program of student experiments and class discussion within the same room. Large schools, however, often have separate demonstration-discussion rooms and laboratories because this arrangement places a strong emphasis on laboratory work which might otherwise be slighted in favour of teacher demonstrations.

Size

The size of physics rooms depends of course upon the class size. We have referred earlier to a slow trend toward a more flexible policy concerning class size in schools. Large demonstration classes and smaller seminar and laboratory classes are to be expected in the future. Currently, the average physics room provides between 40 and 50 square feet per student for a class of 24 students plus about 250 square feet for storage and preparation. Thus we are talking about an area of roughly 1200 square feet for one classroom-laboratory

Figure 13. Combination classroom-laboratory for physics at Garden City (New York) High School. The demonstration table (right foreground) faces tablet-arm chairs. Project booths, laboratory tables and benches are at rear of room. The average class size is about 24 students.



unit in physics. We suggest, however, that any average space estimates of this kind not be taken too seriously. The total space requirements for physics in a particular school should evolve from the programming discussions mentioned previously. Twelve hundred square feet devoted to physics might be lavish for one school program and grossly inadequate for another. Moreover, whether the room is used for physics alone or for physics and some other subject must be considered in deciding upon the size.

Shape

The shape of the physics room is not critical except that rooms should not be excessively long and narrow if they are to be used for teacher demonstrations. The problem of making demonstrations visible is too difficult in long rooms regardless of whether the demonstration table faces the long dimension or the short one. A more nearly square room or square area is preferable for demonstrations.

Ventilation, Lighting, and Acoustics

Ventilation, lighting, and acoustics in the physics room, with certain exceptions, generally do not require special measures for adequate levels of control. Ventilation requirements recommended by the several states[9] average about 3 to 4 complete changes of air per hour in laboratories where chemical fumes are not produced, and up to 9 changes of outside air per hour in chemistry laboratories. General illumination should be between 30 and 50 foot-candles. Additional illumination, up to a total of 70 foot-candles (see Chapter 5) may be needed on the demonstration table. In some schools windows are placed high on the walls so that the wall area beneath them can be used for mounting apparatus and so that sunlight does not produce glare on shiny surfaces in the room. Freedom from glare and sharp contrasts and the use of attractively colored paints, wall tiles, and floor coverings are most important. The use of washable paints reduces maintenance costs. Acoustical treatment of physics classrooms and laboratories is strongly recommended. A suspended ceiling which combines lighting and acoustical panels on a modular grid may be worth considering.

Utilization

Utilization of physics rooms requires careful interpretation. Occupancy of the room by classes every school period is one possible—and common—definition of full utilization. Such use may not produce the best educational results, however, if it bars the physics teacher from setting up needed demonstrations or prevents project work in the physics laboratory. Currently, around 80% class occupancy of the physics laboratory is about the maximum that can be expected considering schedule difficulties and the need for set-up time and projects. When sound-proof and flexible partitions at moderate cost become widely available, the utilization of the large and expensive classroom areas can approach 100% because the smaller specialized areas such as the demonstration table, project areas, and so on, can be temporarily closed off with partitions. Encouraging progress is being made in developing flexible, adequately soundproof partitions for school use. An acoustical curtain of metal filament interwoven with other fibers, now under development[8] may prove to be the flexible divider long sought for.

Flexibility

Flexibility in physics classrooms includes not only the ability to subdivide the space with sound-proof, easily moved partitions, but also provision for the addition of services as teaching requirements change. For example, it is a defensible practice to install gas and water pipes and electrical conduit in exposed parallel runs wherever possible. The advantages in installation, use, and maintenance of exposed service lines outweigh the dust problem. When installing service lines, provide spare plugged tees in the water and gas lines and spare junction boxes in the electrical conduits to provide for extra work stations in the laboratory or to convert a classroom into a laboratory at some future time. A recent trend in industrial laboratory and shop furniture may offer some advantages of flexibility in school physics rooms. Piping, valves, and electrical outlets are confined to the service strip rigidly fastened to the perimeter wall of the room. Except for the sinks, all furniture is completely free to be rearranged as the room occupants wish. Patent metal struts are available commercially that can be attached to walls and that permit shelves or table tops to be easily set up at desired heights.

Floor Coverings

The floor coverings currently most used in physics laboratories are vinyl tile and asphalt tile.

Table Top Materials

Table top materials (see Chapter III), listed in order of increasing cost, include:

1. Solid wood top, laminated, lacquered, or oil finished (for general use)
2. Pressed wood fiber such as Masonite
3. Solid hardwood, such as birch or maple, laminated with resinous finish
4. Cement asbestos surface such as Transite (heat resistant—for glass-blowing benches)
5. Plastic sheet such as Formica, Panelyte, or Textolite
6. Solid natural stone with baked resinous finish
7. Stainless steel sheet (for photographic darkroom benches whenever a high degree of cleanliness is required)

Sinks

Sinks and cup sinks (see Chapter III), listed in order of increasing cost, are available in several materials:

1. Porcelain on metal base
2. Acid-resistant silicon iron alloy such as Duriron or Corosiron
3. Soapstone, or Alberene stone
4. Moulded or welded plastic such as polyvinyl chloride, polyethylene, Fiberglas with resin
5. Stainless steel, pressed or welded
6. Pyrex glass

Most sinks are available integral with tops of the same material. Costs are generally reduced, however, by installing the sink separately on the job in a cut-out in the top. Patent rims and jointing compounds have reduced the problems of field installation, but should be compared for tightness and for the amount of rim obstruction which each presents; many are far from flush.

SOME EXAMPLES OF PHYSICS ROOMS IN HIGH SCHOOLS

A. The classroom-laboratory in physics

George E. Thompson (Illinois) High School (Figure 14 a, b, c)
East Orange (New Jersey) High School (Figure 15 a, b, c, d)
Westmoor (California) High School (Figure 16)

B. The physics-chemistry room

Death Valley (California) Union High School (Figure 17 a, b, c)
Darien (Connecticut) High School (Figure 18)

C. Separate classrooms and laboratories

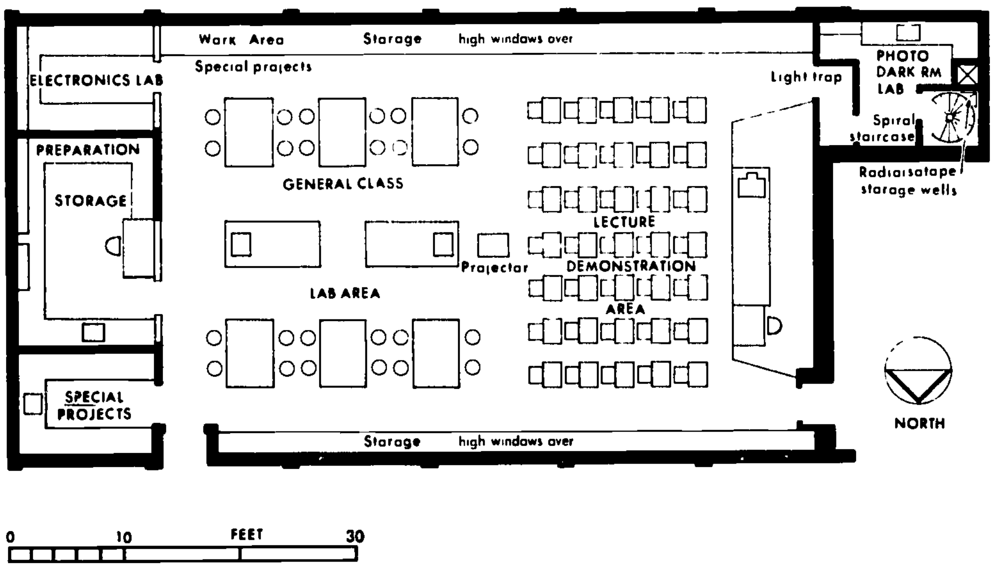
Bronx High School of Science (New York) (Figure 19 a, b, c, d, e, f)

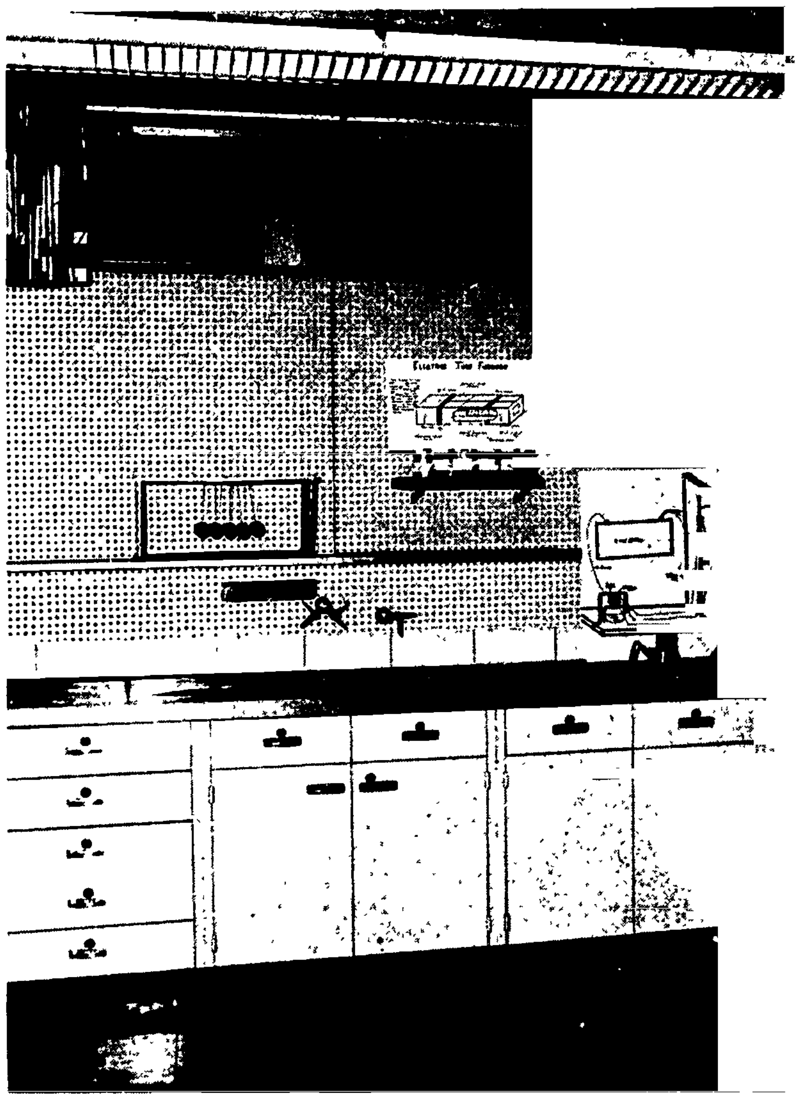
D. The science project room

Evanston (Illinois) High School (Figure 20 a, b, c)

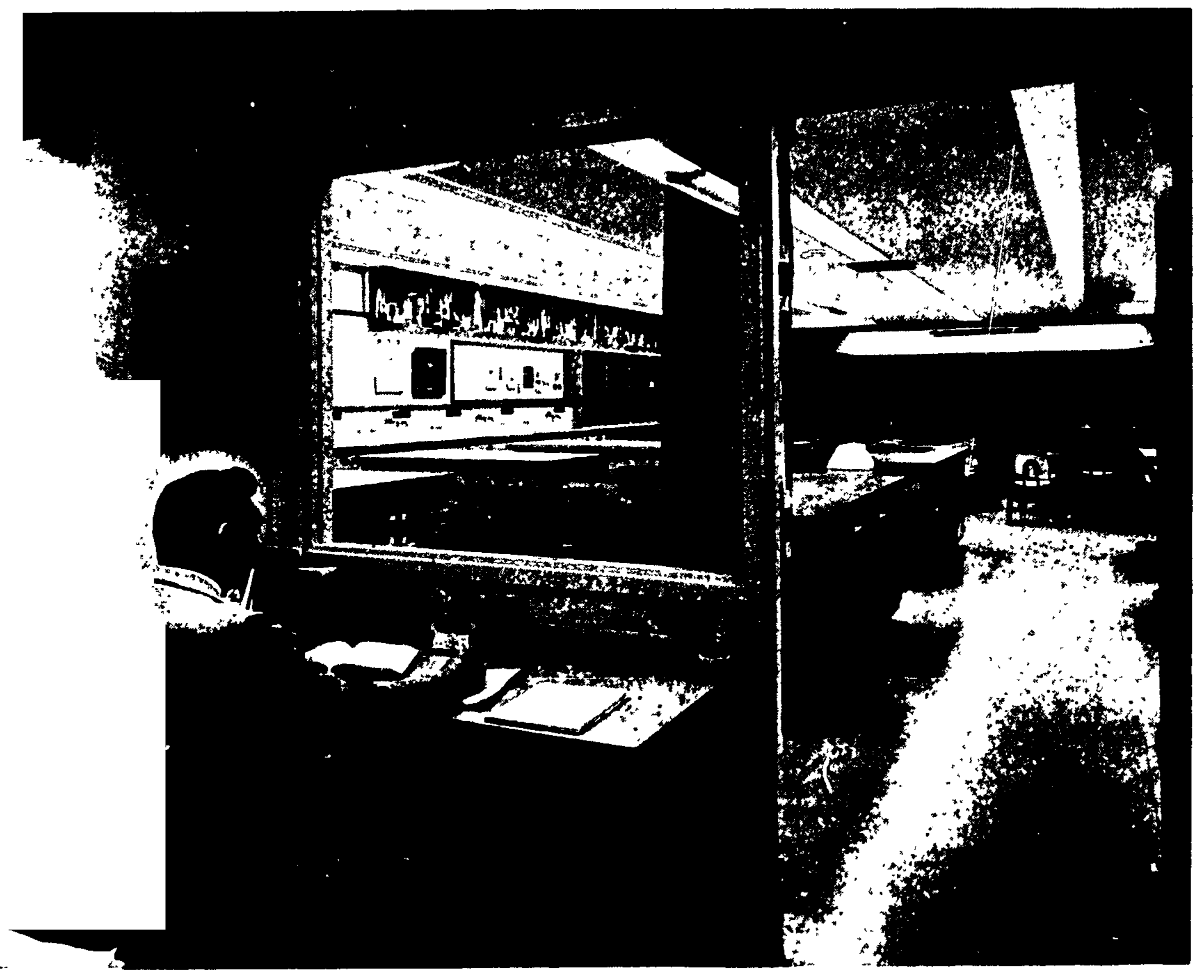
The classroom-laboratory in physics

Figure 14. Floor plan of physics laboratory in Science Wing of George E. Thompson High School, St. Charles, Illinois. Nicol and Nicol, Architects, St. Charles.

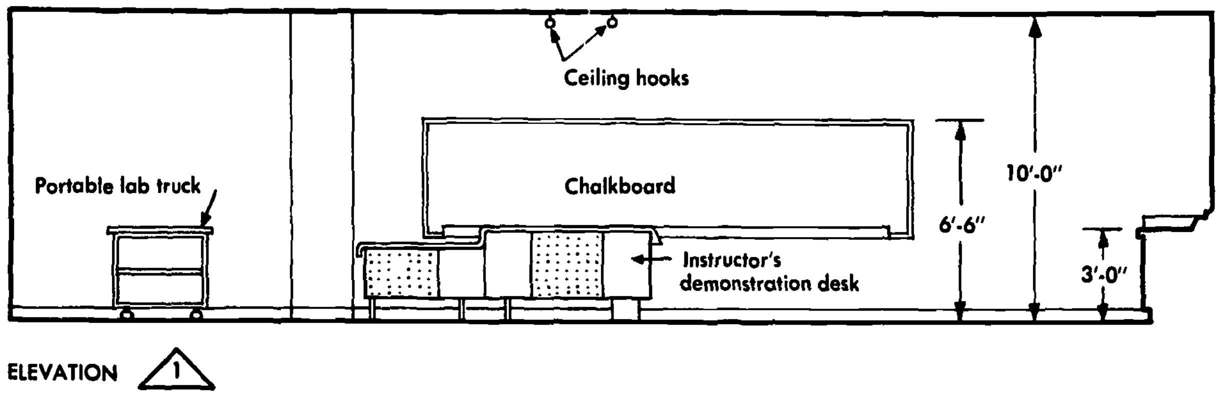


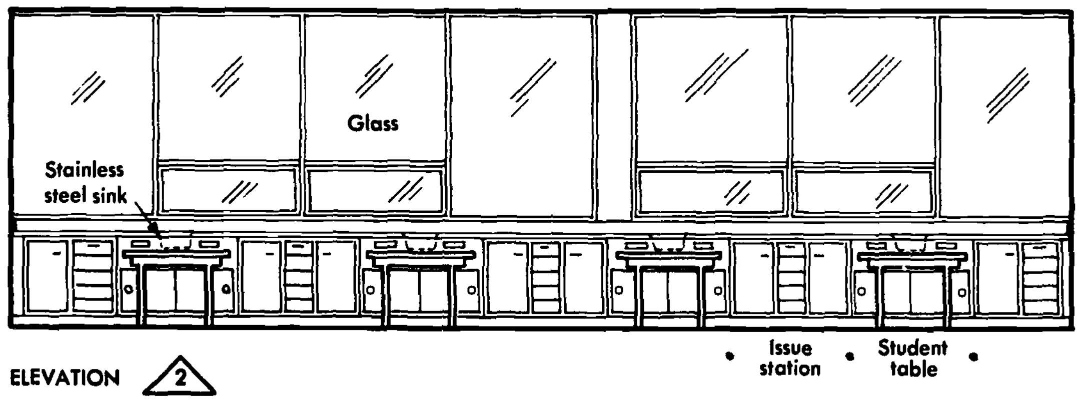


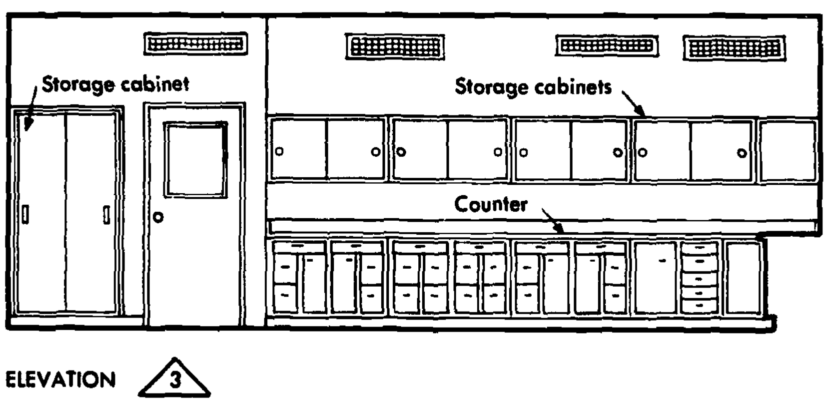
Work area showing high windows which permit more efficient use of wall beneath. Hooks are installed throughout entire ceiling of the laboratory to facilitate the performance of experiments.



Instructor's office, looking into classroom. Flexibility is provided by separate functional areas for lecture, laboratory, and project work.







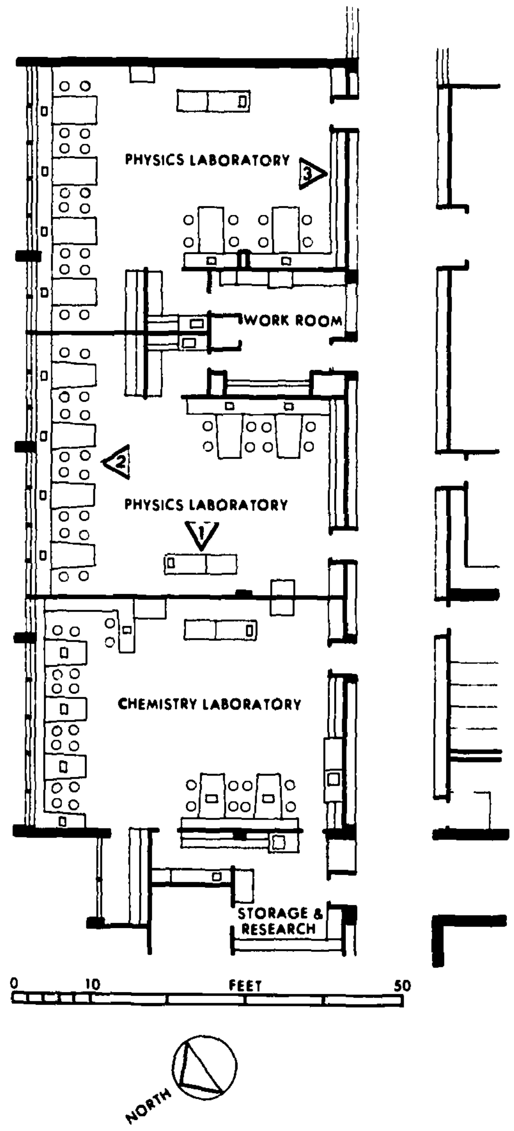
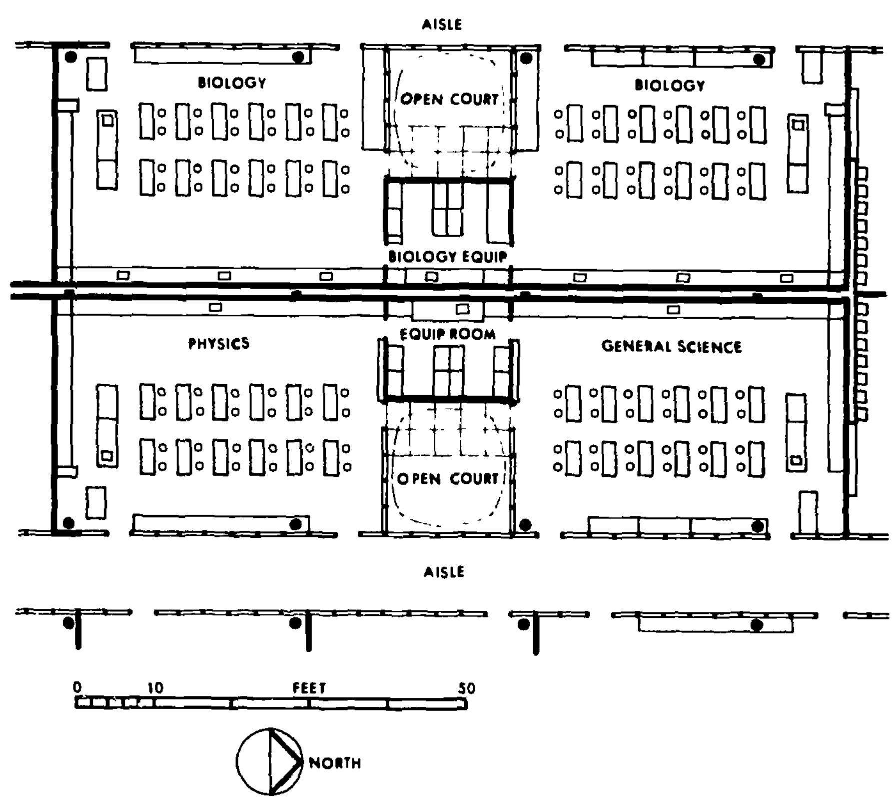


Figure 15. Floor plan of Physics and Chemistry Wing and three strip elevations of physics laboratory, East Orange High School, East Orange, New Jersey. Emil A. Schmidlin, Architect, East Orange. Point of view for each elevation is shown on plan.

Figure 16. Floor plan of Science Wing, Westmoor High School, Daly City, California. Mario Ciampi, Architect, San Francisco.



The physics-chemistry room

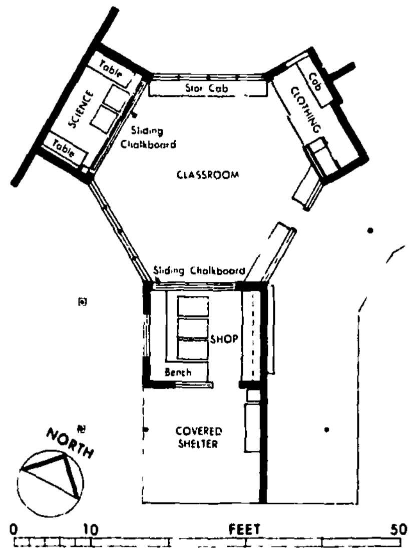
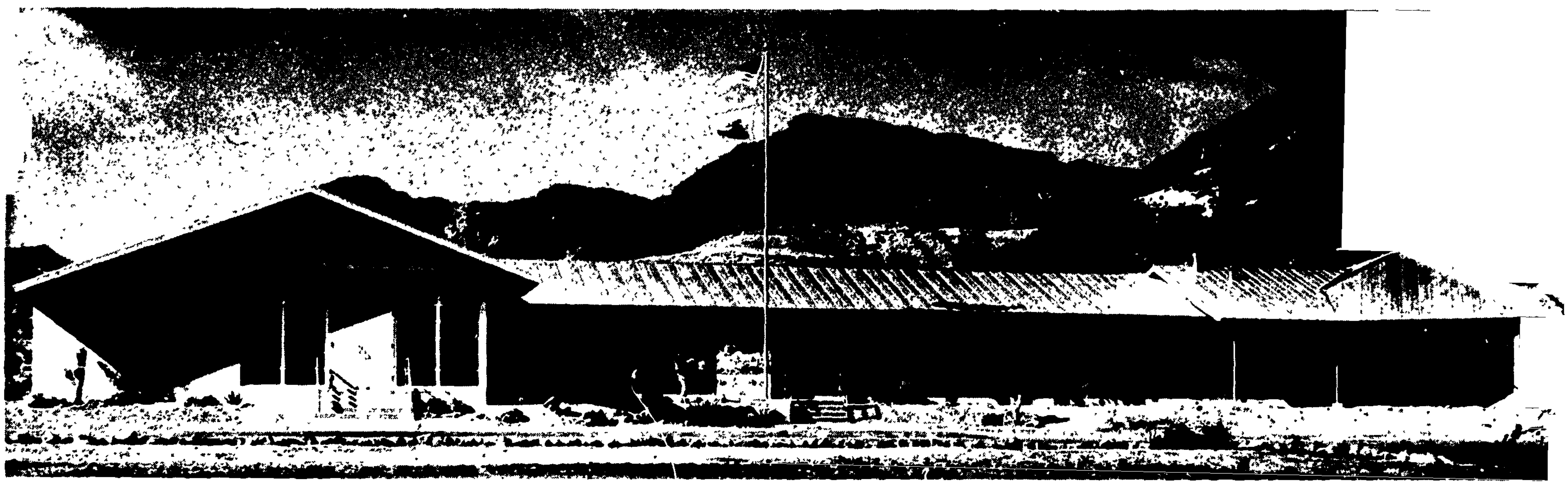


Figure 17. Floor plan of Death Valley High School, Shoshone, Inyo County, California, showing classroom with adjoining alcoves for science, clothing (domestic science), and shop. This is a small school with 3 teachers and a student enrollment of 21. Note that flexible arrangement of a common classroom and alcoves for special equipment permits fuller utilization of space. The alcoves can be closed by means of the sliding blackboards. Robert Trask Cox, Architect, Los Angeles.



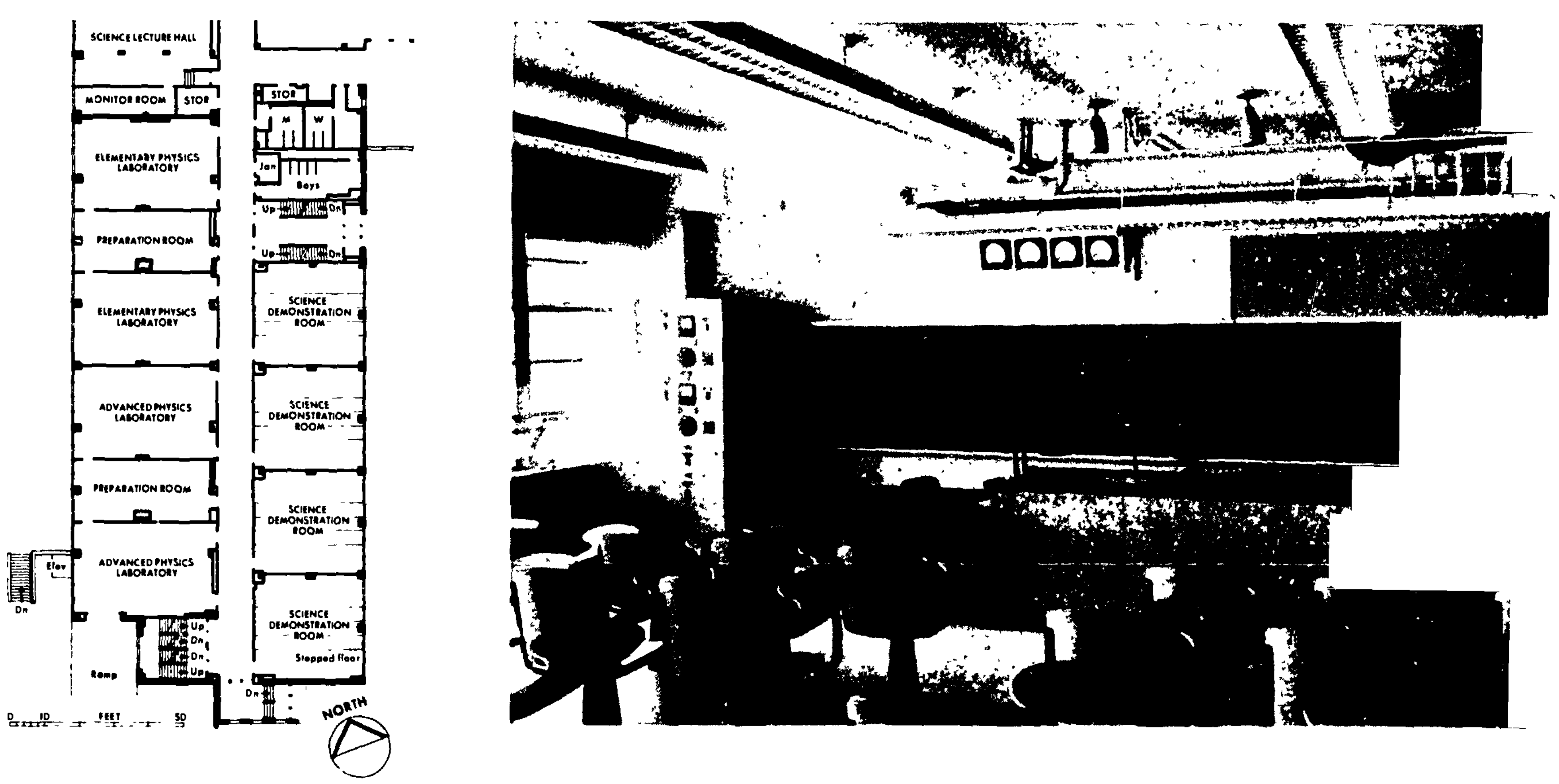
Exterior of school building.

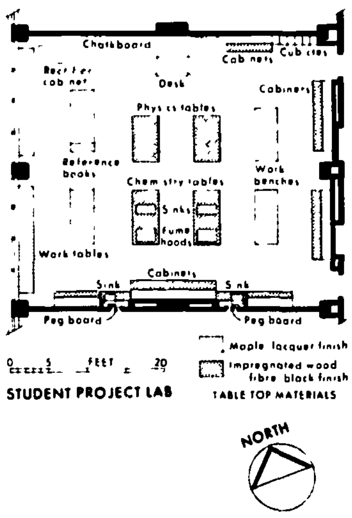
Science area viewed from shop through open sliding chalkboard.

Figure 18. Floor plan of the Science-Mathematics Wing, Darien High School, Darien, Connecticut. Ketchum and Sharp, Architects, New York.

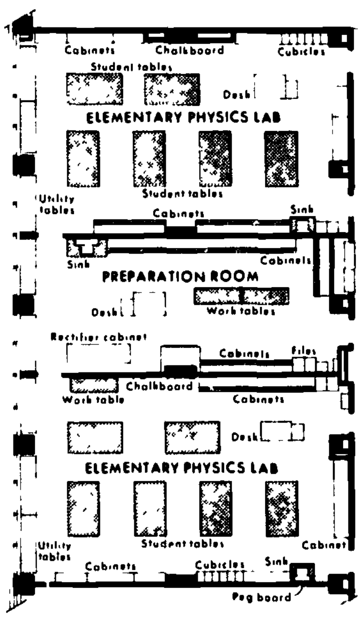
Separate classrooms and laboratories

Figure 19. Typical science demonstration room, Bronx High School of Science, New York. Note stepped floors in floor plan of Science Wing at left. Emory Roth and Son, Richard Roth, Architect, New York.





Student project laboratory. Note down-draft fume hoods at right.



Floor plan, elementary physics laboratories and preparation room.

Science lecture hall which seats 105 students.

The science project room

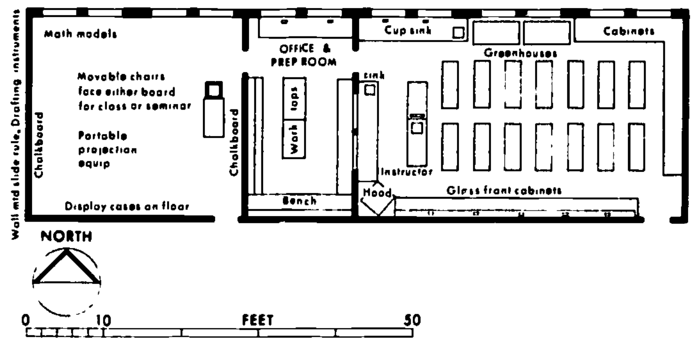


Figure 20. Science project room at Evanston High School, Evanston, Illinois. Note L-shaped bench in rear of laboratory for electrical and electronics work. Research bench in office and preparation room is shown below. Shades in slots permit darkening of room.

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