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INSTRUMENTATION TECHNOLOGY, A SUGGESTED 2-YEAR POST HIGH SCHOOL CURRICULUM. TECHNICAL EDUCATIONAL PROGRAM SERIES, NUMBER 6.

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A 2-YEAR POST-SECONDARY CURRICULUM FOR TECHNICIANS IS PRESENTED. IT IS DESIGNED TO AID SCHOOL ADMINISTRATORS, SUPERVISORS, AND TEACHERS TO PLAN AND DEVELOP NEW PROGRAMS OR EVALUATE EXISTING PROGRAMS. IT WAS PREPARED PURSUANT TO A U.S. OFFICE OF EDUCATION CONTRACT BY THE INSTRUMENT SOCIETY OF AMERICA AFTER A NATIONAL SURVEY OF INSTRUMENTATION MANUFACTURERS, USERS, AND EDUCATIONAL INSTITUTIONS. A CURRICULUM, DESCRIPTION OF EACH COURSE, AND A DISCUSSION OF THE CONTENT RELATIONSHIPS ARE GIVEN. OUTLINES FOR EACH COURSE GIVE HOURS REQUIRED, A COURSE DESCRIPTION, MAJOR DIVISIONS, TEXTS, AND REFERENCES, AND VISUAL AIDS. THE SPECIALIZED NATURE OF THE CURRICULUM REQUIRES THAT THE TEACHERS HAVE SPECIAL COMPETENCIES BASED ON PROFICIENCY IN TECHNICAL SUBJECT MATTER AND INDUSTRIAL EXPERIENCE. IN GENERAL, STUDENTS ENTERING THE PROGRAM SHOULD HAVE COMPLETED 2 YEARS OF HIGH SCHOOL MATHEMATICS AND 1 YEAR OF PHYSICS OR THE EQUIVALENT. INFORMATION ON FACILITIES, EQUIPMENT, AND COSTS INCLUDES FLOORPLANS, AN EQUIPMENT LIST, AND A SUMMARY OF COSTS. AN EXTENSIVE BIBLIOGRAPHY OF SUGGESTED TEXTS AND REFERENCES IS INCLUDED. THE APPENDIX CONTAINS A LIST AND DESCRIPTION OF RELATED ORGANIZATIONS AND SOCIETIES, A GUIDE FOR REPORT WRITING, AND SAMPLE INSTRUCTIONAL MATERIALS. THIS DOCUMENT IS ALSO AVAILABLE AS FS 5.280--80033 FROM THE SUPERINTENDENT OF DOCUMENTS, U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C. 20402, FOR $0.75 (EM)

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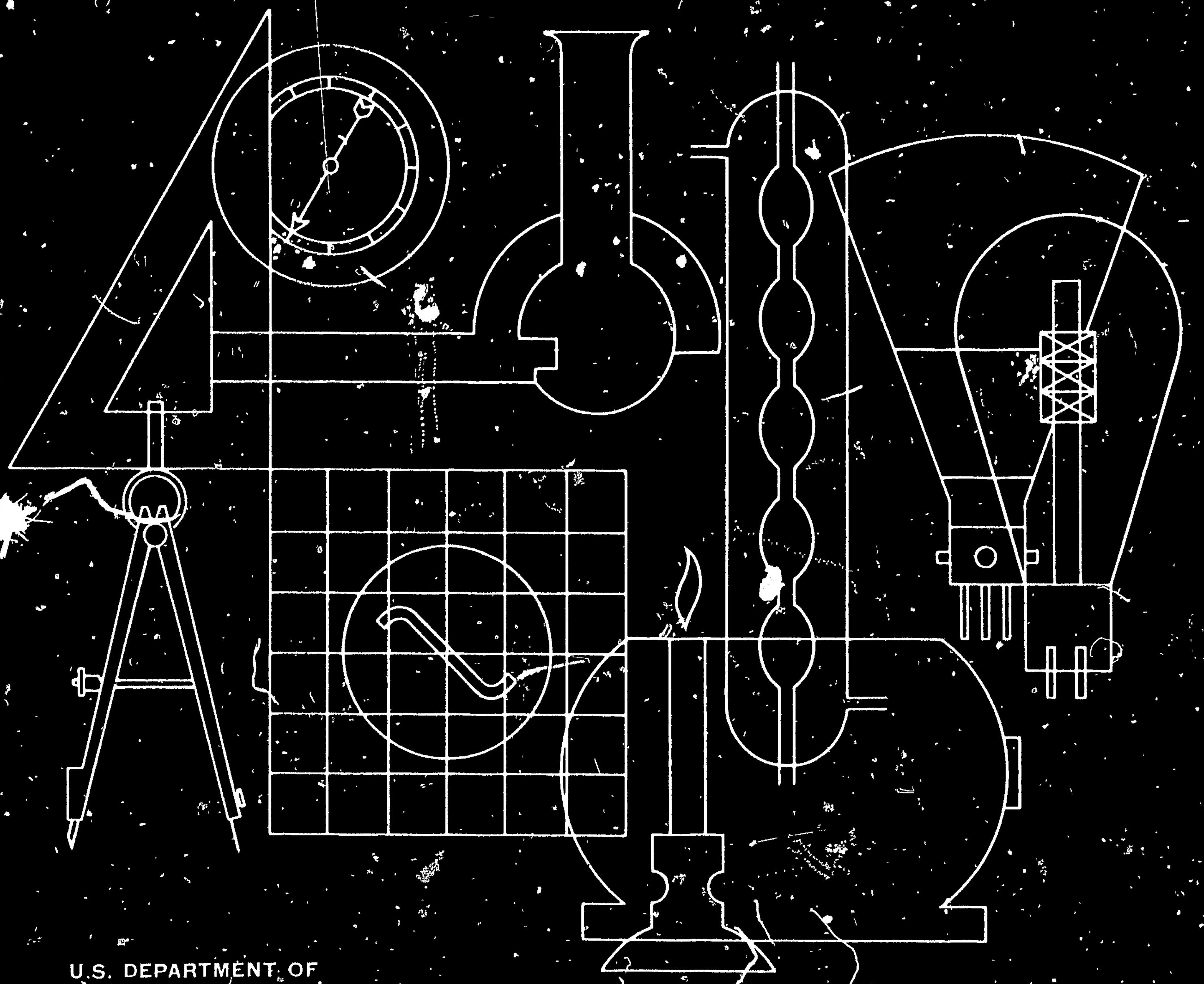
TECHNICAL EDUCATION PROGRAM SERIES NO. 6

Instrumentation Technology

A Suggested 2-Year Post High School Curriculum



U.S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
Office of Education

OE–80033

TECHNICAL EDUCATION PROGRAM SERIES NO. 6

INSTRUMENTATION TECHNOLOGY

A Suggested 2-Year Post High School Curriculum

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE . . . . . . ANTHONY J. CELEBREZZE, *Secretary*

Office of Education . . . . FRANCIS KEPPEL, *Commissioner*

Foreword

THIS SUGGESTED CURRICULUM for a 2-year full-time educational program to train technicians to be highly skilled in instrumentation has been developed to assist in meeting the need for instrumentation specialists. Persons who master this type of preparatory curriculum will be prepared to serve as assistants to engineers and scientists in the broad field of instrumentation.

The guide offers suggested course outlines, sequences of technical education procedure, laboratory layouts, texts and references, and laboratory equipment lists. It is designed to assist school administrators, supervisors, and teachers who will be planning and developing new programs or evaluating existing programs in instrumentation technology. Although the indicated level of instruction is post high school, the sequence of course work may well start at any grade level where students have the prerequisite background and understanding.

The Instrument Society of America prepared the technical materials, pursuant to contract with the U.S. Office of Education. The suggested curriculum provides the educational content a national survey showed was needed by instrumentation manufacturers, users, and educational institutions teaching instrumentation at the post secondary level.

Many useful suggestions were received from special consultants and from administrators and teachers in schools of technology. Although all suggestions could not be incorporated, each was considered carefully in the light of the publication's intended use. Consequently, it should not be inferred that the curriculum is completely endorsed by any one institution, agency, or person.

The technical accuracy of the curriculum materials is due largely to the work of a group of 12 outstanding instrumentation engineers and educators who thoroughly reviewed these materials in conference with the staff of the Technical Education Branch.

WALTER M. ARNOLD,
Assistant Commissioner for
Vocational and Technical Education

Acknowledgments

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Oklahoma State University
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Ryerson Institute of Technology
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Tacoma Vocational-Technical Institute
Tacoma, Wash.
Temple University Technical Institute
Philadelphia, Pa.
Ward School of Electronics
Hartford, Conn.
Wentworth Institute
Boston, Mass.

Contents

The Instrumentation Technology Program

SPACE EXPLORATION—manned and unmanned, communication by Telstar, exploration of the ocean's depths, automated petrochemical and similar complex manufacturing and processing systems, biomedical studies—all of these and many other triumphs of applied science would be impossible without the sensitive and responsive instruments which provide the means for scientific measurement, control, and information storage and retrieval. This rapidly growing and increasingly important branch of applied science is broadly termed instrumentation.

Although some of the principles of instrumentation and automatic control have been known for almost 200 years, it is only within the last 30 years that much of the theory, mathematica

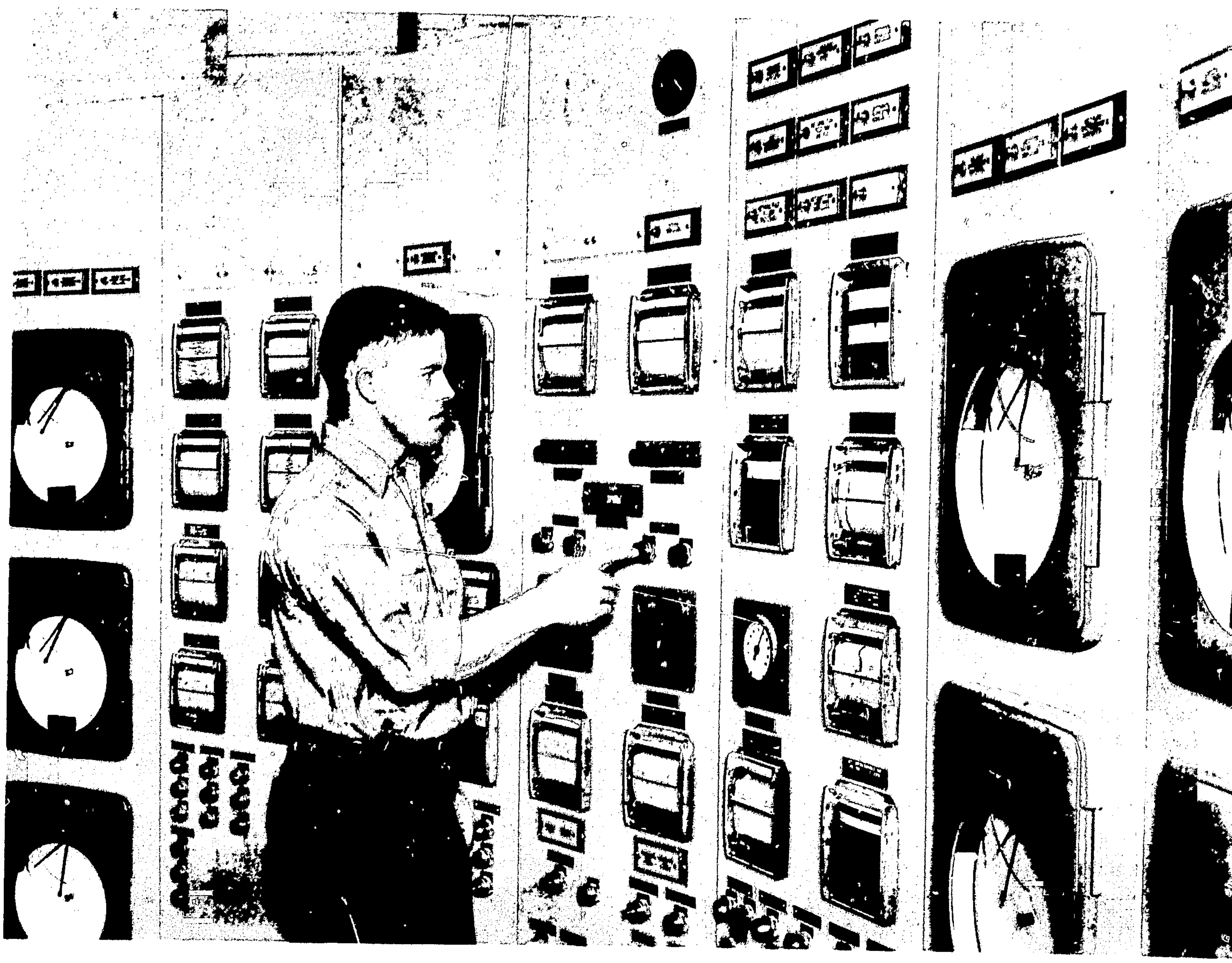


Figure 1
Instrument technician checking out the control system for processing a complex organic chemical in a chemical producing plant.

means for expressing the many and varied relationships, and advanced techniques for system analysis have been developed. Extreme demands for varied capabilities for measurement and control equipment have forced the rapid development of new methods and devices in instrumentation. New industries, new applications, and the increased rate of development of the many phases of physics are creating an almost explosive expansion of the many facets of instrumentation and control.

The availability of analog and digital computers, the development of minutely accurate position sensors, and the techniques for storing vast quantities of information with easy retrieval are creating a revolution in the business machine industry and in the machine tool field, and are promoting new capabilities in industries which require closed-loop control systems to provide automatic process or system control.

Adequate training of engineers, scientists, and supporting technical personnel for this rapidly growing and vital segment of the Nation's research, production, and operational activities is an increasing problem. The process of educating individuals to be highly qualified instrumentation personnel is complicated by the fact that they must be competent in not one but several of the traditional scientific or engineering disciplines. They must combine a mastery of portions of both mechanical and electrical-electronic engineering with theoretical and applied physics in order to develop and apply the principles, devices, and concepts of instrumentation.

GENERAL CONSIDERATIONS

This suggested curriculum guide is designed to provide an intensive 2-year full-time program of study for students of instrumentation technology. The courses in the plan of study are designed and organized to provide a knowledge of the physical sciences and of control devices, and to develop the technical skills involved in their application to instrumental control of processes, systems, and operations in modern industry.

Instrumentation as used in this guide is defined as the use of a mechanism(s) in an industrial or research process, or operation, which (1) senses some physical variable or phenomenon; (2) measures the amount of the variation; (3) may or may not automatically record the measurement; and (4) responds by making an adjustment in some element affecting the control of the process. In its simplest concept, instrumentation involves one variable in a process, and one instrument which senses fluctuations in the variable and may automatically respond to control the variable. The use of a thermostat to control room temperatures is a simple, yet common, example of one use of elementary instrumentation; one in which there is no recording of the temperature, but a sensing of temperature and an automatic adjustment of heat to maintain room temperature within an acceptable or predetermined range.

Applied instrumentation in modern industrial research or processing has become increasingly complex. In addition to using instruments separately to measure single variables, whole systems of instruments are interconnected for the transmission, acquisition, and reduction of data and standardization of performance. Often an analog or digital computer is built into the system to bring about the completely automatic operation and control of a complex system of processing. The automated petroleum refinery is an example of a more complex industrial instrumentation system.

Highly complicated instruments are currently in common use measuring such variables as motion, dimension, pressure, force and torque, flow of materials, sound, electric and magnetic quantities, temperature, chemical composition analysis, time and frequency, electromagnetic radiation, nuclear penetrating radiation, humidity, and material level. At present, some 5,500 separate manufacturing companies produce instrumentation devices; and the number of manufacturers, both domestic and foreign, increases annually. Thus, the instrumentation field represents one of the fastest growing and most complex segments of American industry.

Effectiveness of the use of instrumentation is a measure of the Nation's scientific progress. Instruments extend man's senses and control in manned and unmanned space exploration, weather prediction, missile guidance, communications, environmental control, industrial research, automated processing and production, medical research and therapy, and many other areas of applied science.

Instrumentation scientists and engineers must not only be trained physical scientists, but must be competent in both electrical-electronic engineering and in mechanical engineering.

Highly skilled instrumentation technicians must be capable of working closely with instrumentation engineers and scientists and also must have the capability to supervise and coordinate the efforts of skilled craftsmen and instrument maintenance men. These capabilities allow technicians to be effective members of the scientific team whose work is to plan, assemble, install, calibrate, evaluate, and operate instruments as they apply to processes or systems.

Because instrumentation technicians are employed in so varied, numerous, and often specialized situations, the adequately trained instrumentation technician must have attained certain abilities, scientific knowledge, and technical skills. These have been broadly defined as follows: [1]

1. Facility with mathematics; ability to use algebra and trigonometry as tools in the development of ideas that make use of scientific and engineering principles; an understanding of, though not necessarily facility with, higher mathematics through analytical geometry, calculus, and differential equations, according to the requirements of the technology.
2. Proficiency in the application of physical science principles, including the basic concepts and laws of physics and chemistry that are pertinent to the individual's field of technology.
3. An understanding of the materials and processes commonly used in the technology.
4. An extensive knowledge of a field of specialization, with an understanding of the engineering and scientific activities that distinguish the technology of the field. The degree of competency and the depth of understanding should be sufficient to enable the individual to do such work as detail design using established design procedures.
5. Communication skills that include the ability to interpret, analyze, and transmit facts and ideas graphically, orally, and in writing.

[1] U.S. Department of Health, Education, and Welfare, Office of Education, *Occupational Criteria and Preparatory Curriculum Patterns in Technical Education Programs.* Washington: U.S Government Printing Office, 1962. p. 5. (OE-80015)

The instrumentation technician will use the foregoing abilities, knowledge, and skills, as he performs several (but usually not all) of the following general activities: [1]

1. Applies knowledge of science and mathematics extensively in rendering direct technical assistance to scientists or engineers engaged in scientific research and experimentation.
2. Designs, develops, or plans modifications of new products and processes under the supervision of engineering personnel in applied engineering research, design, and development.
3. Plans and inspects the installation of complex equipment and control systems.
4. Advises and recommends procedures or programs for the maintenance and repair of complex equipment used in extensive control systems.
5. Plans production as a member of the management unit responsible for efficient use of manpower, materials, and machines in mass production.
6. Advises, plans, and estimates costs as a field representative of a manufacturer or distributor of technical equipment and/or products.
7. Is responsible for performance or environmental tests of mechanical hydraulic, pneumatic, electrical, or electronic components or systems and the preparation of appropriate technical reports covering the tests.
8. Prepares or interprets engineering drawings and sketches.
9. Selects, compiles, and uses technical information from references such as engineering standards, handbooks, and technical digests of research findings.
10. Analyzes and interprets information obtained from precision measuring and recording instruments and makes evaluations upon which technical decisions are based.
11. Analyzes and diagnoses technical problems that involve independent decisions.
12. Deals with a variety of technical problems involving many factors and variables which require an understanding of several technical fields.

Mastery of this curriculum is preparatory to employment as a highly skilled technician in the broad field of instrumentation. Graduates in many cases will be employed as: Instrumentation technicians; engineering aids—instrumentation; engineering associates—instrumentation; service specialist in instrumentation; laboratory technician—instrumentation; research technicians; electro-mechanical technicians; instrument field service technicians; laboratory assistants.

A 2-year curriculum must concentrate on primary or fundamental needs if it is to prepare individuals for responsible technical positions in modern industry. It must be honestly pragmatic in its approach and must involve a high order of specialization. *The curriculum suggested in this bulletin has been designed to provide maximum technical instruction in the time that is scheduled.*

To those who are not familiar with this type of educational service (or with the goals and interests of students who elect it) the technical program often appears to be inordinately rigid and restrictive. While modifications may be necessary in certain individual institutions, the basic structure and content of this curriculum should be maintained.

In designing this program, it was recognized that the study of instrumentation cuts across several recognized fields of technology. An instrumentation technician must be prepared and competent in mechanics, electricity, electronics, physics, and chemistry. Often he must play the part of a middleman—acting as intermediary between the designer-engineer groups and production, fabrication, or operational personnel. Knowledge of applied theory and experience of technical skills must be coupled with the ability to communicate and appreciate the practical concepts of manufacturing, operation, or research and development programs. The rapid advancements in the various fields of science, and the resulting changes in instrumentation devices demand that he have sufficient knowledge of the underlying scientific and engineering principles to keep abreast of the evolving technology by independent study.

The specialized technical courses in instrumentation are laboratory-oriented. They provide application of the scientific principles concurrently being learned in the courses in physics and mathematics. *For this reason, mathematics and science courses must be coordinated carefully with technical courses at all stages of the program.* This coordination is accomplished by scheduling mathematics, science, and technical courses concurrently during the first two terms, a curriculum principle that will be illustrated at several points. General education courses constitute a relatively small part of the total curriculum. It has been found that students who enter a technical program do so because of the depth in the field of specialization that the program provides. In fact, many students who elect this type of education program will bring to it a background of general study.

Faculty

The effectiveness of the curriculum depends largely upon the competence and the enthusiasm of the teaching staff. The specialized nature of the curriculum requires that the teachers of instrumentation subjects have special competencies based on proficiency in technical subject matter and industrial experience. It is important also that all members of the faculty understand the educational philosophy, goals, and unique requirements that characterize this area of education.

To be most effective, members of the faculty responsible for this program must have interests and capabilities which transcend their area of specialization. All of the faculty members should be reasonably well oriented in the requirements for study in instrumentation and its applications so that they may use instrumentation examples or subject matter as supporting material as they teach their respective courses. For example, if the communications courses are to be of maximum value, the teacher should be familiar with the communications problems and demands placed on instrumentation personnel Without such a background, the communications course work may not offer the support that is needed in the total program of education for the technician. Similarly, various scientific principles may be taught in courses in physics, mathematics, and measurements with the respective course instructors emphasizing and illustrating how the principles are applied in instrument design and application.

Teachers of specialized technical subjects require advanced technical training. In the past, many of these teachers have been recruited from the ranks of the engineering profession. Recent experience has shown that engineering technology graduates who have acquired suitable industrial experience and who have continued their technical education often become excellent teachers in this type of program. Persons with this background are more likely to understand the objectives and unique instructional requirements of technical education. Furthermore, individuals with this particular background often bring to the program enthusiasm and an appreciation of the values of technical education characteristics that are essential to the success of any educational program.

Faculty members should be encouraged to participate in the activities of professional and technical societies. To be effective, they must keep up with the literature in their field, and maintain close liaison with industry in the area of their specialties. This encouragement may be provided in the form of released time and financial assistance to attend special institutes, such as those conducted by the National Science Foundation. Periodic sabbatical leave for industrial experience or further study should be encouraged.

When teaching loads for faculty members conducting specialized technical courses are determined, consideration should be given to the number of *contact* hours rather than to the normal assignments for shop teachers or to the number of course credit hours. These teachers need to devote a large amount of time in preparation for laboratory sessions, for the development of special instructional aids, for assisting students with individual projects, and for reviewing reports—in addition to the usual teaching responsibilities. An effective teaching load probably would be 15 to 20 contact hours per week. The use of a trained but nonteaching laboratory assistant to prepare apparatus setups and teaching materials, and to perform other routine tasks for the teachers may increase the total effectiveness of the teaching staff.

Class sizes, in general, should be limited to approximately 25, especially where laboratory programs are involved. This limitation will make it possible to have two laboratory sections of about 12 members each. Assigning any more than this number to the laboratory with only one instructor at one time will limit the learning situation. By using a qualified and competent assistant instructor, the number of students per laboratory session may be increased if laboratory facilities permit. Some of the best teaching oftentimes occurs in the laboratory when the instructor may have the opportunity to spend some time with each student during each laboratory period. Because good teaching involves the stimulation of the student, conditions should be created which will foster and promote the general development of the student's curiosity, objectivity, and specific skill competence, and ability to communicate, to solve new problems, and to draw valid conclusions from an observed series of facts and situations.

Student Selection and Services

While the effectiveness of a technical education program depends greatly upon the quality of the faculty, its ultimate success depends upon the quality of its graduates. It is essential, therefore, that the students accepted into the program have certain capabilities. If the incoming student's background is inadequate, instructors will tend to compromise the course work to allow for the inadequacies with the probable result that the program will be inadequate in depth and scope.

Students chosen for this program should have similar backgrounds and capabilities and should exhibit some evidence of maturity and seriousness of purpose; otherwise the program may not be able to achieve its objectives. Wide ranges of ability among students can create an inefficient teaching situation, thereby preventing progression of the program at the necessary rate. The amount of material to be presented and the principles to be mastered require students who not only are well prepared in formal course material, but those who have the ambition, desire, and will to master a difficult program and to develop their capabilities to the limit.

The curriculum is designed for high school graduates who have particular abilities and interests. In general, students entering the program should have completed 2 years of high school mathematics, including simultaneous linear equations, exponentials, and radicals; and 1 year of physics, or the equivalent. The ability levels of those who do, and those who do not meet these general requirements will vary greatly; some students may have to take refresher courses in mathematics, science, or English to make satisfactory progress in the program. Major deficiencies in mathematics or science should be remedied before the student begins formal classes.

Effective guidance and counseling are essential. The student should be aided in selecting educational and occupational objectives consistent with his interests and aptitudes. Whenever possible, institutions offering technical education programs should consider the use of standardized or special tests to assist in student selection, placement, and guidance. A student should be advised to revise his educational objectives if it becomes apparent that he is more suited to other programs.

either by reason of his lack of interest in the technical program, or his lack of ability to make satisfactory scholastic progress in the curriculum.

The graduate should be given all possible assistance in finding suitable employment. Placement personnel should be aware of the needs of industry and should acquaint prospective employers with the qualifications of graduates. The placement function is extremely valuable to the student, the institution, and industry. In the final analysis, the placement of graduates is an important responsibility of the department head or the instructor who teaches the technical specialty.

The school also has a continuing responsibility for the follow-up of employed graduates. The success of these graduates indicates the effectiveness of the program. In addition, the graduates can provide a helpful advisory service.

Textbooks, References, and Visual Aids

Textbooks, references, and visual aids for teaching any technology must constantly be reviewed and supplemented in light of (1) the rapid development of new knowledge in the field, and (2) the results of research in *methods* of teaching and developing basic concepts in the physical sciences and mathematics. The development of new areas of theoretical and applied scientific knowledge causes the production of new textbooks, new references, new material in scientific and technical journals, and new visual aid materials.

New textbooks will reflect new methods of teaching scientific principles and applications as fast as current educational research becomes applicable. Extensive research in methods of teaching science in recent years almost certainly will produce changes in teaching materials and methods. It is therefore mandatory that instructors constantly review new texts, references, and visual aid materials as they become available, and *adopt* them when they evidence an improvement over those here recommended or being used in present programs.

The suggested texts have been carefully selected. From the lists included, it should be possible to select suitable texts. It should not be interpreted, however, that unlisted books are not suitable; there are, no doubt, many excellent ones which have not been included.

Before a department head or instructor undertakes a program in instrumentation technology, or any course contained in the curriculum, it is urged that he familiarize himself with the texts and references listed here, and any new ones available. He then will be able to select the text which best serves his particular needs in providing a lucid, high-level technical presentation to his students.

Visual aids can be of great help in many teaching programs. The aids listed have been selected from an extensive list, and were considered suitable at the time the curriculum was prepared. Again, there are many which are not listed because the variety and extent of the materials make an all-inclusive study prohibitive. From those listed and others available and pertinent, an instructor may select those visual aids which meet his teaching objectives.

Scientific and technical societies are an important source of instructional materials. Such societies provide in their publications and in their regularly programed meetings, a continuing disclosure and discussion of new concepts, processes, techniques, and equipment in the science and related technologies. They are probably the greatest single means by which persons engaged in applying a particular body of science keep abreast of new developments. These societies present their data in such manner as to provide a bridge between the creative theoretical scientist and the applied science practitioners, including the technicians.

Teachers in technical programs should be encouraged to become active members in scientific and technical societies to help keep abreast of new developments in the technology and to foster acquaintance with the persons in the community who are most actively interested in the field. Some educational institutions pay part or all of the cost of membership in selected societies and part or all of the cost of attendance at local or national society meetings as a means of encouraging staff activity in such societies.

Students of instrumentation technology should be made aware of the literature and services of scientific, technical, and engineering societies early in their study program. Student affiliate memberships are offered by some of these societies, and students should be encouraged to become such members.

The Instrument Society of America, 530 William Penn Place, Pittsburgh Pa., is a technical society which specifically serves the needs of instrumentation and control scientists, engineers, and technicians. The society has in excess of 15,000 members, and more than 100 local sections. It publishes a monthly *Journal*. Examples of other societies which may be of special interest to instructors and students of instrumentation are:

- American Chemical Society (ACS)
- American Institute of Aeronautics and Astronautics (AIAA)
- American Institute of Physics (AIP)
- American Nuclear Society (ANS)
- American Society for Metals (ASM)
- American Society of Mechanical Engineers (ASME)
- Institute of Electrical and Electronic Engineers (IEEE)
- Institute of Radio Engineers (IRE)
- Precision Measurement Association (PMA)
- Society of Automotive Engineers (SAE)

A brief description of each of these societies is given in Appendix A.

Laboratory Equipment and Facilities

Laboratories and equipment for teaching instrumentation technology programs must meet high standards of quality since the objectives and the strength of the programs lie in providing valid laboratory experience, basic in nature, broad in variety, and intensive in practical experience. Well-equipped laboratories with sufficient facilities for all students to perform the laboratory work are required for these courses. The training program should include experiences which illustrate the function and application of a wide variety of instruments and their use in instrumentation systems.

Variety and quality of equipment and facilities are more important than quantity in equipping laboratories. Laboratory equipment and facilities are a major element of the cost of such a program; they are indispensable if the training objectives are to be met.

In the staff's selection of laboratory equipment, the need for each item should be well established. Expensive apparatus may not always be required. Many significant experiments can be built around relatively inexpensive components. In fact, they can, in many cases, make the principles more evident because they present only the essentials. The number of units purchased, the particular areas of interest, the particular industry emphasis, and the ingenuity of the instructor(s) in adapting equipment to teaching needs will play a major part in governing the laboratory equipment which is selected and its cost. Throughout the program, the emphasis should be on the basic underlying principles which serve as the bases for so many different instruments and control systems.

Library Content and Use

Dynamic developments causing rapid changes in technological science and practice make it imperative that the student of any technology learn to use and retain an association with the library. The school should provide a central library, staffed by professional librarians, and well stocked with current and pertinent books, scientific and technical journals, basic encyclopedic references, and visual aids.

In any evaluation of a technical education program the qualifications of the librarian; the physical library facilities; the quality, quantity, and relevancy of content; and the organization of the library give tangible indications of the strength of the program.

Instruction in technologies should be library-oriented. Students should learn the use of a library and form the habit of using it as a tool in the learning process. This helps to develop the professional attitude in the student, and further assists him to depend on libraries as a means of keeping abreast of the developments in a rapidly changing technology.

Instructors of all courses should keep the student constantly aware of the extent to which the use of a library is a part of his curriculum. Planned assignments of projects calling for the student to go to the library and prepare information on pertinent subjects in his courses enable him to understand the resources available in libraries and how they relate to his technology. Open book examinations requiring the use of the library provide excellent and objective experiences for the student. Under the incentive of the examination and the press of time, the understanding of his own competency in library skills becomes clear to each student.

The library should contain those books required as references, and every attempt should be made to insure extensive use of the library facilities. In addition to the standard references and texts, current and pertinent periodicals should be available to apprise the students of the rapid changes taking place in their technology. It is suggested that most of the texts and references and at least some of the visual aids listed in the bibliography and visual aid lists might well be considered the starting point of the instrumentation library content. Instructors should take the initiative in recommending new library content to keep it current, pertinent, and useful.

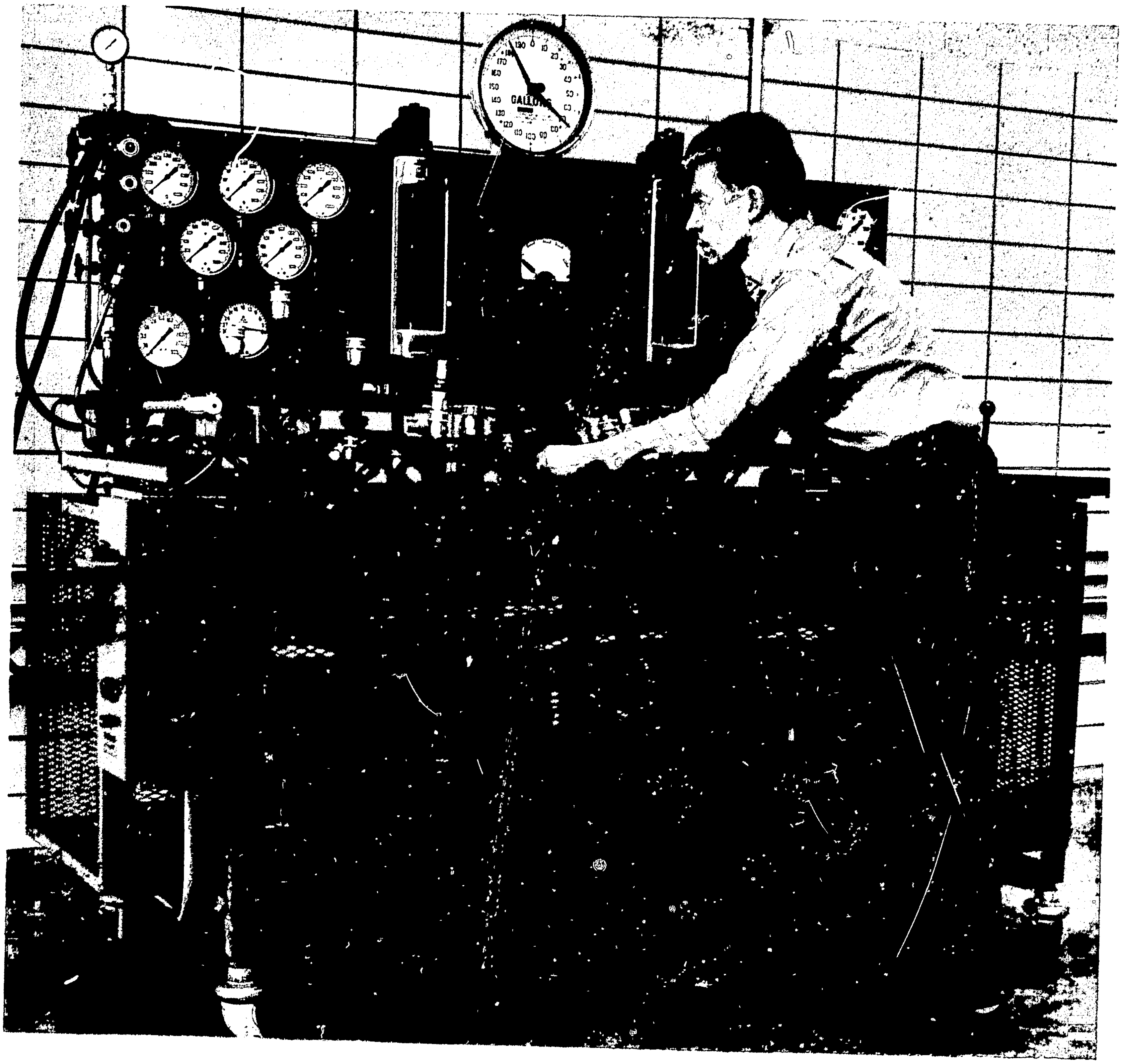


Figure 2

Testing instrument system components is a part of a technician's work. Here a student learns a method for testing hydraulic pressure control valves.

THE CURRICULUM

Curriculum outline	Class hours	Laboratory hours	Outside study	Total hours
First semester:				
Physics for Instrumentation I	3	4	6	13
Mathematics I	5	0	10	15
Measuring Principles I (Mechanical)	3	6	6	15
Communication Skills	3	0	6	9
Instrument Shop Practices	0	4	0	4
	14	14	28	56
Second semester:				
Physics for Instrumentation II	3	4	6	13
Mathematics II	4	0	8	12
Electrical Circuits—AC and DC	3	6	6	15
Technical Reporting	3	6	6	15
	13	16	26	55
Summer session (optional):				
Studies to meet special requirements of State or institution.				
Chemistry for instrumentation (optional).				
Third semester:				
Measuring Principles II (Electrical)	3	6	6	15
Electronics I	3	6	6	15
Control Principles and Telemetry	3	4	6	13
Calibration and Standardization	0	3	0	3
General and Industrial Economics	3	0	6	9
	12	19	24	55
Fourth semester:				
Control Systems Analysis	4	4	8	16
Electronics for Instrumentation	3	3	6	12
Computer Principles and Systems	3	2	6	11
Instrumentation Project	1	6	0	7
Industrial Organizations and Institutions	3	0	6	9
	14	15	26	55

Brief Description of Courses

First Semester

PHYSICS FOR INSTRUMENTATION I

A study of the basic principles of physics, emphasizing mechanics and heat, with particular emphasis on those principles embodied in the design of mechanical indicating and sensing devices.

MATHEMATICS I

A course in algebra, analytic geometry, and introductory trigonometry; with particular stress on slopes and rates of change and the determination of maxima and minima conditions as related to instrumentation.

MEASURING PRINCIPLES I (MECHANICAL)

A study of the more common sensing devices and components employed for the measurement of temperature, pressure, flow, and related phenomena. It is designed to coordinate with the material presented in PHYSICS FOR INSTRUMENTATION I.

COMMUNICATION SKILLS

A program designed to promote greater competence in reading, writing, talking, and listening.

INSTRUMENT SHOP PRACTICES

A laboratory course designed to provide practical information on the application of basic theories to commercial instruments; instrument construction, tests, and accepted test procedures; and safety precautions which must be observed when working on instruments. This course is presented concurrently with MEASURING PRINCIPLES I (MECHANICAL).

Second Semester

PHYSICS FOR INSTRUMENTATION II

A study of electrical principles, sound, light, magnetic theory, and elementary electronics. This course and ELECTRICAL CIRCUITS—AC and DC, taught concurrently, form the basis for MEASURING PRINCIPLES II (ELECTRICAL), taught in the third semester.

MATHEMATICS II

A course which completes the study of necessary principles of analytic geometry and concludes with introductory phases of calculus required for optimum performance in instrumentation and control.

ELECTRICAL CIRCUITS—AC and DC

A study of the basic laws pertaining to series and parallel circuits, reactance, impedance, and polyphase systems.

TECHNICAL REPORTING

A study of effective ways of presenting information. The student learns the utility of graphs, drawings, sketches, and outlines for various types of oral and written reports.

Summer Session (Optional)

STUDIES—to meet special requirements of State or institution.

CHEMISTRY FOR INSTRUMENTATION (Optional)

This course should present the basic and underlying principles of chemistry employed in industrial and commercial applications, with particular emphasis on the elementary principles required for instrumental analysis.

Third Semester

MEASURING PRINCIPLES II (ELECTRICAL)

A study of the basi types of transducers, employing electrical or electronic energy. Photoelectric, potentiometric and position-responsive devices are considered. Data logging and recording devices are also studied.

ELECTRONICS I

A study of the elementary electronic principles, components, and devices. This course is preparatory to the study of electronics for instrumentation.

CONTROL PRINCIPLES AND TELEMETRY

A course in which the process being controlled is considered as a major element in any control system. The effects of resistance, capacitance, and transportation lag or dead time upon a control system are examined. Pneumatic, hydraulic, and electrical controllers are studied and methods for transmitting signals and creating responses at a distance are considered.

CALIBRATION AND STANDARDIZATION

A laboratory course designed to illustrate the philosophy of measurement and control, emphasizing the meaning of validity, sensitivity of control devices, units of measurement, and levels of accuracy and traceability.

GENERAL AND INDUSTRIAL ECONOMICS

A study of general economics principles, and an analysis of the factors involved and importance of cost control in an industrial enterprise.

Fourth Semester

CONTROL SYSTEM ANALYSIS

A study of the response of systems to instrumental control based upon consideration of the system components. Negative and positive feedback along with the implications of closed loop control are covered.

ELECTRONICS FOR INSTRUMENTATION

A study of the application of basic electronic principles in devices such as transducers, recorders, analytical instruments, data storage and retrieval apparatus; and consideration of the various means for utilizing frequency as analog of some variable.

COMPUTER PRINCIPLES AND SYSTEMS

This course employs virtually all previous courses as it familiarizes the student with both analog and digital computers for measurement, comparison logging, and control. Numerical control is an integral part of the course.

INSTRUMENTATION PROJECT

A laboratory project to promote individual initiative and project responsibility. It involves a review of major concepts in previous courses since the student has maximum opportunity to develop, evaluate, and carry his project to successful conclusion.

INDUSTRIAL ORGANIZATIONS AND INSTITUTIONS

A study of roles played by labor and management in the development of American industry. An analysis is made of forces affecting labor supply, employment, and industrial relations under the democratic system of government.

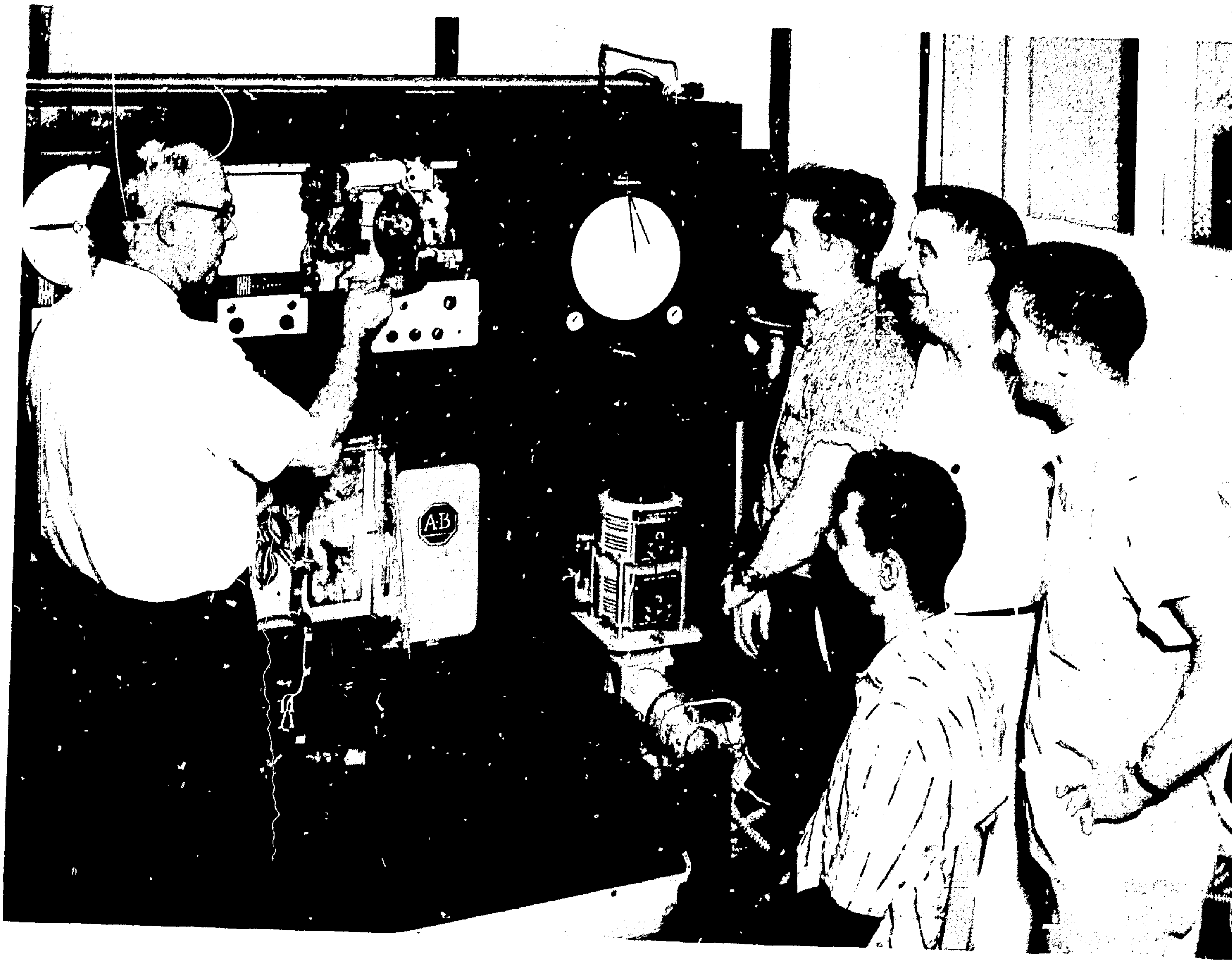


Figure 3

Instrument technicians are taught the mechanical details as well as the scientific principles applied in control instruments.

Curriculum Content and Relationships

Functional competence in a broad field such as instrumentation technology has at least three components around which the curriculum must be structured: (1) The training should prepare the graduate to take an entry job in which he will be productive; (2) the broad, technical training, together with a reasonable amount of experience, should enable the graduate to advance to positions of increasing responsibility; and (3) the foundation provided by the training should be broad enough so that the graduate can do further study within his field of technology. This curriculum has been designed to meet these three requirements.

A 2-year technology program has certain unique requirements that influence the content and organization of the curriculum. Some of these requirements are imposed by the occupational functions that graduates must be prepared to perform; some result from the need for special courses that will maximize the effectiveness of teachers who have special competencies; and others arise because of the need to teach both technical principles and related practical applications in the limited time available. This instrumentation technology curriculum reflects three basic requirements: Functional utility, units of instruction in specialized technical subjects, and provision for the teaching of principles by application.

The sequence of the courses in a 2-year technical curriculum is as important as the content of the courses. In general, the subject matter in the curriculum is carefully correlated in groups of concurrent courses. This is in sharp contrast to the arrangement of professional curriculum in which basic and somewhat unrelated courses make up the first part of the study program and specialization is deferred to subsequent terms.

In technical curriculums it is mandatory that specialized technical course work be introduced in the first term. Deferring this introduction even for one term imposes serious limitations on the effectiveness of the total curriculum. Several important advantages accrue from the early introduction of the technical specialty: (1) student interest is caught by practical aspects of instruction, and if the first term consists entirely of general subjects—mathematics, English, social studies—students often lose interest; (2) it is possible to obtain greater depth of understanding in specialized subjects in the latter stages of the 2-year program; and (3) there is practice in the application of mathematics in the technical courses. The student's study in mathematics is reinforced by his application of the disciplinary value obtained therefrom.

Principles of safety and precaution must be taught as an underlying requisite of all instrumentation work. The technician's work often involves potential dangers that precautionary procedures, combined with understanding of the materials, equipment, and safe working practice, can avoid. Safety must be a constant preoccupation, and its practice must be taught continually from the beginning of the course.

The course outlines in this guide are short and descriptive. The individual instructor will have to prepare complete courses of study and arrange the curriculum material in logical order of teaching before starting instruction. Suggested laboratory layouts and equipment, found in the Facilities, Equipment, and Cost Section, may help in organizing the program.

The subjects of specialization are introduced during the first semester in close correlation with the other subject matter. This procedure provides motivation and reinforces the teaching of physics and mathematics. It also supplies timely subjects for the discussion and report-writing phases of the communication skills courses.

Unlike many of the technologies which are concerned primarily with a single professional discipline, the instrumentation technology must employ several. To present and teach effectively so broad an array of essential material in so short a period of time requires that each element of the program supplement and strengthen other portions. By presenting many aspects of the same principle in diverse courses, the principle is emphasized and the learning process is strengthened.

During the first semester *Physics for Instrumentation I* provides the theory which will be needed for *Measuring Principles I (Mechanical)* and *Instrument Shop Practices*. The *Physics* course is primarily a study of mechanics and heat, and the *Measuring Principles* course is largely devoted to measurement and measuring instruments which sense and respond to variations and operate mechanically, rather than electrically. The course in *Instrument Shop Practices* is presented at this time to provide students with intensive laboratory experience in which they begin to learn instrument practices, devices, construction, operation, calibration, and adjustment. A total of 14 semester hours of laboratory work is included in the first semester. The course in *Mathematics I* strengthens the understanding of the course in *Physics* and both courses teach principles which are then reflected and emphasized by practical application in the *Measuring Principles* course and *Instrument Shop Practices*.

The second semester continues the same type of integrated teaching, with *Mathematics II* the more important part of the curriculum because of its relationship to other subjects being taught, particularly *Physics for Instrumentation II* and the study of the *Electrical Circuits*, both AC and DC. The 16 semester hours of laboratory work in *Physics for Instrumentation II*, *Electrical Circuits* and *Technical Reporting* further provide for practical application of principles learned previously. The study of electrical circuits inherently involves a study of circuitry and the voltage-current-resistance relationships, thereby providing a basis for advanced study of electrical and electronic instrumentation.

The third semester's study is based on the student's accumulated knowledge of physics, mechanics, electricity, and measuring principles introduced in the first two semesters. *Measuring Principles II* (Electrical) presents instrumental measurements using devices which operate electrically. *Electronics I* is studied concurrently, thus continuing the student's knowledge of electronic and electrical principles and devices. *Control Principles and Telemetry* extends the theory of the use of measurement devices in process or operation control during the third semester and *Calibration and Standardization* provides the student further knowledge of, and practice in the use of maintaining accurate equipment for both laboratory and field use. The third semester is laboratory-oriented with 19 semester hours. Because of the great variety of mechanical and electrical measuring devices which must be studied, this amount of laboratory experience is considered necessary to allow the student to gain the necessary comprehensive experience which he must have to be competent in his field.

The scope of the student's understanding of the application of instrument measuring and control devices is further enlarged in the fourth semester. The student extends his understanding of electronics as used in instrumentation (*Electronics for Instrumentation*), and studies the design of instrumentation systems to control complex production or operational systems automatically (*Control Systems Analysis*). The study of *Computer Principles* teaches the student the function and application of analog and/or digital computers as an engineering tool or as a key component in the controlled system.

Because so many modern instrumentation systems employ electronic techniques and principles the study of electronic applications in the general area of instrumentation and control are stressed. The instrumentation project gives the student a chance to work independently and with a minimum of direction. The results of the entire programed learning process may well be reflected in this one project.

Communication Skills emphasizes the mechanics of reading, writing, listening, and speaking. *Technical Reporting* is presented early in the curriculum to permit the exercise of reporting skills in subsequent course laboratory reports. The emphasis on sketching and freehand drawing is designed to teach technicians the drawing and graphic skills which constitute the second language of scientists and engineers.

Instructors should establish standards of clarity, conciseness, and neatness of reports in the beginning courses. In addition, instructors in technical courses should set increasingly high quality standards for student work in reporting. Not all reports, however, should be of a type which requires a disproportionately large number of hours for preparation. Freedom to report on technical subjects of their own choice may add reality and extra motivation for technology students. Instructors should encourage individual style and initiative by allowing as much freedom as possible in reporting, consistent with established school standards.

The courses in *General and Industrial Economics* and *Industrial Organizations and Institutions* are designed to broaden the student's understanding of the society in which he lives and will be employed. These courses include broad economic and industrial concepts; and place sufficient emphasis on corporate structure and economics to enable the student to comprehend the terminology and recognize the motives, methods, objectives, and administrative procedures of employers.

The course outlines shown are concise and comprehensive, intended as guides rather than as specific plans of instruction to be covered in an inflexible order or sequence. They represent a judgment on the relative importance of each instructional unit, especially where time estimates are shown for the divisions within each course. The principles outlined in these courses should be supplemented with industrial applications wherever possible. Industrial practices must be studied and followed in drafting and report writing, and materials from industry should be utilized throughout the program wherever it is possible to do so. Field trips will add greatly to the effectiveness of the instruction if they are carefully planned in advance and scheduled at a stage in the course where the applications of instrumentation observed will be understood in terms of the instruments used and the scientific principles being applied.

Outside study is a significant part of the student's total program. In this curriculum *2 hours of outside study time have been suggested for each hour of scheduled class time*. In the limited amount of class time available the student will not be able to master all of the material which is presented. Consequently, homework assignments are designed to provide the extra student effort which should insure his mastery. The assignment of study problems or other material should not be made haphazardly, but rather with a view to helping the student master the essential elements. A typical weekly work schedule for a student in the first semester of this curriculum would be: Class attendance, 14 hours; laboratory, 14 hours;

outside, 28 hours—a total of 56 hours per week. This is a full schedule, but not excessive for this type of program. The second term weekly schedule is 55 hours.

The average semester will probably last for 17 weeks, though the indicated hours have been based on actual class attendance for 16 weeks. The other week is available for examinations, holidays, and other normal interruptions of educational activities.

Advisory groups representing employers and employees should aid the faculty and individual teachers in deciding the emphasis on units to be presented, time spent on each, and suitable texts. The curriculum can do no more than lay down the broad guidelines which indicate the knowledge and degrees of competency required for successful entrance into the industrial and commercial world.

A summer session might be offered, during which courses required by the institutions but not provided for in this curriculum could be taken by the students of instrumentation technology. A summer session after the first 2 semesters would be a desirable time for the instrumentation technician to take a course in chemistry for instrumentation.

This publication is intended as a guide for program planning and development, primarily in post high school institutions. Adaptations can be made to suit various situations in several kinds of schools. The level of instruction indicated represents a consensus on the level of proficiency required for success in occupations in which manpower is in short supply today and threatens to be even more so in the future. The curriculum is a product of the efforts of a large number of people—educators, engineers, employers, and the staff of the Office of Education, Technical Education Branch—concerned with the improvement of public education services.

The program is not intended to make the individual proficient in all of the duties he might be asked to perform. Proficiency in work of a highly specialized nature will come only with practice and experience. It is impossible to forecast the exact requirements of any individual, and it is almost impossible to predict accurately the course or rate of change of various technologies. Employers generally recognize that recent engineering graduates may require a year or more to obtain the specific training needed and to orient themselves to their responsibilities and role in an organization. Similarly, employers of newly graduated instrumentation technicians must generally provide a 3- to 6-month period to orient the technician to the special situations, processes, and problems encountered on the job.

Furthermore, the productive graduate technician will continue to study throughout his career in order to develop to his fullest capabilities.

The material herein is not intended to be applied to a given situation exactly as outlined; it is presented to illustrate the form and content of a complete 2-year instrumentation technology program. In keeping with the form of previously published guides, it is planned as a full-time post-high-school preparatory program. These materials will be of use also in planning extension courses and preparatory technical programs in secondary schools.

Suggested Continuing Study

A 2-year curriculum must concentrate on the primary needs of science, mathematics, and the related knowledge and skills of the technology necessary to preparing the student for employment upon graduation. Obviously, such a program of study cannot cover in depth all of the subjects pertinent to the technology in 2 years; certain important related subjects may be only touched upon in that time.

Some form of continuation of study for graduates of technology programs is therefore desirable. By reading the current literature related to the technology, by scientific and technical society activity, and by study on his job, the student can keep abreast of the technical developments of his special field. However, such study tends to build on the organized technological base provided by the curriculum he followed. Formal continuation of supplementary courses provides the most efficient and practical means for the graduate technician to add important related areas of knowledge and skill to his initial education. These courses have the advantages of systematic organization of subject matter, disciplined and competent teaching, and class discussion. They may be scheduled for evening or Saturday hours outside of the graduate student's working day.

Some suggested continuation or extension courses for graduates of this instrumentation technology curriculum might include the following courses:

Chemistry for Instrumentation
Psychology and Human Relations
Numerical Control
Analytical Techniques in Systems Control
Guidance and Control Techniques—telemetry, missiles, rockets, etc.
Microminiaturization problems and techniques
Development of Supervisory Capabilities

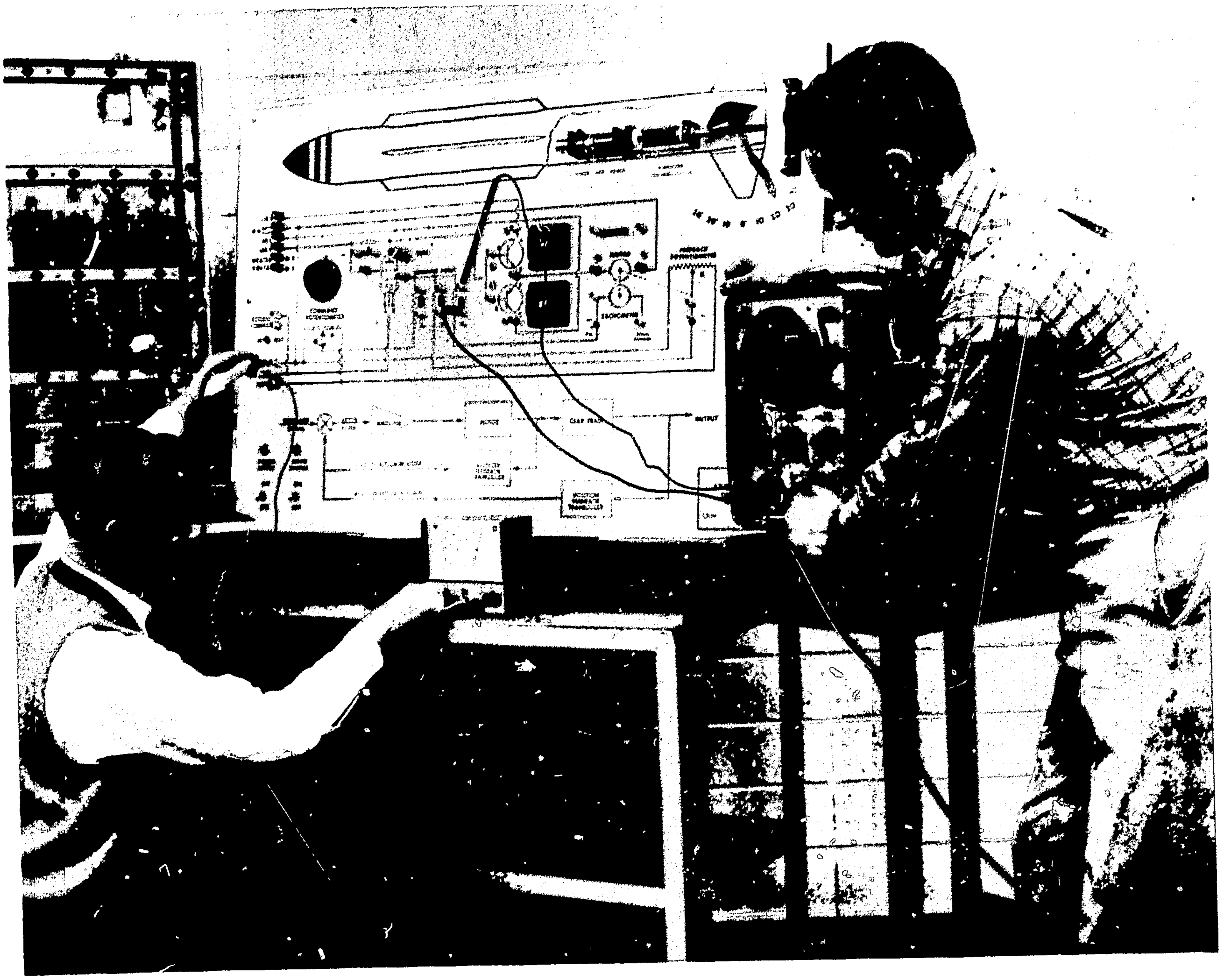


Figure 4

Knowledge of the use of electronic circuits and components comprise an important part of the education of these instrumentation technology students.

COURSE OUTLINES

Technical Courses

Measuring Principles I (Mechanical)

Hours Required

Class, 3; Laboratory, 6

Course Description

Measuring Principles I (Mechanical) is a study of the more common sensing elements and components which are *mechanical* (as opposed to electrical) instruments. The devices studied in this course are those employed for measurement of temperature, pressure, flow, and related phenomena. Most of them employ principles which are taught in *Physics for Instrumentation I*, and, therefore, these two courses should be carefully integrated to be mutually supporting. The physics courses should draw liberally upon illustrations and applications which have commercial significance in the area of measurement.

Study of the fundamental behavior of materials when subjected to stresses provides the basis for understanding instrumental devices which rely upon the measurement of changes in elastic materials—regardless of particular design or application. Emphasis should be placed on how *few* basic principles are employed—in the wide variety of instruments available—to provide the *many* responses and readings required for process or system control.

Attention should be focused on principles underlying instrument construction. The principles do not change, but details of design of instruments using a particular principle may change with the development of new materials or the adaptation of the instrument to new applications.

Major Divisions

		Hours Class	Hours Laboratory
I.	Review of Basic Principles	4	6
II.	Pressure Gages	9	18
III.	Liquid and Gas Flow Measurements	11	24
IV.	Liquid Level Measurements	6	12
V.	Temperature Measurements (non-electrical)	9	18
VI.	Humidity Measurements	3	6
VII.	Specific Gravity Measurements	3	6
VIII.	Viscosity Measurements	3	6

Division I. Review of Basic Principles

A. Units of instruction
1. Properties of elastic materials
2. Moment balance
3. Force balance
4. Time-constant responses of several types

B. Laboratory projects
1. Safe laboratory procedures and rules
2. Artificial respiration
3. Using electrical, thermal, and mechanical systems comprising resistor-capacitor combinations, determine the responses to step changes in input. Limit the experiment to single capacitor-resistor groupings. Present the response of both the resistor and the capacitor graphically. The similarity of their behavior should be considered and stressed.

Division II. Pressure Gages

A. Units of Instruction
1. Range of pressure measurements
2. Spans of various designs
3. Pressure-balance, manometers
4. Force-balance—bell-type elastic deformation—bellows, bourdon tube
5. Differential pressure
   (a) Manometers
   (b) Bellows
   (c) Bourdon tube
   (d) Bell-type
6. Pressure transmitters, pneumatic
   (a) Pneumatic baffle-nozzle relationships
   (b) Installation and application notes
7. Problems
8. Questions
9. Examination

B. Laboratory Projects
1. Compare and calibrate the following pressure gages against known standards; then, make a series of pressure measurements:
   (a) Manometer

(b) Bellows
(c) Bell gage
(d) Bourdon tube

2. Choose a gage capable of making a differential pressure measurement. Determine its range of measurement and maximum safe input pressure.
3. Choose two gages of the force-balance type which use the elastic deformation principle, and make a series of pressure readings.
4. Install a pneumatic pressure transmitter in a pneumatic circuit, and make a series of relative readings of input and output transmitter pressures. Prepare a table of input vs. output pressure readings for comparison.

Division III. Liquid and Gas-Flow Measurements

A. Units of instruction
1. Theory of flow measurements
2. Various methods of measuring flow
3. Direct flow measurements—positive displacement measurements
4. Inferential flow measurements
(a) Venturi
(b) Orifice plate
(c) Variable area
(d) Weirs
5. Flow calculations
(a) Bernoulli's equation
(b) Flow-constriction head meters
(c) Coefficients for various types of meters
(d) Reynolds number—meaning and application
(e) From nomographs
6. Problems
7. Questions
8. Examination

B. Laboratory projects
1. Using positive displacement meters, after suitable calibration, as the standard reference, determine the pressure differentials and the flow rates for the following:
(a) Venturi meters
(b) Orifice plate meters
(c) Variable area meters
(d) Weirs
2. From the data obtained, determine the coefficients for the various combinations tested and the value of the Reynolds number for each test.

Division IV. Liquid Level Measurements

A. Units of instruction
1. Direct methods and related theories; gage glasses, cable and float
2. Inferential types, and related theories
(a) Hydrostatic pressure, the diaphragm box
(b) Hydraulic pressure created by float position
(c) Weight of container plus fluid
(d) Pneumatic pressure, purge or bubbler systems
(e) Float and pointer, with no mechanical connections
(f) Buoyancy forces, force balance, pneumatic applications
3. Problems
4. Questions
5. Examination

B. Laboratory projects
1. Using the diaphragm box, plot pressure as a function of the depth of the box. Repeat the experiment, using different liquids if available.
2. In a tank with controlled depth, use a purge or bubbler system to measure liquid depth. Plot pressure vs. depth for liquids of different specific gravities. Consider any problems encountered in this determination.
3. Plot pressure vs. height of liquid for a series of liquids of different specific gravities. Determine feasibility of ascertaining depth (or height) of liquid in this manner.
4. Using available force-balance pressure devices, compare their performance with the diaphragm box, purge or bubbler systems.
5. Evaluate all devices in terms of their accuracy and ease of use.

Division V. Temperature Measurements (non-electrical)

A. Units of instruction
1. Temperature ranges
2. Temperature spans for all types of thermometric devices
3. Common divisions of thermometric measurements

4. Inferential temperature measurements based on;
   (a) Change in volume of a liquid
   (b) Change in pressure of a gas
   (c) Change in vapor pressure of a liquid
   (d) Change in dimension
   (e) Liquid-filled thermometers
   (f) Gas-filled thermometers
   (g) Vapor-pressure thermometers
   (h) Bimetal thermometers
   (i) Temperature transmitters, pneumatic
5. Application considerations
   (a) Time-constant response
   (b) Importance of location, dead-time, and speed of fluid
   (c) Use of thermometer well and other protection. Effects of phase shift
6. Questions
7. Problems
8. Examination

B. Laboratory projects
1. Using gas-filled and liquid-filled thermometers, measure the temperature of different fluids at various temperatures. Determine the relative accuracy of measurement for each type of thermometer.
2. By varying the temperature of the fluid(s), determine the thermometer time-constants.
3. Determine the factors affecting the time-constants of the thermometers.
4. Vary the locations of a thermometer in a fluid, then:
   (a) Agitate the fluid.
   (b) Still the fluid.
   (c) Vary the location of the thermometer in the liquid.
   (d) Add a protective well around the thermometer.
   Compare responses.

Division VI. Humidity Measurements

A. Units of instruction
1. Definitions of terms
2. Relative and absolute humidity
3. Sling psychrometer
4. Wet-dry bulb hygrometer
5. Change-in-length hygrometer
6. Principles of application
7. Questions
8. Problems
9. Examination

B. Laboratory projects
1. Using the dry- and wet-bulb hygrometer, determine the relative humidity of the classroom. Compare the results with that obtained using a resistance-type hygrometer. Outline the factors affecting the reliability of the results.
2. Using fibers of several types, construct a hygrometer which utilizes the principle of change-in-length method of measurement. Compare its performance with commercially available hygrometers using the same measurement principle.

Division VII. Specific Gravity Measurements

A. Units of instruction
1. Basic principles involved:
   (a) Definition of terms
   (b) Buoyancy and the use of floats
   (c) Hydrostatic pressure, for given height
   (d) Buoyant force
   (e) Boiling point
2. Specific gravity scales
3. Application notes and considerations
4. Questions
5. Problems
6. Examination

B. Laboratory projects
1. Measure the specific gravities of several fluids by using pneumatic specific gravity bubbler systems. Devise a scale of specific gravities based on pressure.
2. Compare the specific gravities of several fluids when using different scales. Determine a correlation factor (or factors) which permit conversion from one scale to the other.
3. Design a pneumatic or hydraulic transmitter the output of which will be proportional to the specific gravity.

Division VIII. Viscosity Measurements

A. Units of instruction
1. Basic principles involved and influencing factors
2. Systems commonly employed
3. Correlation between systems
4. Common means for measuring viscosity
5. Problems
6. Questions
7. Examination

B. Laboratory projects
   1. Using commercially available instruments, determine the viscosity of several common liquids at room temperature. Use more than one type of instrument and correlate results.
   2. Raise the temperature of the liquids by 30 or 40 degrees and repeat the above experiment.

Texts and References

BECKWITH and others. *Mechanical Measurements*
CARROLL. *Industrial Process Measuring Instruments*
CONSIDINE. *Process Instruments and Controls Handbook*
FRIBANCE. *Industrial Instrumentation Fundamentals*
INSTRUMENT SOCIETY OF AMERICA. *Basic Instrumentation Lecture Notes and Study Guide—Part I*
MANNING, MAXWELL *and* MOORE, INC. *Ashcroft Gauges, Catalog 300–B*

Visual Aids

Cinefonics, Cook Electric Co., 6401 W. Oakton St., Morton Grove, Ill.
New Look at Instruments, 28 min., 16 mm, color, sound

Daniel Orifice Fitting Co., *in cooperation with* AMERICAN GAS ASSOCIATION, *and* American Society of Mechanical Engineers, P.O. Box 19097, Houston 24, Tex.
Project NX–4, Large Meter Tube Tests, 20 min., 16 mm, sound

Instrument Society of America, Penn-Sheraton Hotel, 530 William Penn Place, Pittsburgh 19, Pa.
Measurement Fundamentals, 35 mm, black and white, complete set of five filmstrips

Midwestern Instruments, Inc., P.O. Box 7509, Tulsa 18, Okla.
Heart of Instrumentation, 25 min., 16 mm, color, sound

Minneapolis-Honeywell Regulator Co., Education Assistance Group, Station 213, Industrial Division, Wayne and Windrim Aves., Philadelphia 44, Pa.
Basic Automatic Control, Radiation Pyrometers, Pressure and Vacuum Gages, Pressure-Type Thermometers, Electrical Temperature Measurements. Flowmeters, Electronic Potentiometers, Filmstrip series, 30–45 min. each, 35 mm, black and white

Westinghouse Electric Corp., Motion Picture Dept., P.O. Box 868, Pittsburgh 30, Pa.
Semiconductor Training Course, 35 mm, color, sound

Measuring Principles II (Electrical)

Hours Required

Class, 3; Laboratory, 6

Description

A study of electrical instrumentation devices, transducers, and elements, and the principles underlying their design and use. It begins with a review of electric circuits and the responses of typical components; and progresses to a study of the principles and electrical instruments for measuring temperature, level, flow, viscosity, humidity, pH, and displacement. Photo-electric devices and speed and position-sensing transducers are considered. The generation and measurement of counting responses are presented to prepare the student to understand numerically-controlled machines and devices.

The course concludes with a consideration of some of the more complex measuring devices such as radiation instruments for the measurement of thickness, density, corrosion, and related effects; analytical instruments, employing infrared or ultraviolet energies; and electrical humidity measuring devices. Potentiometric measurements, instruments for indication and recording, and the form of data required for logging are also considered.

Major Divisions

	Hours: Class	Hours: Laboratory
I. Review of Fundamentals	3	6
II. Electrical Pressure Transducers	7	12
III. Electrical Flow Devices	6	12
IV. Electrical Level Transducers	3	6
V. Electrical Temperature Transducers	6	12
VI. Potentiometric Devices	5	12
VII. Indicating, Recording, and Registering Equipment	6	12
VIII. Analytical Instruments	6	12
IX. Radiation-type Transducers	3	6
X. Humidity-Measuring Devices	3	6

Division I. Review of Fundamentals

A. Units of instruction

1. Review of simple AC, DC circuits
2. Factors which affect resistance, capacitance, and potential

B. Laboratory projects

1. Maintain a piece of carbon at constant temperature, such as room temperature, and determine the effect of potential upon resistance. Use potentials from 1 to 500 volts. Use care and observe safe procedures. Ascertain any relationship between potential and voltage. The sample can be a commercial carbon resistor.
2. Repeat Experiment 1 above using a thermistor. Allow sufficient time and control to keep the specimen at constant temperature.
3. Heat a thermistor in a controlled oven and determine its resistance as a function of temperature. Then pass current through it when in still room air, and determine its temperature from its resistance. Obtain temperature as a function of power.

Division II. Electrical Pressure Transducers

A. Units of instruction

1. Spans covered by the various types of instrument
2. Heat-conduction pressure gages—the Pirani-type gage as an example
3. Ionization-type gages
4. Strain-type gages
5. Variable capacitance gages
6. Electro-mechanical transducers
   - (a) Potentiometric
   - (b) Moment-balance
7. Manometer transducers
8. Pressure-to-current converters
9. Electro-pneumatic converters
10. Differential pressure transmitters
11. Various electro-pressure transducers
12. The linear variable differential transformer (LVDT)
    - (a) Position balance
    - (b) Force balance
    - (c) Moment balance
13. Application notes
14. Questions

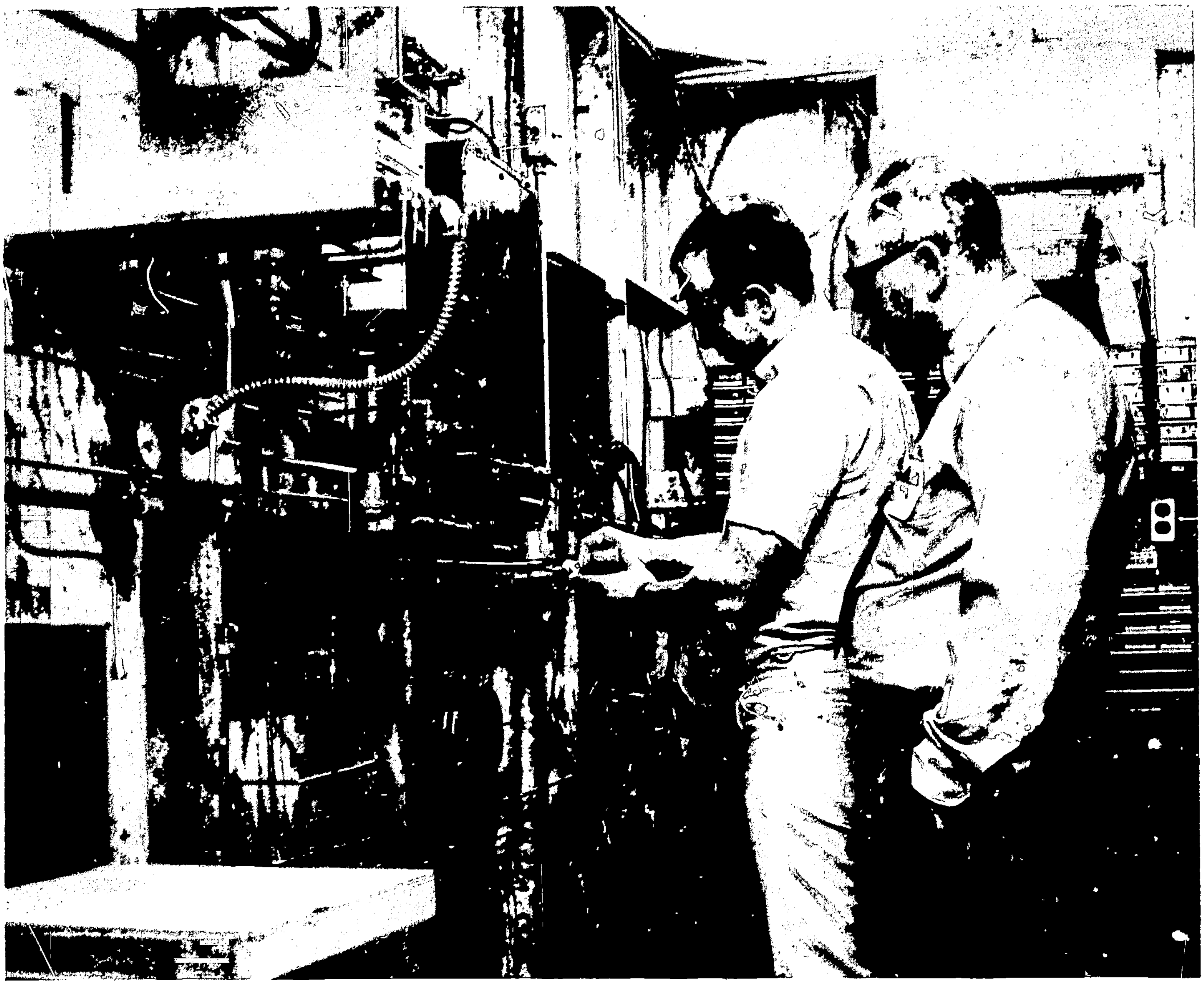


Figure 5

An instrumentation student working on the circuits, mechanisms, and parts which operate an instrument control panel, under the guidance of his instructor. The technician must know what is behind the control console and must be able to make it work properly.

15. Problems
16. Examination

B. Laboratory projects
1. Using a Pirani-type gage, plot output vs. pressure. Determine the linearity and repeatability of the gage within a short-time interval.
2. Apply a load to a small cantilevered beam. Using a strain gage, determine the deflection and compare the reading with a direct measurement. Measure the strain developed in a piece of pipe for some specific load using a strain gage. Compare measured and computed values.
3. Repeat experiment 2, using a linear variable differential transformer to provide a voltage proportional to deflection. Compare the results with the previous experiment.
4. Study various pressure-to-current and current-to-pneumatic devices available in the laboratory. Apply them in a system constructed in the laboratory.

Division III. Electrical Flow Devices

A. Units of instruction
1. Turbine-type flow meters of variable frequency—variable voltage
2. Magnetic flow meter principles
3. Differential pressure, with mechanical integration and square-root extraction.
4. Impact flow meters
5. Variable-area flow meters
6. "Heat" flow devices—principles
7. Devices for measuringthe flow of dry materials
8. Automatic weighing, transmission, and totalizing
9. Application notes
10. Questions
11. Problems
12. Examination

B. Laboratory projects
1. Calibrate a turbine-type flow meter.
2. Calibrate a magnetic-type flow meter and determine the effect of the resistivity of the fluid.
3. Measure the flow of a gas by determining the electrical input required to maintain a resistor at temperature.
4. Compare the various types of square-root extractors, and evaluate the relative accuracy of mechanical and electrical means.

Division IV. Electrical Level Transducers

A. Units of instruction
1. Probe-type elements
   (a) Thermal
   (b) Electronic
2. Ultra-sonic elements
3. Capacitance
4. Radiation
5. Strain gages
6. Floats
7. Buoyant force
8. Application notes
9. Questions
10. Problems
11. Examination

B. Laboratory projects
1. Construct a liquid-level detector using
   (a) A vacuum tube
   (b) A transistor
2. Compare and evaluate the designs of several commercial types of level indicators.

Division V. Electrical Temperature Transducers

A. Units of instruction
1. Span and ranges of the various types of electrical thermometers
2. Resistance-type transducers
   (a) Metallic
   (b) Nonmetallic
3. Various types of bridges used
4. Thermocouple measurements, installation, and use
5 Temperature-difference measurements
6. Radiation and optical pyrometry
   (a) Temperature by color-matching
   (b) Radiation as a measure of temperature
7. Indicating and recording instruments
   (a) Millivoltmeters
   (b) Electro-mechanical and electronic potentiometers
   (c) Automatic potentiometers
8. Temperature-measuring practices
   (a) Speed of response
   (b) Span
   (c) Location and type of sensing element
   (d) Dynamic errors
9. Application notes
10. Questions
11. Problems

12. Examination

B. Laboratory projects

1. Calibrate a resistance thermometer, determine the linearity of the resistance vs. temperature.
2. Determine resistance vs. temperature for both positive and negative thermistors.
3. Calibrate a thermocouple and determine its maximum percentage error.
4. Calibrate a student-made optical pyrometer against commercial device. Using a stabilized voltage source, determine its repeatability.

Division VI. Potentiometeric Devices

A. Units of instruction

1. Basic theory
2. Manual vs. automatic standardization
3. Standard cells, zener diodes, regulated power supplies
4. Mechanical and electronic converters for DC inputs
5. Mechanical and electronic balancing
6. Use of the linear differential transformer
7. Applications
8. Questions
9. Problems
10. Examination

B. Laboratory projects

1. Compare and contrast purely mechanical balancing techniques with those used by modern electrical device designs.
2. Use a differential linear transformer, with the core connected to a pointer, to balance the output of a thermocouple. Filter the output of the transformer to provide good quality DC.

Division VII. Indicating, Recording, and Registering Equipment

A. Units of instruction

1. Recorders, indicators, data storage and retrieval
2. Central recording and control vs. remote single stations
3. Monitoring, scanning, and supervision
4. Data logging
   (a) Electrical inputs
   (b) Non-electrical inputs
5. Analog-to-digital conversion
6. Digital-to-analog conversion
7. Applications
8. Questions
9. Problems
10. Examination

B. Laboratory projects

1. Select several pieces of commercial data logging equipment. Study each component to ascertain its operating principles. Sketch the chief mechanical components and provide a schematic diagram of the main circuit elements. Evaluate the general design.
2. Repeat experiment 1 with digital-to-analog and analog-to-digital conversion equipment.
3. Compare the accuracy of equipment, ease of reading, and general performance of several types of recording devices. Strip-chart units should be compared with circular chart instruments for accuracy and ease of reading over the whole scale, along with effects created by variables which vary with the square of the measured variable—such as flow phenomena.

Division VIII. Analytical Instruments

A. Units of instruction

1. General types and applications
2. Thermal conductivity gas analyzers
3. Oxygen analyzers
4. Mass spectrometers
5. pH meters
6. Optical analyzers
   (a) Infra-red
   (b) Ultra-violet
7. Gas chromatography
8. Refractometers
9. Gravimetric devices
10. Combustible-gas analyzers
11. Application notes
12. Questions
13. Problems
14. Examination

B. Laboratory projects

1. Calibrate a thermal conductivity type of gas analyzer.
2. Calibrate a pH meter using standard solutions.
3. Evaluate in terms of circuits, materials used, performance and accuracy two other analytical instruments which are available for study.

Division IX. Radiation-type Transducers

A. Units of instruction

1. Types of radiation and industrial applications.
2. Thickness gaging
3. Liquid-level gaging
4. Density measurements
5. Radioisotopes as tracers
6. Application notes
7. Questions
8. Problems
9. Examination

B. Laboratory projects

1. Using some suitable source of radiation and a detector, such as a Geiger-Mueller counter, determine the effect of both distance and materials which are interposed between detector and source. Try to determine the effect of *mass* as opposed to simple *thickness*.
2. Determine the density of a number of liquids and materials by determining the amount of absorption when placed between source and detector.

Division X. Humidity-Measuring Devices

A. Units of instruction

1. Dewpoint determination
2. Moisture-content of fabrics
3. Electrical conductivity techniques
4. Water vapor recorders
5. Installation and operational notes
6. Questions
7. Problems
8. Examination

B. Laboratory projects

1. Using a solid state device to produce the low temperatures, with manual control of the power inputs, determine the dew point for a variety of conditions. Ascertain the relative and the absolute humidity for each measurement.

Texts and References

One of the books on the following list may be selected for a text. Others may be used for reference.

BUCKSTEIN. *Industrial Electronic Measurement and Control*

CARROLL. *Industrial Process Measuring Instruments*

CONSIDINE. *Process Instruments and Controls Handbook*

DIKE, H. W. *The Use of Primary Elements in Measurement of Flow (TDS-10D101)*

DIKE, P. H. *Temperature Measurements with Rayotubes*

ELFERS. *Liquid Level Control*

FRIBANCE. *Industrial Instrumentation Fundamentals*

INSTRUMENT SOCIETY OF AMERICA. *Basic Instrumentation Lecture Notes and Study Guide—Part I*

———, *Recommended Practice—Specification Forms for Instruments, Gages, Thermocouples, Orifice Plates and Flanges, Control Valves, and Pressure Safety Valves*

KIRK and RIMBOI. *Instrumentation*

PRIMER. *Capacitance Type Electronic Liquid Level Controller*

SNELL. *Nuclear Instruments and Their Uses*

TAYLOR INSTRUMENT COMPANIES. *Determination of Orifice Throat Diameters*

TYSON. *Industrial Instrumentation*

Visual Aids

Adel Precision Products Corp., Engineering Service Dept., Burbank, Calif.

Fluid Flow in Hydraulic Systems, 10 min., 16 mm, color, sound

Cinefonics Cook Electric Co., 6401 W. Oakton St., Morton Grove, Ill.

New Look at Instruments, 28 min., 16 mm, color, sound

Daniel Orifice Fitting Co., P.O. Box 19097, Houston, Tex.

Project NX-4, Large Meter Tube Tests, 20 mins., 16 mm, color, sound

o Corp., 161 E. California Blvd., Pasadena, Calif.

bration and Its Measurement, 20 mins., 16 mm, color, sound

McGraw-Hill Book Co., Text-Films Dept., 330 W. 42nd St., New York, N.Y.

Principles of Chromatography, 20 mins., 16 mm, color, sound

Modern Talking Pictures Service, Inc., 3 E. 54th St., New York, N.Y.

Infrared Spectroscopy, 35 mins., 16 mm, color, sound

U.S. Army, Signal Officer, Military District of Washington, Washington, D.C.

Introduction to Radiation Detection Instruments, 17 mins., 16 mm, black and white, sound

Rocket Instrumentation, 15 mins., 16 mm, black and white, sound

U.S. Atomic Energy Commission, Public Information Service, Washington, D.C.

Gauging Thickness with Radioisotopes, 4½ mins., 16 mm, black and white, sound

Industrial Applications of Radioisotopes, 57 mins., 16 mm, color, sound

Practical Procedures of Measurement, 48 mins., 16 mm, color, sound

Primer on Monitoring, 30 mins., 16 mm, color, sound

U.S. Steel Corp., Film Distribution Center, 525 William Penn Place, Pittsburgh, Pa.

New Neighbor, 23 mins., 16 mm, black and white, sound

Paths of Steel, 26 mins., 16 mm, color, sound

University of Illinois, Urbana, Ill.

Techniques of Gravimetric Analysis, 30 mins., 16 mm, black and white, sound

Varian Associates, Instrument Division, 611 Hansen Way, Palo Alto, Calif. Attention: Lee Langan

The Varian M-49 Proton Free Precession Magnetometer, 16 mins., 16 mm, color, sound

Instrument Shop Practices

Hours Required

Class, 0; Laboratory, 4

Course Description

This is a laboratory study of mechanical instruments. Because instrument shop practice is such an important part of any instrumentation program, the student should at the earliest possible moment begin to learn some of the technical details involved in meter construction, tests, performance, recording, testing procedures, and safe working practices. Because this subject begins before the student has had much time for learning about the instruments themselves, enough theory should be presented with the practice so that he will obtain some understanding of the instruments and the significance of the tests and measurements which he will see or make. Every attempt should be made to coordinate this program with that of *Measuring Principles I (Mechanical)* which is given concurrently.

Major Divisions

		Laboratory hours
I.	Safety Rules and Precautions	2
II.	Organization and Function of an Instrument Shop	4
III.	General Classification of Commercial Instruments	6
IV.	Records Required	6
V.	Test Fixtures	8
VI.	Routine Check of Performance	8
VII.	Disassembly, Cleaning, and Assembly of Common Mechanical and Pneumatic Instruments	20
VIII.	Performance Tests	10

Division I. Safety Rules and Precautions

Laboratory projects

1. Instruction in safe ways of handling instruments, lifting heavy objects, and on the importance of good housekeeping.
2. Precautions to be followed in disassembling instruments, releasing tension in springs, and other potentially hazardous operations.
3. Precautions to be followed in the use of compressed air, cleaning fluids, noxious gases, and solvents.
4. The safe use of electrical equipment, such as drills, power saws, and similar units. The use of grounded 3-wire cables for portable equipment.

Division II. Organization and Functions of an Instrument Shop

Laboratory projects

1. Test section, routine and special
2. Repair section
3. Standards section
4. Design, modification, and construction section
5. Storage, inventory, and records section

Division III. General Classification of Commercial Instruments

Laboratory projects

1. Have the student study several commercial catalogs of instruments and prepare lists o instruments and meters which well might be classified together. This classification should be made in terms of uses rather than construction. The multiplicity of types and applications should be stressed.

Division IV. Records Required

Laboratory projects

1. Using copies of record cards used by local industries, have the students catalog the various shop instruments, bring their histories up to date, obtain performance charts or records, determine the reasons for the intervals after which routine tests are made.

Division V. Test Fixtures

Laboratory projects

1. Study each of the test fixtures in the shop. Sketch each one. Include significant piping or other connections. Indicate pressure, temperature, or other ranges. Describe its operation and uses.
2. Instruction in safe and correct uses of tools normally used in shop.

Division VI. Routine Check of Performance

Laboratory projects

1. Using the various test fixtures, run a complete test on each of the main classes of instruments. Keep a record of the deviations from the standard. Pay particular attention to the speed of response of the various types of instruments and the conditions of the test which might alter the response—for example, a thermometer partly surrounded by still liquid will not have the same response as one in agitated liquid.

Division VII. Disassembly, Cleaning, and Assembly of Common Mechanical and Pneumatic Instruments

Laboratory Projects

1. Disassemble, clean, and assemble:
   - (a) Pressure gages—bellows, bell, bourdon tube types
   - (b) Pressure recorders
   - (c) Differential pressure gages
   - (d) Temperature gages—gas, liquid-filled, vapor-filled
   - (e) Compensated temperature gages.
2. Temperature Recorders
   - (a) Circular chart recorders and rectangular recorders
3. Pneumatic pressure and temperature transmitters

Division VIII. Performance Tests

Laboratory projects

1. Study the various pressure standards—mercury and other manometers, deadweight tester, and any others available.
2. Sketch and note the various baths and methods required for temperature calibration for non-electrical instruments. Note the importance of immersion and agitation of the fluid.
3. Study the use of weight-tanks, weirs, and other devices to measure liquid flow when calibrating or standardizing.

Texts and References

AMERICAN STANDARDS ASSOCIATION, INC. *Catalog of American Standards*

GENERAL MOTORS CORP. *ABC's of Hand Tools*

MCGRAW-HILL BOOK CO., INC. *Henry Ford Trade School—Shop Theory*

NATIONAL SAFETY COUNCIL. *Accident Prevention Manual for Industrial Operation*

——— *National Safety Council Catalog 1962–63*

PHILCO CORP., TECH-REP DIVISION. *Shop Practices*

Visual Aids

Imperial-Eastman Corp., 6300 W. Howard St., Chicago 48, Ill.

Don't Build Hazards Into Your Tubing Systems. 20 min., 16 mm, color, sound

The Pennsylvania State University, University Park, Pa.

Reaming with a Taper Hand Reamer. 15 min., 16 mm, sound

A Safe Shop. 10 min., 16 mm

Safety in the Shop. 12 min., 16 mm

Use and Care of Hand Files. 15 min., 16 mm, sound

Uses and Abuses of Twist Drills. 26 min., 16 mm, sound

Save Those Tools. 10 min., 16 mm, sound

Control Principles and Telemetry

Hours Required

Class, 3; Laboratory, 4

Course Description

This course studies of the general factors involved in any control problem, stressing the prime importance of the process itself.

The transfer of energy and the capacitances and resistances involved are studied, particularly as they affect the time constant of the system or component. When the time constant is known, then the frequency response can be ascertained. The behavior of the open loop is used to predict the closed loop performance. The response of the closed loop is of uppermost importance and considers the calculated response and the factors which determine the stability, as well as the means by which the system can be tuned or the controller adjusted for the best response.

Typical hydraulic and pneumatic controllers and controller modes are studied in detail, followed by an introduction to hydraulic and pneumatic logic systems which can be used for computation, selection, control, and sequencing. The response characteristics of valves, dampers, and other final elements conclude the unit.

Major Divisions

	Hours: Class	Hours: Laboratory
I. What Constitutes a Process	3	0
II. Process Characteristics—Static Conditions	8	12
III. Process Characteristics—Kinetic Conditions	8	12
VI. Responses of Components and Systems	6	8
V. Energy Characteristics of the Process	4	6
VI. The Block Diagram	5	0
VII. Feedback Control Systems—Open and Closed Loop	8	12
VIII. Pneumatic and Hydraulic Controllers and Final Operators	6	14

Division I. What Constitutes a Process

- A. Units of instruction
  1. Introduction
  2. Historical development
  3. Review of types of controller action
  4. Types of responses which must be controlled
  5. Problems
  6. Questions
  7. Examination
- B. Laboratory projects

Division II. Process Characteristics—Static Conditions

- A. Units of instruction
  1. The basic problem
  2. Principles of energy transfer
  3. Resistor elements—thermal, fluid
  4. Capacitor elements—thermal, gas, liquid
  5. Problems
  6. Questions
  7. Examination
- B. Laboratory projects
  1. Determine the thermal resistance for an object in air and in a liquid, with and without agitation.
  2. Determine the capacitances of several containers for liquids and for gases, and of materials for thermal conditions.

Division III. Process Characteristics—Kinetic Conditions (Rotary and Lineal)

- A. Units of instruction
  1. General
  2. The mass of an object
  3. Lineal acceleration and motion
  4. Rotary acceleration and motion
  5. Rotary mass and polar moment of inertia
  6. Combining several systems
  7. Problems
  8. Questions
  9. Examination
- B. Laboratory projects
  1. Determine the mass of an object by determining its response to a constant force—linear conditions
  2. Determine the polar moment of inertia of an object by measuring its response to a constant torque.
  3. Using the object of Experiment II, keep the mass constant, but reposition some

of the components and determine the polar moment of inertia for several configurations.

Division IV. Responses of Components and Systems (Step and Frequency Changes)

A. Units of instruction
   1. Time-constant determination for a resistor-capacitor combination
   2. Response to step changes—static and kinetic systems
   3. Time-constants and analogs of linear systems
   4. Response to a step change—exponential lags
   5. Determining the time constant from the step response
   6. Disadvantages of the step-response technique
   7. Determination of the time constants in combination with dead time
   8. Determination of the frequency response from the time constant—components
   9. Determination of the frequency response from the time individual responses—systems or groups
   10. Questions
   11. Problems
   12. Examination

B. Laboratory projects
   1. Plot the response of a thermometer to a step change in temperature. By graphical means determine the time-constant of the thermometer. Alter the resistance to heat transfer by agitation of the fluid or placing a virtually weightless film around bulb to impede the transfer of heat.
   2. In as nearly a sinusoidal manner as possible, modulate the flow of heat to a container of fluid (such as water). Measure and record the temperature of the fluid. Gradually increase the rate of cycling of the thermal energy, recording the temperature. From the decreased temperature rise, determine the frequency response and the time constant of the combination.
   3. Determine the angular shift as a function of the speed of the fluid, when there is an appreciable dead time.

Division V. Energy Characteristics of the Process

A. Units of instruction
   1. General
   2. Kinetic energy—linear motion
   3. Thermal energy storage
   4. Electrical energy storage
   5. Responses of several systems
   6. Energy stored in springs, fluids, tanks
   7. Magnetic energy, electrostatic energy
   8. Questions
   9. Problems
   10. Examination

B. Laboratory projects
   1. Using a fairly stiff spring with several inches of normal change in length, determine the spring constant and the energy stored. Assuming that weights, caused by gravitational pull, are used to stretch the spring, plot the energy stored in the spring as a function of the distance the spring is stretched. Repeat for different types of springs.
   2. Using a grinding wheel or some other object whose polar moment of inertia can be determined quite readily, plot stored energy as a function of speed. If an automobile flywheel is available, determine its stored energy for a speed of 3600 rpm.
   3. Using a freely falling body determine the speed to kinetic energy relationship—assuming no frictional losses. Prove by analogy that this relationship will hold for other types of linear motion.

Division VI. The Block Diagram

A. Units of Instruction
   1. Difference between schematic and block diagrams
   2. Flow of information around the loop
   3. Different types of blocks, gain of the block
   4. System representation, introduction of other signals
   5. Feedback loops, positive and negative
   6. Adding and eliminating blocks from a diagram
   7. Block diagram algebra
   8. Problems
   9. Questions
   10. Examinations

Division VII. Feedback Control Systems—Open and Closed Loop

A. Units of Instruction
1. The block diagram for open loop systems
2. Gain
3. Decibels
4. Resistance and proportional blocks
5. Capacitance and the block diagram
6. Steady-state solution to flow-level problems
7. Block diagrams for the closed loop
8. Calculation of the closed loop response
9. The Nyquist plot; the Bode plot
10. Error-detection systems
11. Servo-mechanisms, basic requirements
12. Servo-mechanism systems
13. Questions
14. Problems
15. Examination

B. Laboratory Projects
1. For a series of valves and tanks, determine the valve resitances as well as the various capacitances. Predict the final level in each tank when they are connected in series. Check your answer by assembling such a system.
2. Using thermal components, in effect repeat the first experiment, only this time predict final temperatures.
3. Using a governor-controlled gas engine to drive a pump, construct the complete block diagram. Determine, if possible, the gain of each element in both the forward and the feedback loops. Modify some of the forward-loop components to prove that the feedback components are the most vital elements. Prepare a complete report of the results.

Division VIII. Pneumatic and Hydraulic Controllers and Final Operators

A. Units of Instruction
1. Hydraulic pumps and motors
2. Hydraulic valves
3. Continuous hydraulic process control
4. Hydraulic and pneumatic proportional controllers
5. Hydraulic and pneumatic controllers with proportional and reset action
6. Hydraulic and pneumatic controllers with rate, proportional and reset action, timing the controller to the process
7. Hydraulic-pneumatic logic systems
8. Hydraulic-pneumatic computers
9. Analog to digital conversion, and vice versa
10. Questions
11. Problems
12. Examination

B. Laboratory Projects
1. Determine the response to load changes of a pneumatic controller with the various modes of control. Create instability with with high gain proportional action, then tune the controller to the process. (The load may be a bath which is to be heated. If possible, the amount of material to be heated or the thermal resistance, for example, should be variable to show to what degree the process itself governs the response.)
2. Using pneumatic or hydraulic valves, pistons, and actuators, establish the basic elements of computing and logic systems.
3. Design analog-to-digital pressure units for hydraulic and pneumatic installations. If the required apparatus is available, prove the design. What modifications were required to make it work as desired? The design should involve a complete report of design possibilities.

Texts and References

BUCKSTEIN. *Industrial Electronic Measurement and Control*

CONSIDINE. *Process Instruments and Controls Handbook*

DELAHOOKE. *Industrial Control Instruments*

——— and ZOSS. *Theory and Applications of Industrial Process Control*

GREER. *The Measurement and Automatic Control of pH*

HOLZBOCK. *Instruments for Measurement and Control*

——— *Automatic Control: Principles and Practice*

JOHNSON. *Servomechanisms*

KIRK *and* RIMBOI. *Instrumentation*

LAJOY. *Industrial Automatic Controls*

THE BRISTOL COMPANY. *Pneumatic Controller Actions and Their Application to Automatic Control of Industrial Processes, Parts I and II*

RUITER *and* MURPHY. *Basic Industrial Electronic Controls*

STOLL. *Theory of Automatic Control in Simple Language*

REINHOLD PUBLISHING COMPANY. *Temperature—Its Measurement and Control in Science and Industry, Part 2, Vol. 3—Applied Methods and Instruments*

YOUNG. *Process Control*

Visual Aids

Buehler, Ltd., 2120 Greenwood St., Evanston, Ill.
Automation in the Metallurgical Laboratory. 30 mins., 16 mm, color, sound

Encyclopaedia Britannica Films, 1150 Wilmette Ave., Wilmette, Ill.
Atom and Industry. 11 mins., 16 mm, black and white, sound

Fisher Governor Company, Marshalltown, Iowa
Muscles of Control. 25 mins., 16 mm, color, sound
Napoleon's Gun Barrels. 28 mins., 16 mm, color, sound

Leeds and Northrup Co., 4901 Stenton Ave., Philadelphia 44, Pa., Attention:
A. R. Floreen, Sales Promotion and Exhibits Section
Nuclear Power Controls. 30 mins., 16 mm, black and white, sound

Instrument Society of America, Penn-Sheraton Hotel, 530 William Penn Place, Pittsburgh 19, Pa.
Automatic Process Control. 33 mins., 16 mm, color, sound
Principles of Frequency Response. 37 mins., 16 mm, color, sound

Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, Calif.
Deep Space Instrumentation Facility. 19 mins., 16 mm, color, sound

Midwestern Instruments, Inc., P.O. Box 7509, Tulsa 18, Okla.
Heart of Instrumentation. 25 mins., 16 mm, color, sound

Modern Talking Pictures Service, Inc., 3 E. 54th St., New York 22, N.Y.
Paper in the Making. 24 mins., 16 mm, color, sound

U.S. Army, Signal Officer, Military District of Washington, Washington, D.C.
Rocket Instrumentation. 15 mins., 16 mm, black and white, sound

U.S. Steel Corp., Film Distribution Center, 525 William Penn Place, Pittsburgh 30, Pa.
The Making, Shaping, and Treating of Steel: The Blast Furnace. 7½ mins.
The Open Hearth Furnace. 7 mins., 16 mm, color, sound
The Electric Arc Furnace. 7 mins., 16 mm, color, sound
Semi-Finished Steel. 8 mins., 16 mm, color, sound
Hot Rolling of Steel Sheets. 7 mins., 16 mm, color, sound
Chemistry of Iron and Steel. 14 mins., 16 mm, color, sound

Western Electric Company, Inc., Motion Picture Bureau, 195 Broadway, New York 7, N.Y.
Engineering Notebook. 16 mm, color, sound

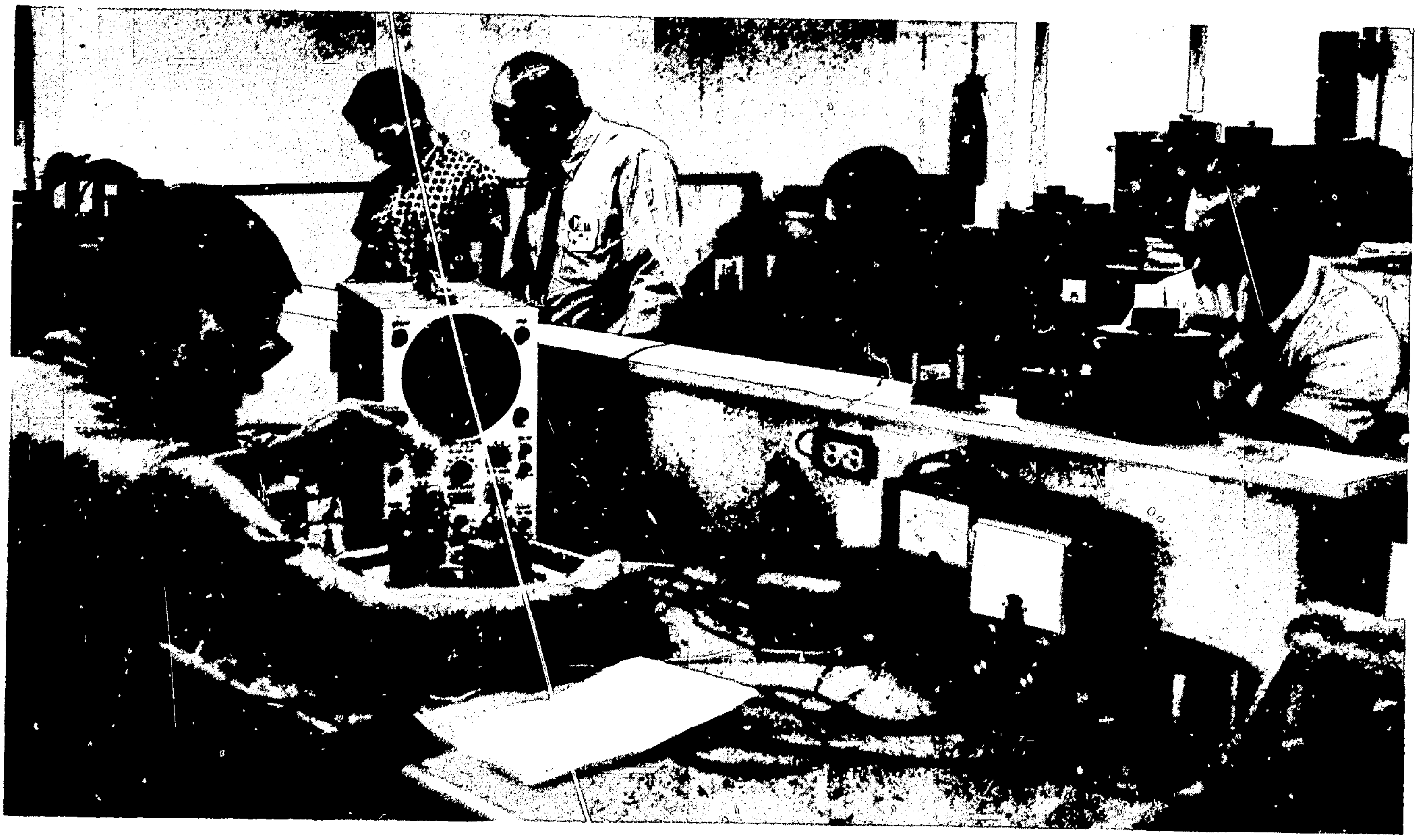


Figure 6

These student technicians are testing electronic materials and components. As they plan the tests, assemble the apparatus, and make the tests, they get practice in practical instrumentation as well as a better understanding of applied scientific principles.

Electronics for Instrumentation

Hours Required

Class, 3; Laboratory, 3

Description

The object of this course is to provide the student with an understanding of the use of electronics in instrumental devices and systems control. Because equipment, apparatus, and instrumentation techniques employed today for measurement and control rely in an increasing degree upon electronic devices and techniques, it is imperative that the technician understand the various ways in which electronic devices and principles may be employed. Due to limitations of time, the emphasis in this course must be restricted to those principles which are most vital to the field of instrumentation and control.

The many facets and extremely rapid changes in the field of electronics make it imperative that the material studied illustrate and explain principles which are not dated, but which are basic and universal.

Major Divisions

	Hours: Class	Hours: Laboratory
I. Auxiliary Electrical Devices and Means for Recording and Storing Data	10	10
II. Electrical Control of Temperature, Energy, Speed, and Motion	12	12
III. Electrical Logic Systems	6	6
IV. Electrical Position-Finding Systems	9	9
V. Numerical Control of Machines	11	11

Division I. Auxiliary Electrical Devices and Means for Recording and Storing Data

A. Units of instruction

1. Timers, time-constant networks
   (a) Resistance-capacitance and resistance-inductance combinations, thyratron timers, miscellaneous timers
2. Power supplies
   (a) Full-wave and half-wave sources of power, the effect of filtering
3. Relays, contactors, solenoids, and other electromagnetic actuators
4. The generation of both AC and DC, variable frequency generation, oscillators
5. AC and DC motors, speed control
6. Polyphase AC motors, wound-rotor motors
7. Combinations of AC and DC motors with electrical feedback between motors
8. The Ward-Leonard system of speed control
9. The amplidyne method of speed and position control
10. Electrical instruments—voltmeters, ammeters, oscilloscopes, recorders, [illegible]meters, watthour meters
11. Electrical transducers—pressure, temperature, thickness, position, light intensity, color, speed, position.
12. Synchronous transmitters and receivers.
13. Use of foregoing electric-electronic devices in data storage and retrieval systems and units.
14. Questions
15. Problems
16. Examination

B. Laboratory projects

1. Design and build a transistor oscillator, also a saw-tooth oscillator using any accepted design. Trace the output waves as shown on an oscilloscope.
2. Operate a relay the current of which is controlled by a transistor or tube, which in turn is governed by an RC timing network.
3. Select a number of electrical transducers and run a calibration test on them. Determine deviations from linearity.
4. Design a control circuit in which the output of a thermocouple governs the amount of heat delivered to a load.

Division II. Electrical Control of Temperature, Energy, Speed, and Motion

A. Units of instruction

1. Temperature control, the heat transfer problem. Different methods of modulating the energy input. Effect of location of the transducer. Evaluation of

different types of transducers and their limitations.

2. Electrical generator control systems—for voltage and frequency.
3. Motor speed control, DC. Field and armature voltage control techniques, compensation for current drop in armature. Constant torque systems. Starting problems.
4. Motor speed control, AC. Variable frequency, variable energy inputs, control of wound-rotor motors and associated systems.
5. Magnetic, hydraulic, and electromechanical drives.
6. The effect of energy storage and absorption on performance.
7. Frequency responses for resistor-mass combinations.
8. The responses of several systems which are coupled.
9. Questions
10. Problems
11. Examination

B. Laboratory projects

1. Control the speed of a DC motor under load by means of a variable resistor in the armature circuit. Compare the performance with that obtained when the speed is governed by armature voltage. For given values of resistance and voltage, vary the load.
2. Use a polyphase induction motor and govern its energy input by means of a saturable reactor. Plot speed vs. load.
3. Use a magnetic coupling to provide variable speed (use a polyphase AC motor as the prime source of energy). Compare the performance under variable load with that of the other types previously studied.

Division III. Electrical Logic Systems

A. Units of instruction

1. Resistor-diode arrays
2. Relay AND, OR, NOR circuits
3. Magnetic AND, OR, NOR circuits
4. Transistor AND, OR, NOR circuits
5. Optical logic systems—photovoltaic and photoresistive

B. Laboratory projects

1. Use single pole, double throw, switches to establish AND, OR, and NOR circuits
2. Replace the switches with relays to provide the same types of operation.
3. Replace the relays with magnetic elements
4. Employ transistor components to create the 3 basic circuit groups.
5. Replace the switches or relays with photoelectric components which will result in the same functioning

Division IV. Electrical Position-Finding Systems.

A. Units of instruction

1. Electro-mechanical position-finding systems
2. Voltage analog of position (X, Y, and Z axes)
3. Position by discrete counts
4. Synchros—fine and coarse
5. Resolvers
6. Point-to-point systems
7. Continuous-path generation
8. Error determination systems
9. Effects of friction, mass, backlash, system gain
10. Questions
11. Problems
12. Examination

B. Laboratory projects

1. Draw a block diagram of a numerically controlled machine. Show all feedback loops. Sketch details of the design of the positioning system.
2. Assume that some commercial machine, using a numerically controlled system, is to be redesigned so as to act in half the time of the original design. Moreover, its deviation is to be reduced to one-quarter of the original tolerance. Prepare a report on the ways in which improved performance can be obtained and the probable increase in the cost.

Division V. Numerical Control of Machines

A. Units of instruction

1. Analog to digital conversion for machine tools
2. Functions which must be performed
3. Selection of functions
4. Input devices
   (a) Punched card
   (b) Punched tape
   (c) Magnetic tape

5. Point-to-point programing
   (a) Types of operations
   (b) Input instructions required
6. Point-to-point plus straight-line generation
   (a) Types of operations
   (b) Input and auxiliary devices required
7. Continuous-path generation
   (a) Computer generation of instructions
   (b) Other types of instruction generation
8. Unusual characteristics or features of—
   (a) Electrical systems
   (b) Hydraulic systems
   (c) Pneumatic systems
   (d) Combination systems
9. Problems
10. Questions
11. Examination

B. Laboratory projects
1. Visit a machine shop (either school laboratory or industrial plant) which has numerically controlled tools. Select one machine which is fairly representative of point-to-point operation. Describe the position-finding system, the feedback techniques used, the means of selecting the desired tool or tools. Determine the various types of transducers required and the basic circuits required to produce the desired end results. Prepare a detailed report on its operation.
2. Study a machine tool, numerically controlled, which can provide continuous path generation which is not necessarily linear. Prepare a report which describes the operation of the computer, or other device, which generated the command instructions. Be specific as to the means of feedback to insure that the tool is at the proper point and that the correct path is being generated.

Texts and References

LURCH. *Fundamentals of Electronics*
MANDL. *Industrial Control Electronics*
PRENSKY. *Electronic Instrumentation*
RUITER *and* MURPHY. *Basic Industrial Electronic Controls*
STUDER. *Electronic Circuits and Instrumentation Systems*

Calibration and Standardization

Hours Required

Class, 0; Laboratory, 3

Description

Calibration and standardization of instruments may constitute one of the most important duties of the instrumentation technician. Consequently, he should be well acquainted with the various types of standards and their applicability to the problem at hand. This course consists entirely of laboratory work in order that he may become acquainted with the various procedures through actual experience.

Major Divisions

		Laboratory hours
I.	Calibration of Laboratory Standards	6
II.	Calibration of Plant Standards	6
III.	Calibration and Adjustment of Pneumatic and Mechanical Instruments	11
	(a) Pressure	
	(b) Temperature	
	(c) Flow	
	(d) Pressure transmitters	
IV.	Calibration and Adjustment of Electrical Instruments	25
	(a) Pressure	
	(b) Temperature	
	(c) Level	
	(d) Flow	
	(e) Voltmeters; ammeters	
	(f) Potentiometers	
	(g) Portable instruments	

Division I. Calibration of Laboratory Standards

Laboratory projects

1. Discussion—Philosophy of measurement, repeatability, accuracy, span, range, units, levels of accuracy, traceability, and validity.
2. Calibrate laboratory standards against standards certified by the U.S. Bureau of Standards.

Division II. Calibration of Plant Standards

Laboratory projects

1. Calibrate both mechanical and electrical plant standards against the laboratory standards. These may be for any of the common variables, such as temperature, pressure, or flow.

Division III. Calibration and Adjustment of Pneumatic and Mechanical Instruments.

Laboratory projects

1. Calibrate both a bourdon and a bellows type of pressure gage.
2. Calibrate and adjust two different types of temperature gages or transmitters.
3. Calibrate a flow meter by actual weighing of the fluid.
4. Calibrate different types of pressure transmitters.

Division IV. Calibration and Adjustment of Electrical Instruments

Laboratory projects

1. Calibrate both high and low pressure gages—one of each type.
2. Calibrate one each of the following—radiation, resistance, and emf temperature units.
3. Calibrate an electrical flow meter—may be magnetic, frequency, or potential.
4. Check the calibration on millivoltmeters, voltmeters, and ammeters.
5. Check the calibration of one of the laboratory potentiometers.
6. Check the performance of available portable instruments—both recording and indicating.

Texts and References

CARROLL. *Industrial Instrument Servicing Handbook*

HEWLETT-PACKARD. *Microwave Theory and Measurement*

Visual Aids

National Bureau of Standards, Office of Technical Information, Washington, D.C.

A True Standard. 12 mins., 16 mm, color, sound

Testing Mass Standards by Substitution 22 mins., 16 mm, color, sound

Control Systems Analysis

Hours Required

Class, 4; Laboratory, 4

Description

A study of the principles involved in designing and applying instrumental control to processes or systems of related processes.

The successful design of any control system requires that the designer know as much as possible about the process itself and its peculiarities. In addition, he must know the capabilities and frequency responses of the various components. To all of this information he must add the probable responses of the controllers which are available to him. The more complex the system, the more difficult the control problems. Consequently, the selection of components and the design of entire systems are complex considerations. As important as the controller action may be, the process itself usually is the critical and determining factor in the design of an instrument system for its control.

In this unit an attempt is made to present the significant characteristics of important control elements or combinations of control elements. When basic objectives of instrumental control are operative, resulting in linear responses and no loading of one component by another, system performance can be predetermined to some reasonable degree. This course is designed to provide an understanding of feedback and closed loop control systems. Complex system analyses can be made by considering the frequency responses of components and combinations as they relate to the requirements for system stability.

Major Divisions

	Hours Class	Hours Laboratory
I. Control of DC Electrical Energy to Resistive Loads	4	4
II. Transistor Amplifiers	4	4
III. Silicon Controlled Rectifiers	4	4
IV. Magnetic Amplifiers and Saturable Core Reactors	8	8
V. Electrical Generators, Amplidynes	4	4
VI. Thyratron Control	4	4
VII. Ignitron Control	4	4

Major Divisions—Continued

	Hours Class	Hours Laboratory
VIII. Relay, Magnetic, and Other Logic and Control Systems	4	4
IX. Solid State Devices—Diodes, Transistors in Logic and Control Circuits	4	4
X. Frequency Responses of Components	4	4
XI. Feedback Control	7	7
XII. Controllers and Their Responses	13	13

Division I. Control of DC Electrical Energy to Resistive Loads

A. Units of instruction
   1. Control of resistance
   2. Control of potential
   3. Control of current
   4. Time modulation
   5. Special characteristics
   6. Problems
   7. Questions
   8. Examination

B. Laboratory projects
   1. Using a water heater with electrical heating element, maintain the water at some constant temperature by using the four methods of governing the energy liberated or transferred to the load. The written report should evaluate the ease of control along with the relative efficiencies of the methods

Division II. Transistor Amplifiers

A. Units of instruction
   1. Review of transistor operation
   2. Comparison of the various types of resistors and their current and voltage ratings
   3. The various types of transistor amplifiers commonly used for control purposes
   4. Characteristics of transistor amplifiers
   5. Questions
   6. Problems
   7. Examination

B. Laboratory projects
   1. Using several different types of transistors, construct simple amplifiers. De-

termine their voltage and current performances as well as the wave form of their outputs. The rise time is of particular importance

Division III. Silicon Controlled Rectifiers

A. Units of instruction
1. Theory of operation of rectifier
2. Various types of controlled rectifiers
3. Uses with AC and DC
4. Typical circuits for time and magnitude modulation
5. Inverters
6. Special applications
7. Current limitations, voltage problems, and related considerations
8. Questions
9. Problems
10. Examination

B. Laboratory projects
1. Using a silicon controlled rectifier as a simple switch, maintain temperature of a water heater. Maintain same temperature but use rectifier to provide time modulation
2. Use silicon controlled rectifier to convert from direct current to alternating current of 60 cycles. Compare the waveform of the inverter with that of commercial frequencies. Discuss the problems created if the waveform is not similar to a good sine wave

Division IV. Magnetic Amplifiers and Saturable Core Reactors

A. Units of instruction
1. Theories of operation
2. Typical performance characteristics
3. Magnitude of units and times of response
4. Comparison with other types of electrical modulating devices
5. Limitation or problems in connection with their use
6. Questions
7. Problems
8. Examination

B. Laboratory projects
1. Determine the complete characteristics of a small magnetic amplifier. Using a variable frequency source, determine the effect of frequency upon performance. Write a report describing the frequency responses as well as the input-output performance.
2. Using a small (under 1 KVA) saturable reactor, maintain temperature of the same water heater, and or the same type of conditions as in Division III. Compare magnitudes of control signals required, rate of response, efficiency, waveform of output, distortion.

Division V. Electrical Generators, Amplidynes

A. Units of instruction
1. Review of DC generator function
2. Various methods of controlling output voltage—speed, field, compounding
3. Theory of amplidyne perform› ıce
4. Typical amplidyne performaı and responses
5. Comparison of amplidynes with other methods of electrical power control
6. Questions
7. Problems
8. Examination

B. Laboratory projects
1. Using a simp · (shunt wound) direct current generator, determine the effect of both field and speed control on the generator output (2 tests). Determine the amplification involved—field power vs. output power for a fixed load such as a resistance bank. Determine the speed of response of the generator to a step change in the field current—that is, a step change in the field resistance or applied voltage.
2. If an amplidyne unit is available, its input-output characteristics should be completely determined.

Division VI. Thyratron Control

A. Units of instruction
1. Review of theory of thyratron operation
2. Sizes, ratings, operational characteristics of thyratrons
3. Control applications of the thyratron—generator control, motor speed control, welders, and related applications
4. Comparison and contrast with devices previously considered
5. Questions
6. Problems
7. Examination

B. Laboratory projects
  1. Use a thyratron to control the field to a direct current generator; use a diode across the field to provide virtually pure DC for the winding, even though the input is pulsating. Compare the current from the tube with the current in the field winding. Determine the linearity of the output voltage with respect to the input signal to the thyratron. Energize the generator field well up into the saturated region. Comment upon the sensitivity at this point and its effect upon control behavior.

Division VII. Ignitron Control

A. Units of instruction
  1. Review of theory of ignitron operation
  2. Sizes, ratings, operational characteristics
  3. Control applications—motor, generator, welder, and related uses.
  4. Compare and contrast with the thyratron, the silicon controlled rectifier, the saturable reactor.
  5. Questions
  6. Problems
  7. Examination

B. Laboratory projects
  1. Using a transformer of 1 KVA (approximately, and 1:1 turns ratio), in series with some heating load (i.e., resistor), control the power to the load by governing the time of firing of the ignitron. Determine the range of control and the efficiency of the unit. Control the ignitron by conventional phase-shift or potential modulating means.

Division VIII. Relay, Magnetic, and Other Logic and Control Systems

A. Units of instruction
  1. Fundamentals of logic systems
  2. Common examples of such systems
  3. The use of switches for selection
  4. The use of relays for selection
  5. Control of performance by magnetic means
  6. The transistor in logic systems
  7. The basic building blocks—AND, OR, NOR, NAND
  8. Questions
  9. Problems
  10. Examination

B. Laboratory projects
  1. Create a logic array of switches or relays which require at least four AND responses to get an output.
  2. Repeat but employ two AND and two OR combinations.
  3. Repeat but employ two AND and two NOR combinations.
  4. Employ all four types in a circuit which requires an output.

Division IX. Solid State Devices—Diodes, Transistors in Logic, and Control Circuits

A. Units of instruction
  1. The diode in logic arrays
  2. The transistor in logic arrays
  3. The use of photocells in logic systems
  4. All other solid state devices which are used commercially for logic systems
  5. Comparison and contrast of the various components and their characteristics
  6. Problems
  7. Questions
  8. Examination

B. Laboratory projects
  1. Using neon lamps and photo-resistive cells, create a logic array which requires at least four AND inputs to get an output.
  2. Repeat, but employ two AND and two OR combinations.
  3. Using transistors, repeat steps 1 and 2.

Division X. Frequency Responses of Components

A. Units of instruction
  1. Determination of the time constant from the values of R and C
  2. Frequency responses of a single linear lag from its time constant
  3. System frequency responses based on the individual frequency responses
  4. Various methods for presenting phase shifts and attenuation with frequency
  5. Questions
  6. Problems
  7. Examination

B. Laboratory projects
  1. Determine the resistance and capacitance values for two containers filled with liquid. Determine the time constants for a variety of conditions. Verify your answers by applying cyclic (sinusoidal, if possible) variations of temperature by means of the external liquid fluid. In-

crease the frequency until the change in temperature has dropped to 30 percent of its maximum change (for the same cyclic changes in the bath temperature). Do the experimental and calculated 70 percent attenuation points agree? If not, what might influence the results?

2. Repeat 1, but have 2 resistor-capacitor combinations in series

Division XI. Feedback Control

A. Units of instruction
1. Open loop response
2. Closed loop operation
3. The block diagram
4. Positive feedback, effect upon control
5. Negative feedback, effect upon control
6. Effect of closing the loop, stability
7. Requirements for stable operation
8. Factors which create unstable operation
9. Ways of improving stability
10. Tests for stability
11. Questions
12. Problems
13. Examination

B. Laboratory projects
1. Using a single pole, double throw switch, or relay, connect a thermostat so as to get both positive and negative feedback. Plot the responses for each mode of operation. Compare with open loop operation for similar conditions
2. Determine the frequency response of a simple device, such as a tea kettle, with a fixed heat input. Use a thermostat placed in the fluid in the kettle to control the heat input. Record fluid temperature vs. time. Place a piece of material having significant thermal capacitance between the source of heat and the kettle. Compare the control action with the second thermal capacitance in position. Plot the results and explain the type of performance obtained

Division XII. Controllers and Their Responses

A. Units of instruction
1. On-Off controllers
2. Proportional controllers—theory of operation, time, magnitude, pulse modulation, effect of changes in load, characteristic responses
3. Proportional, plus reset controllers; theory of operation, requirements for reset action, characteristic responses to load changes, frequency response
4. Proportional, plus rate controllers; theory of operation, requirements for rate action, characteristic responses, frequency response
5. Proportional, plus reset, plus rate modes of response theory of operation, characteristic and frequency responses
6. Sensitivity and effect upon instability
7. Factors which may be modified to improve stability
8. Consideration of the process and its effect upon performance

B. Laboratory projects
1. Using a recorder for identical load conditions, determine the responses for each mode of control. The load should consist of two resistor-capacitor combinations (a tea kettle placed on a block of steel which in turn is heated by a gas flame or an electric element). Increase the gain of the controller to the point where instability occurs, then tune the system to provide the best response. Modify the weight and material on which the kettle rests. If the source of heat is gas, note the effect of transportation time, or dead time, by moving the valve as far as possible from the point of use.
2. Determine the conditions which most seriously affect the behavior of the controllers used in number 1. Compare the relative advantages of each of the modes of control.

Texts and References

THE BRISTOL COMPANY. *Pneumatic Controllers and Their Application to Automatic Control of Industrial Processes, Parts I and II*
BUCKSTEIN. *Basic Servomechanisms*
———. *Industrial Electronic Measurement and Control*
CLARK. *Introduction to Automatic Control Systems*
CONSIDINE. *Process Instruments and Controls Handbook*
DELAHOOKE. *Industrial Control Instruments*
——— and ZOSS. *Theory and Applications of Industrial Process Control*
GREER. *The Measurement and Automatic Control of pH*
HOLZBOCK. *Automatic Control: Principles and Practice*
———. *Instruments for Measurement and Control*
KIRK and RIMBOI. *Instrumentation*

LAJOY. *Industrial Automatic Controls*
REINHOLD PUBLISHING CO. *Temperature—Its Measurement and Control in Science and Industry, Part 2, Volume 3—Applied Methods and Instruments*
RUITER and MURPHY. *Basic Industrial Electronic Controls*
STOLL. *Theory of Automatic Control in Simple Language*
TUCKER and WILLS. *A Simplified Technique for Control Systems*
YOUNG. *Process and Control*

Visual Aids

Buehler, Ltd., 2120 Greenwood St., Evanston, Ill.
Automation in the Metallurgical Laboratory. 30 mins., 16 mm, color, sound

Ferranti, Ltd., Ferry Road, Edinburgh 5, Scotland.
Numerical Control. 20 mins., 16 mm, black and white, sound

Instrument Society of America, Penn-Sheraton Hotel, 530 William Penn Place, Pittsburgh 19, Pa.
Automatic Process Control. 33 mins., 16 mm, color, sound

International Business Machines Corp., Department of Information, 590 Madison Avenue, New York 22, N.Y.
Introduction to Feedback. 11½ mins., 16 mm, color, sound

Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, Calif.
Deep Space Instrumentation Facility. 19 mins., 16 mm, color, sound

Midwestern Instruments, Inc., P.O. Box 7509, Tulsa, Okla.
Heart of Instrumentation. 25 mins., 16 mm, color, sound

Minneapolis-Honeywell Regulator Co., Education Assistance Group, Station 213, Industrial Division, Wayne and Windrim Aves., Philadelphia, Pa.
Film Strip Series—*Basic Automatic Control, Radiation Pyrometers, Pressure and Vacuum Gages, Pressure-Type Thermometers, Electrical Temperature Measurements, Flowmeters, Electronic Potentiometers.* 30–45 mins., 35 mm, black and white

Modern Talking Picture Service, Inc., 3 E. 54th St., New York, N.Y.
Paper in the Making. 24 mins., 16 mm, color, sound

U.S. Army, Signal Officer, Military District of Washington, Washington, D.C.
Rocket Instrumentation. 15 mins., 16 mm, black and white, sound

U.S. Steel Corp., Film Distribution Center, 525 William Penn Place, Pittsburgh 19, Pa.
Chemistry of Iron and Steel. 14 mins., 16 mm, color, sound
Hot Rolling of Steel Sheets. 7 mins., 16 mm, color, sound
Semi-Finished Steel. 8 mins., 16 mm, color, sound
The Electric Arc Furnace. 7 mins., 16 mm, color, sound
The Making, Shaping, and Treating of Steel: The Blast Furnace, 7½ mins., 16 mm, color, sound
The Open Hearth Furnace. 7 mins., 16 mm, color, sound

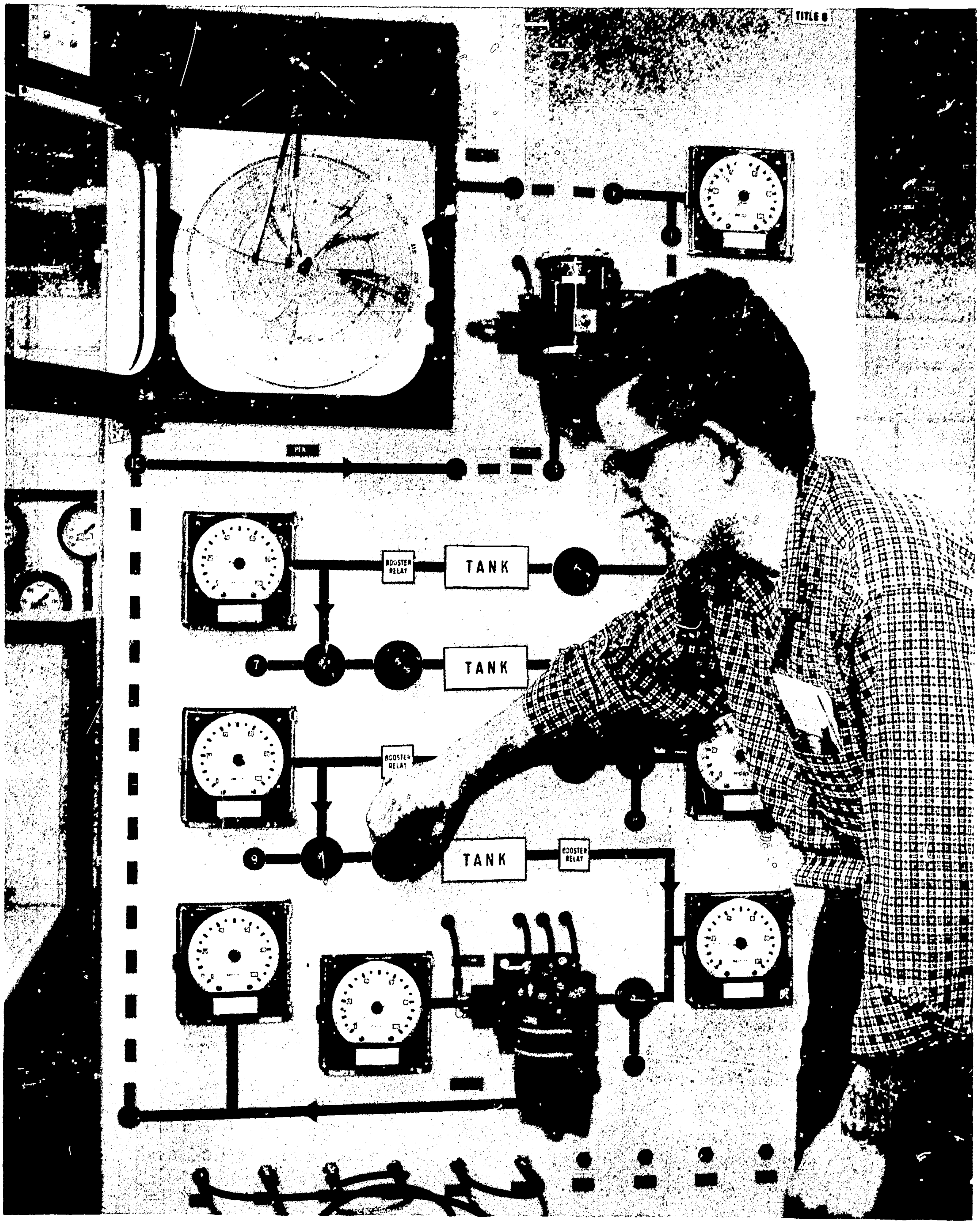


Figure 7

A student technician setting up a process control problem on a pneumatic analog computer—one of the devices employed in instrument systems used for the automation of modern processes.

Computer Principles and Systems

Hours Required

Class, 3; Laboratory, 2

Description

This course is designed to teach the student the principles and theories underlying the design and function of computers and computer systems. In many ways, this course represents a synthesis of almost all the previous programs of study. In order to teach the theories of computer operation, it is necessary to employ physics, AC and DC principles, mathematics through an introduction to calculus, logic, and many other areas of knowledge which have been presented in previous courses. Consideration of the various types of computers, computing systems, and their applications is based upon an understanding of the preceding subjects studied.

Because of the rapid development of the art at this time, and the ever widening applications and implications of computing systems for instrumentation, it is important that the student understand computer principles. As the study proceeds from the historically simple computer to the complex installations which are becoming parts of control systems, it is necessary to consider the various types of computers and their abilities as well as their limitations. It is also necessary to become familiar with much auxiliary equipment, such as input-output devices, analog-to-digital and digital-to-analog units, data storage components, and the myriad types of switching and conversion apparatus which have become part of some modern systems.

The advent of computer control of processes along with the use of numerical control for positioning and machine-tool operations, entirely aside from applications in the field of computation and data handling, imposes an ever greater demand upon the abilities of the instrumentation technician. The emphasis of the course is on process and position control.

Major Divisions

	Hours	
	Class	Laboratory
I. Historical Development of Computing Systems	2	0
II. Fundamentals of Analog Computers	7	4
III. Applications of Analog Computers	7	4
IV. Basic Principles of Digital Computers, Computer Elements	17	12
V. Input-Output Devices and Data Conversion, Registers	3	2
VI. Theory of Programing Computers	7	7
VII. Applications in Process and Numerical Control	5	3

Division I. Historical Development of Computing Systems

A. Units of instruction

1. Computing devices and apparatus since 1500 AD
2. Methods of computing—digital, analog, hybrid
3. Reasons for use of three computing methods

Division II. Fundamentals of Analog Computers: Mechanical, Hydraulic, Pneumatic, and Electrical

A. Units of Instruction

1. Basic parts of any analog computer
2. Operations which can be performed: summing, integration, differentiation, and theory
3. Mechanical computers—theory and components
4. Hydraulic computers—theory and components
5. Pneumatic computers—theory and components
6. Electrical computers—theory and components (operational amplifiers)
7. Comparison of the various analog computing elements
8. Questions
9. Problems
10. Examination

B. Laboratory projects
  1. Using a potential for one analog and current for the other, show how watt-meters and watthour meters function as analog computers. In the alternating current meter, show that the cosine of the phase angle is also included in the product.
  2. Design and construct a lever-type of mechanical computer which can add and subtract several quantities. Use pneumatic means to obtain a balance and provide an analog pressure for the read-out.
  3. Design an electrical analog device for adding and substracting various values. Provide both current and potential outputs which may be multiplied by a constant, both more and less than one.

Division III. Applications of Analog Computers
A. Units of instruction
  1. Mechanical—slide rule, speedometer
  2. Mathematical—finding areas, products
  3. Electrical—potential, current, watt-meter, watthour meters
  4. Simulation of aircraft, machines
  5. Fire-control problems
  6. Flight control—automatic pilot
  7. Limitations on use—size, personnel
  8. Questions
  9. Problems
  10. Examination

B. Laboratory projects
  1. Use slide rule as one type of analog computer—distance is the analog of value.
  2. Use the ordinary speedometer as another example of an analog computer—determine the number of analog relationships. (Is the odometer portion of the device an analog or digital unit?)
  3. Visit a large computer installation—study type of projects, accuracy of computer, analysis of answers, and type of readout.

Division IV. Basic Principles of Digital Computers, Computer Elements
A. Units of instruction
  1. Computer operations—applications and uses in the control field, special purpose and general purpose computers
  2. Principles underlying computer programing
  3. Number systems—decimal and binary in addition, multiplication, and division—other number systems
  4. Basic logic circuits—transistor gate logic, multi-vibrators, triggers, timing oscillators, ferromagnetic devices
  5. Computer units—counters, coders, storage and shift registers, arithmetic units, memory devices
  6. Input-output devices
  7. Questions
  8. Problems
  9. Examination

B. Laboratory projects
  1. Examine and identify the chief components of a commercial computer. Construct a flow chart showing the main interconnections and the direction of information flow. From the manual, determine the input-output devices, the construction of the memory and the arithmetic units.
  2. Program a simple problem and verify the results.
  3. Construct a mathematical model for some simple process. Verify the design by programing it on the computer.

Division V. Input-output Devices and Data Conversion, Registers
A. Units of instruction
  1. Requirements for codes and conversions
  2. Tape, punched card, printers
  3. Alpha-numeric and binary-decimal conversions
  4. Analog to digital conversion
  5. Digital to analog conversion
  6. Converting position to analog or digital values
  7. Basic requirements for registers or shift registers—vacuum tube designs, transistor, magnetic core, the circulating register
  8. Magnetic tape recorders: data acquisition—conversion, AM and FM techniques

B. Laboratory projects
  1. Study commercial designs of analog-to-digital and digital-to-analog converters. Sketch the most important components and subassemblies. Describe in detail the operating cycle of each device and

the ways in which it is made compatible with other components.

Division VI. Theory of Programing Computers

A. Units of instruction

1. Planning the program—determination of the sequence of steps
2. Use of *flow* diagrams
3. Coding the steps
4. The use of special languages—Fortran
5. Questions
6. Problems
7. Examination

B. Laboratory projects

1. Program a simple project and test the program on a computer to verify the work.

Division VII. Applications in Process and Numerical Control.

A. Units of instruction

1. Open loop process control
2. Closed loop process control
3. Quality and limit control
4. The computer and point-to-point machining.
5. The computer and continuous path generation.
6. Programing the computer for process work.
7. Programing the computer for continuous path operation.
8. Questions
9. Problems
10. Examination

B. Laboratory project

1. Visit an industrial organization which is using computers for the control of machining equipment. Study the type of programing, the accuracy of the installation, the various types of position sensors and synchros, the speed of operation. Write a complete report.

Texts and References

ARDEN. *An Introduction to Digital Computing*
BARTEE. *Digital Computer Fundamentals*
BURROUGHS CORP. *Digital Computer Principles*
SIEGEL. *Understanding Digital Computers*

Visual Aids

Bell Telephone Business Office (Local)
Memory Devices. 27 mins., 16 mm, color, sound

Fortune Films, Time & Life Bldg., Rockefeller Center, New York 20, N.Y.
The Computer Comes to Marketing. 30 mins., 16 mm, black and white

International Business Machines Corp., Department of Information, 590 Madison Ave., New York 22, N.Y.
The Information Machine. 10 mins, 16 mm or 35 mm, color, sound

Modern Talking Picture Service, Inc., 3 E. 54th St., New York, N.Y.
Piercing the Unknown. 22 mins., 16 mm, color, sound

Pennsylvania State University, University Park, Pa.
The Search: Automation. 27 mins., 16 mm

Remington Rand, Univac Div., Audio-Visual Engineering Section, Univac Park, St. Paul 16, Minn.
Computer Programing. 20 mins., 16 mm, black and white, sound
Introduction to Digital Computers. 25 mins., 16 mm, color, sound
Magnetic Core Memories. 12 mins., 16 mm, color, sound
Mines, Mills, and Minutes. 17 mins., 16 mm, black and white, sound
Univac 1. 22 mins., 16 mm, black and white, sound

Instrumentation Project

Hours Required

Class, 1; Laboratory, 6

Description

This course provides the time and the opportunity for the student to work on the design, fabrication, assembly, and testing of some instrument, test fixture, or other suitable device of his choice. Its purpose is to promote independent study, initiative, and the assumption of responsibility and work, without specific instruction upon initiation of the project. The student will draw upon all his previous courses of study in order to arrive at satisfactory project completion. It will be necessary for the student to select materials, means of fabrication, sizes and dimensions, tests, and evaluation of performance.

Major Divisions

	Hours	
	Class	*Laboratory*
I. Conferences with Faculty Adviser at Beginning and During Project	16	0
II. Design and Construction		
(a) Design of instrument, transducer, or similar device—study calculations	----	20
(b) Drawings and plans	----	10
(c) Construction of unit	----	44
(d) Test and evaluation	----	10
(e) Test report	----	12

Mathematics and Science Courses

Mathematics I

Hours Required

Class, 5; Laboratory, 0

Course Description

The choice of topics and the order in which they are presented integrate mathematics with the technical courses in the curriculum to their mutual benefit. Thus the basic slide rule operations are introduced early in the course so that the student can use this tool to advantage in other courses.

As the various topics are introduced, the meaning and underlying principles of each and the role each plays in instrumentation technology should be considered before the subject proper is explored. Practical problems following the exposition of each major topic will help to motivate the student and will strengthen his understanding of the principles involved. Insofar as possible, the course should draw upon physical relationships which are considered in PHYSICS FOR INSTRUMENTATION.

Prerequisite: Two years of high school mathematics, including simultaneous linear equations, exponentials, and radicals, or the equivalent.

Major Divisions

		Class hours
I.	Review and Basic Slide Rule	4
II.	The Set	5
III.	Solution of Inequalities	3
IV.	Grapping	10
V.	The Remainder Theorem	3
VI.	Slope of a Line	10
VII.	The Derivative	10
VIII.	Applications Involving Maxima and Minima	9
IX.	Applications of Negative, Fractional, and Zero Exponents	4
X.	Exponential and Logarithmic Equations	5
XI.	Sequences	4
XII.	Fundamental Principles of Permutations and Combinations	4
XIII.	Probability and Quality Control	9

Division I. Review and Basic Slide Rule

1. Types of slide rules and calculators
2. Multiplication and division
3. Powers of ten
4. Combined multiplication and division
5. Squaring, cubes, square root, and cube root
6. Logarithms

Division II. The Set

Units of Instruction

1. Basic rules of algebra
2. Field postulates
3. Combing fractions
4. Special notation
5. Inequalities
6. Absolute value
7. Functions and relations
8. Theory of the solution of equations
9. The delta functions
10. Problems
11. Questions
12. Examination

Division III. Solution of Inequalities

Units of Instruction

1. Solution of inequalities
2. Coordinate systems
3. The distance between two points
4. Equations, inequalities, and loci
5. Solutions of inequalities of higher degree
6. Problems
7. Questions
8. Examination

Division IV. Graphing

Units of Instruction

1. Intercepts
2. Approximate intercepts
3. Discontinuities
4. Behavior of loci for large values of X
5. General characteristics of loci

6. Problems
7. Questions
8. Examination

Division V. The Remainder Theorem

Units of Instruction

1. Synthetic division
2. Rational roots
3. Upper and lower bounds for intercepts
4. Symmetry of points
5. Symmetry of loci, tests for symmetry
6. Applications
7. Problems
8. Questions
9. Examination

Division VI. Slope of a Line

Units of Instruction

1. The equation of a line
2. The line tangent to a curve at a point
3. Limit of a function
4. Continuous function
5. Slope of a tangent line
6. Increments
7. Problems
8. Questions
9. Examination

Division VII. The Derivative

Units of Instruction

1. The delta process
2. Labor-saving generalizations
3. Basic theorems
4. The derivative of a polynomial
5. Derivatives of functions and products
6. Maxima and minima points
7. Tests for maxima and minima
8. Problems
9. Questions
10. Examination

Division VIII. Applications Involving Maxima and Minima

Units of Instruction

1. Average rate of change
2. Instantaneous speed
3. General rates of change
4. Extreme values
5. Problems
6. Questions
7. Examination

Division IX. Applications of Negative, Fractional, and Zero Exponents

Units of Instruction

1. Scientific notation
2. Floating point notation
3. Approximation of results
4. Logarithms
5. Logarithms to various bases, natural logarithms
6. Properties of logarithms and computation
7. Problems
8. Questions
9. Examination

Division X. Exponential and Logarithmic Equations

Units of Instruction

1. The use of bases other than *10*, natural logarithms
2. Derivatives of logarithmic and exponential functions
3. Hyperbolic functions
4. Falling bodies with air resistance
5. Nomograms which employ logarithms, the slide rule
6. Problems
7. Questions
8. Examination

Division XI. Sequences

Units of Instruction

1. Arithmetic sequences
2. Geometric sequences
3. Infinite sequences
4. Repeating decimals
5. Mathematical induction—new theorems
6. Finite differences
7. Curve-fitting
8. Interpolation techniques
9. Areas
10. Problems
11. Questions
12. Examination

Division XII. Fundamental Principles of Permutations and Combinations

Units of Instruction

1. Permutations
2. The binomial expansion
3. The compound interest law
4. Combinations

5. Problems
6. Questions
7. Examination

Division XIII. Probability and Quality Control

Units of Instruction

1. Probability
2. Mutually exclusive events
3. Conditional probability
4. Binomial distributions
5. Mean and standard deviations
6. Quality control basics
7. Statistical quality control
8. Problems
9. Questions
10. Examination

Texts and References

ADAMS. *Intermediate Algebra*

COMBELLACK. *Introduction to Elementary Functions*

COOKE. *Basic Mathematics for Electronics*

HALL and KATTSOFF. *Unified Algebra and Trigonometry*

JUSZLI and RODGERS. *Elementary Technical Mathematics*

LENNHARDY. *College Algebra*

RICE and KNIGHT. *Technical Mathematics with Calculus*

SCHWARTZ. *Analytic Geometry and Calculus*

Mathematics II

Hours Required

Class, 4; Laboratory, 0

Course Description

This course is a continuation of Mathematics I. Certain phases of analytic geometry are presented first, with particular emphasis on slopes and rates of change, intersection of straight lines, equations of lines, and related material. This is followed by differential calculus with particular stress on the mathematical language and the use of the derivative to express speed, acceleration, induced potentials. The use of the La Place transform is also introduced. There should be a close correlation between this course and Physics for Instrumentation II.

Major Divisions

	Class hours
I. Functions	16
II. Areas	16
III. Rates, Derivatives, Integration	20
IV. Volumes and Solids	6
V. The La Place Transform	6

Division I. Functions

Units of Instruction

1. Representation of functions by tables
2. Representation of functions by graphs
3. Mathematical representation of functions
4. The equation of a straight line
5. The intersection of two straight lines
6. The distance between points
7. The use of quadratic equations
8. The parabola
9. Expressions of continuity
10. Problems
11. Examination

Division II. Areas

Units of Instruction

1. Areas of rectangles
2. Area of triangles
3. Series relationships
4. Theory of limits and their applications
5. The circle
6. Radian measure
7. Area under a curve
8. The definite integral
9. Integration by a *limit of a sum* process
10. Finite sums
11. Special cases of the definite integral
12. Problems
13. Examination

Division III. Rates, Derivatives, Integration

Units of Instruction

1. The derivative
2. Differentiation rules
3. Differentiation of simple functions
4. Integration by antidifferentiation
5. The chain rules
6. The differential
7. Newton's method
8. Maxima and minima
9. Motion—linear, rotary, freely falling
10. Laws of refraction
11. The method of least squares
12. Minimum functions of two variables
13. Problems
14. Examination

Division IV. Volumes and Solids

Units of Instruction

1. Volumes of prisms, cylinders, cones
2. The law of the lever
3. Mass center of regions and solids
4. Volumes of solids by integration
5. Problems
6. Examination

Division V. The La Place Transform

Units of Instruction

1. Theory and derivation
2. Tables of transforms and their uses
3. Typical problems and solutions
4. Problems
5. Examination

Texts and References

ADAMS. *Applied Calculus*
COOKE. *Basic Mathematics for Electronics*
JUSZLI. *Analytic Geometry and Calculus*
RICHMOND. *Calculus for Electronics*
SAGAN. *Integral and Differential Calculus*
SMITH *and others, Calculus*
TUITES. *Basic Mathematics for Technical Courses*

Physics for Instrumentation I

Hours Required

Class, 3; Laboratory, 4

Course Description

Virtually all theories of measurement and control are based on certain principles of physics; changes of shape or dimension, magnetic variation, resistance modifications, or the effect of adding or removing energy for some set of conditions. Consequently, physics is perhaps the most fundamental of the courses in the curriculum, and the one which is most vital to a successful consideration of instrumentation and control. The subject matter which is included is essentially a study of mechanics and heat, but the presentation of the various subsections emphasizes the conditions which must exist if there are to be interchanges in energy.

The subject matter should be presented in a way which shows the similarity of processes, conditions, and events rather than their differences. Because it is important in understanding the frequency response characteristics of components and systems, special attention should be given to presenting and developing concepts of resistance and capacitance (which have no relationship to electrical phenomena). These concepts are fundamental to the appreciation of the factors which must be present whenever there is to be an exchange of energy. All common transfers of energy involve the same three factors—some difference of potential, some period of time, and some fixed or specified amount of energy. Potential energy, mechanical energy, energy of motion, thermal energy, and electrical energy—all can be equated to and stated as one common and basic concept and not a series of isolated phenomena which must be treated differently. These basic concepts should be developed early in the course, and emphasized as working principles throughout the entire study of physics and other instrumentation courses.

Major Divisions

	Hours: Class	Hours: Laboratory
I. Forces, Components	6	3
II. Engineering Characteristics of Common Materials	4	6
III. Rectilinear Motion in a Horizontal Plane	4	6
IV. Nonlinear Motion	4	6
V. Work and Energy	3	4
VI. Simple Harmonic Motion	3	4
VII. Temperature, Measurement, Scales	3	4
VIII. Heat Energy	3	2
IX. Transfer of Heat Energy	3	2
X. Thermal Properties of Materials	1	2
XI. Laws of Thermodynamics	4	6
XII. Gas Flow	3	4
XIII. Hydrostatics	1	2
XIV. Hydrodynamics	6	8

Division I. Forces, Components

A. Units of Instruction

1. Forces, components, resultants, parallelogram of forces.
2. Stresses—lineal, shear, Hooke's Law
3. Strain—lineal, shear
4. Young's modulus; modulus of rigidity
5. Simple force systems—conditions and axioms of static equilibrium
6. Free-body diagrams, force analysis
7. Moments, couples
8. Analytical method of joints; method of sections
9. Problems
10. Questions
11. Examination

B. Laboratory Projects

1. By the force triangle and the parallelogram method solve for the resultant of two noncolinear forces.
2. Use the force polygon method to solve for the resultant of three noncolinear forces. Set up the problem on a friction-free force table. Check the answer by the component method.

Division II. Engineering Characteristics of Common Materials

A. Units of Instruction
   1. Resistance to deformation based on shape and material
   2. Moment of inertia
   3. Modulus of rigidity
   4. Fatigue
   5. Engineering properties of common materials subjected to mechanical loads.
      (a) Moduli of elasticity, rigidity
      (b) Tensile, shear, and compressive strengths
      (c) Hardness
      (d) Temperature effects
      (e) Cyclic performance
   6. Problems
   7. Questions
   8. Examination

B. Laboratory Projects
   1. Using a tensile testing machine and electrical strain gages, determine the stress-strain performance of steel, brass, and aluminum. From the plotted results, determine for the linear section the extrapolated stress which would cause a 1-inch sample to stretch an inch. This is the value of Young's modulus.
   2. Using a fatigue-testing machine, determine the stress-fatigue life for some of the common metals. Plot stress vs. cycles and predict probable stresses for specific life expectancies.
   3. Using simple types of specimens in a testing machine, determine the effect of shape upon strength under compression. For example, use a wooden 2" x 4" with 2 inches for the vertical dimension; and another with the 4 inches for the vertical dimension. Compare actual values with ratios predicted from the moment of inertia.

Division III. Rectilinear Motion in a Horizontal Plane

A. Units of Instruction
   1. Constant forces—speed and distance relationships
   2. Constant frictional effects
   3. Viscous friction, resistance
   4. Mass
   5. Acceleration, gravitational attraction
   6. Response to step change in force—time-constant type of response
   7. Problems
   8. Questions
   9. Examination

B. Laboratory Projects
   1. With a constant force applied to an object, determine its acceleration, speed, and distance traveled. Plot results against time. Compare actual and theoretical performance.
   2. Using a viscous grease, determine the force required to keep the object of the first experiment moving at constant speed. Determine the speed. With the object moving at constant speed, double (or otherwise markedly increase) the force applied to the object and plot its speed against time. Determine the type of response. If it did not reach terminal speed, compute the value necessary to reach terminal speed.

Division IV. Nonlinear Motion

A. Units of Instruction
   1. Projectile motion
   2. Circular motion
   3. Polar moment of inertia
   4. Viscous friction
   5. Response to a step change, time-constant response
   6. Problems
   7. Questions
   8. Examination

B. Laboratory Projects
   1. Determine the polar moment of inertia of an object by determining the acceleration which results from the application of a constant torque. Attach weights of various sizes at desired points and determine the new polar moments of inertia. Compare measured and calculated values.
   2. Determine the constant torque required to turn a disc at constant speed through a viscous fluid. Then with a step change in torque, measure the changes in speed and plot vs. time. What type of response is obtained? If a terminal speed is not obtained, determine it.

Division V. Work and Energy

A. Units of Instruction
   1. Work—force, distance
   2. Kinetic energy, momentum, impulse

3. Potential energy
4. Power
5. Problems
6. Questions
7. Examination

B. Laboratory Projects
1. Determine the ideal mechanical advantages of several levels and gear trains. Using some compound pulleys, determine the amount of work required to lift an object a given specified distance when the applied force is acting through different radii.
2. Using carts of different weights which have very little friction, compare the work required to raise them along an incline with that required to lift them through the same vertical distance.

Division VI. Simple Harmonic Motion

A. Units of Instruction
1. Rotary motion—speed, acceleration
2. Straight-line motion
3. Restoring forces
4. The pendulum
5. Energy relationships
6. Problems
7. Questions
8. Examination

B. Laboratory Projects
1. Attach a mass to the end of a spiral spring, and hang the combination so that the mass can oscillate freely. Fasten securely the core of a linear variable differential transformer. Feed the output to an oscilloscope. Determine the frequency and the apparent sinusoidal response. If the transformer has very limited movement, mechanical techniques can be used to reduce the excursion of the core. Compare the actual and theoretical values.
2. Determine the period of vibration of a simple pendulum. Compute its theoretical period. Change the mass of the pendulum and also the length to obtain several sets of conditions. What degree of agreement exists between calculated and actual values?

Division VII. Temperature, Measurement, Scales

A. Units of instruction
1. Temperature concepts
2. Scales
3. Measurement
4. Expansion, change of dimension—linear, volumetric
5. Pressure of gases
6. Thermal stresses
7. Problems
8. Questions
9. Examination

B. Laboratory Projects
1. Make and calibrate a simple thermometer based on the expansion of a liquid. Used two or three sizes of containers for the fluid—the larger the container, the greater the sensitivity. For identical conditions, determine the time constants for the various sizes, for the same magnitude of step change in temperature.
2. Repeat experiment 1, but use a gas (such as air) for the heat-responsive material. Compare time constants for those situations where the physical dimensions are the same as those used with liquids. How can the speed of response be accelerated?

Division VIII. Heat Energy

A. Units of Instruction
1. Internal energy, change of dimension
2. Mechanical equivalent of heat energy
3. Specific heat, thermal capacitance
4. Change of phase—heats of fusion, vaporization
5. Factors affecting boiling and freezing points
6. Problems
7. Questions
8. Examination

B. Laboratory Projects
1. Using the method of mixtures, determine the specific heats of some common materials. Compare computed values with published ones. Explain any major discrepancies in values.
2. Using ice, paraffin, or some other low-melting materials, determine the heats of fusion by the methods of mixtures. Compare the results of the experiment with published values. What might be done to obtain more accurate results?

Division IX. Transfer of Heat Energy

A. Units of Instruction
1. Conduction—thermal resistance
2. Convection—thermal resistance

3. Radiation—thermal resistance
4. Stefan's Law
5. Time-constant responses—static and transient responses
6. Problems
7. Questions
8. Examination

B. Laboratory Projects
1. Determine the time constant for a glass thermometer, for some convenient step change of temperature, in a liquid using:
   (a) Bare bulb, no agitation of liquid
      (1) With some agitation
      (2) With vigorous agitation
   (b) Bulb covered with thin rubber sleeve
      (1) Repeat degrees of agitation
2. Repeat project No. 1 using a temperature step change in air instead of a liquid.

Division X. Thermal Properties of Materials

A. Units of Instruction
1. Molecular theory of matter
2. Expansion and compression of gases
3. The ideal gas
4. Kinetic theory of gases
5. Coefficients of expansion of solids and liquids
6. Problems
7. Questions
8. Examination

B. Laboratory Projects
1. Determine the coefficients of expansion for some of the common materials. Compare experimental values with established ones. Determine from published references the spans where coefficients are constant. Determine where marked nonlinearities occur. The specimen might be heated in a steam bath allowing greater freedom in its choice. The amount of elongation can be computed by use of the optical lever.

Division XI. Laws of Thermodynamics

A. Units of Instruction
1. First and second laws
2. Adiabatic and isothermal processes
3. The Carnot cycle
4. Internal combustion engine
5. Problems
6. Questions
7. Examination

B. Laboratory Projects
Select on the basis of available equipment and facilities.

Division XII. Gas Flow

A. Units of Instruction
1. Resistance
2. Capacitance
3. Flow into resistor-capacitor combinations, time-constant effects
4. Problems
5. Questions
6. Examination

B. Laboratory Projects
1. Determine the gas-flow resistances of various pieces of pipe and valves. Using a variety of pressure differentials, compare the resistance values.
2. Using some of the valves of Experiment 1, compute the time constants for various resistor-capacitor combinations. Verify answers by plotting pressure vs. time for a step change in pressure.

Division XIII. Hydrostatics

A. Units of Instruction
1. Pressures in a fluid
2. Specific gravities
3. Manometers, pressure balance devices
4. Archimedean principles
5. Surface tension
6. Problems
7. Questions
8. Examination

B. Laboratory Projects
1. Relate hydrostatic pressure, either by means of a pressure gage or the pressure required to force air through the fluid, to the depth of the fluid. Use liquids of different specific gravities, and plot pressures vs. depth of liquid. Analyze your results.

Division XIV. Hydrodynamics

A. Units of Instruction
1. Streamline flow
2. Bernoulli's equation, energy relationships
3. Applications in fluid-flow measurements, airfoil design, Venturi meters, orifice plates
4. Viscosity determination, scales
5. Resistance to fluid flow
6. Laminar and turbulent flow

7. Reynolds number
8. Liquid capacitance
9. Response to step changes, time-constant values
10. Problems
11. Questions
12. Examination

B. Laboratory Projects
1. Determine the resistances to fluid flow of a number of valves. Plot the resistances as functions of speed of the fluid, and as functions of the pressure differential.
2. Using some of the valves of the previous experiment, determine both by experiment and calculation the time constants for a number of resistor-capacitor combinations.
3. Using some of the valves from No. 2, make a number of *large* step changes in fluid flow and compare the time-constant results with those of the second experiment.

Texts and References

BEISER. *The Mainstream of Physics*
BLACKWOOD, *and others. General Physics*
HARRIS *and* HEMERLING. *Introductory and Applied Physics*
OREAR. *Fundamental Physics*
RESNICK *and* HALLIDAY. *Physics for Students of Science and Engineering*
SEARS *and* ZEMANSKY. *College Physics*
———. *University Physics*
SEMAT. *Fundamentals of Physics*
WEBER *and others. College Physics*

Visual Aids

Bell Telephone Business Office (Local)
The Bell Solar Battery. 12 mins., 16 mm, color, sound
Brattain on Semiconductor Physics. 30 mins., 16 mm, black and white, sound
Domains and Hysteresis in Ferromagnetic Materials. 36 mins., 16 mm, color, sound

General Electric Co., 1 River Road, Schenectady, N.Y., *and* U.S. Atomic Energy Commission, Public Information Service, Washington, D.C.
"A" Is for Atom. 15 mins., 16 mm, color, sound

Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, Calif.
Deep Space Instrumentation Facility. 19 mins., 16 mm, color, sound

Syndicated Films, 1022 Forbes St., Pittsburgh, Pa.
Melting and Refining of Modern Steels, produced by Allegheny Ludlum Steel Corp., 23 mins., 16 mm, color, sound

Physics for Instrumentation II

Hours Required

Class, 3; Laboratory, 4

Course Description

This course is a continuation of Physics for Instrumentation I. Because of the necessity for extensive subject coverage, electric circuits and devices (both AC and DC) are presented in another course (Electrical Circuits—AC and DC) concurrently with this course in this program. Conventional courses in high school physics usually provide some foundation for the material contained in the Electrical Circuits and Physics for Instrumentation courses. The instructor teaching Physics for Instrumentation II should coordinate his coarse content with that of the instructor teaching AC and DC electrical circuits so the material in each course will provide adequate and timely presentation of the subjects.

Because of the limitations of time certain material has been treated briefly. However, concepts and principles which are important to instrumentation and control have been stressed, along with some of the implications of the theory.

The laboratory experiments are significant parts of the course, and every attempt should be made to present them at the correct time, and in such a way as to indicate their relationship to the program.

A thorough understanding of the material will greatly facilitate the study of many subsequent courses. Emphasis should always be on principles underlying that which is being studied, using laboratory equipment and experiments to teach applied principles, not individual mechanisms or devices.

Major Divisions

	Hours	
	Class	Laboratory
I. The Magnetic Field	2	2
II. The Electro-Magnetic Field	2	2
III. Magnetic Properties of Matter	2	2
IV. Induced Electromotive Forces	3	4
V. Coulomb's Law	3	2
VI. The Electric Field	3	2
VII. Electric Potential	3	4
VIII. Capacitance—Properties of Dielectrics	3	4
IX. Electrochemistry and thermoelectricity	3	4
X. Electronics	3	4
XI. Elementary Solid State Physics	3	4
XII. Sound—Wave Motion	3	4
XIII. Sound—Vibrating Bodies	3	4
XIV. The Nature and Propagation of Light	1	4
XV. Lenses and Lens Aberrations	3	4
XVI. Optical Instruments	3	4
XVII. Mirrors	1	3
XVIII. Photoelectric—Photoresistive and Photovoltaic Devices	3	4
XIX. Diffraction and Polarization	1	3

Division I. The Magnetic Field

A. Units of Study
1. Magnetism
2. The magnetic field
3. Lines of induction, flux densities
4. Charged particles in magnetic fields
5. The cyclotron
6. The charge-to-mass determination
7. The mass spectrograph
8. Currents, forces, and torques
9. Problems
10. Questions
11. Examination

B. Laboratory Projects
1. Map the magnetic fields surrounding permanent magnets of varying shapes. Show the results of combining like fields, unlike fields

Division II. The Electro-Magnetic Field

A. Units of Instruction
1. Current elements and their associated magnetic field
2. Long straight conductors and their magnetic fields
3. Forces developed by currents in parallel conductors
4. The field at the center of a turn, the center of a coil

5. Ampere's law
6. Problems
7. Questions
8. Examination

B. Laboratory Projects
1. Plot the magnetic fields surrounding a straight current-carrying conductor, a curved conductor, a multi-turn coil

Division III. Magnetic Properties of Matter

A. Units of Instruction
1. Magnetic permeability, intensity
2. Ferromagnetism
3. The Curie temperature
4. Hysteresis
5. Theories of magnetism
6. Magnetic poles, forces developed
7. The magnetic circuit
8. Problems
9. Questions
10. Examination

B. Laboratory Projects
1. Determine the hysteresis loops for a variety of magnetic materials. Note particularly the differences between materials which normally are not saturated (such as transformers) and certain magnetic materials used for logic arrays
2. Determine the Curie temperatures for some common and available materials. Note any hysteresis and consider the abruptness of the response to temperature

Division IV. Induced Electromotive Forces

A. Units of Instruction
1. The generation of potentials by motion of a conductor
2. Faraday's Law
3. Lenz's Law
4. AC potentials induced in a rotating coil
5. The direct current generator
6. Means for measuring magnetic flux densities
7. Eddy current effects
8. Problems
9. Questions
10. Examination

B. Laboratory Projects
1. Using an oscilloscope to show the induced emf, sketch the patterns produced when a permanent magnet is inserted into a coil, removed from the coil, moved at different rates; explain the results
2. Use a DC electrical tachometer (with permanent magnet field). Measure the voltage as a function of the speed. Plot the results
3. Use an AC electrical tachometer (with permanent magnet field). Present in graphical form the generated potential and the frequency a function of speed of the tachometer

Division V. Coulomb's Law

A. Units of Instruction
1. Electric charges
2. Atomic structure
3. Charging by content
4. Conductors and insulators
5. Charging a metal by induction
6. Coulomb's Law
7. Rutherford's nuclear atom
8. System of units
9. Problems
10. Questions
11. Examination

B. Laboratory projects
1. Use the electroscope to show the presence of charged particle and to provide the electrification of objects by various means. Also use radio-active materials to discharge a charged electroscope

Division VI. The Electric Field

A. Units of Instruction
1. The electric field
2. Determination of electric field intensity
3. Lines of force
4. Gauss' law, conductors, and fields outside charged conductors
5. Millikan oil-drop experiment
6. Dielectric strength
7. Problems
8. Questions
9. Examination

B. Laboratory projects
1. Map the equipotential lines of an electric field of two equal charges but of unlike sign, of like sign

Division VII. Electric Potential

A. Units of Instruction
1. Electrical potential energy
2. Potential
3. Potential difference
4. Potential of a charged spherical conductor
5. The energy principle
6. Equipotential surfaces

7. Potential gradient
8. Sharing of charge by conductors
9. Van de Graff generator
10. Problems
11. Questions
12. Examination

B. Laboratory projects
1. Use the laboratory model of a Van de Graff generator to produce high potentials. Determine the approximate potential of breakdown by using spheres and measuring the distance. Note change in potential at breakdown when sharp points are used. Map electric fields around different electrodes

Division VIII. Capacitance—Properties of Dielectrics

A. Units of Instruction
1. Capacitors
2. The parallel plate capacitor
3. Voltage relationships—capacitors in series and parallel
4. Energy of a charged capacitor
5. Dielectric coefficient; permittivity
6. Dielectrics and induced charges
7. Theory of induced charges
8. Problems
9. Questions
10. Examination

B. Laboratory Projects
1. Using the bridge method for comparing capacitances, measure the capacitance of a number of capacitors
2. For different series and parallel combinations of the capacitors measured in project 1, compare measured and computed values

Division IX. Electrochemistry and thermoelectricity

A. Units of Study
1. Electrolysis
2. Means of electrolytic conduction
3. Determination of Avogadro's number
4. The electrolysis of water
5. Electrode potentials
6. The refining of metals
7. Galvanic cells
8. Polarization
9. The dry cell and the storage battery
10. Standard cells
11. Thermoelectricity

B. Laboratory projects
1. Using common metals such as iron and copper or nickel and iron, make a thermocouple. Using some suitable source of heat, measure its output potential as a function of temperature. Repeat the experiment with different ambient conditions
2. Study the performance of a commercial unit which employs a thermocouple to produce cooling.

Division X. Electronics

A. Units of Instruction
1. Thermionic emission
2. Diodes, rectification
3. Triodes and multi-element tubes
4. The vacuum tube as a variable resistor
5. The vacuum tube as an amplifier; as an oscillator
6. Detection
7. Cathode-ray tubes
8. X-ray tubes
9. Conduction in gases

B. Laboratory projects
1. Construct a single tube triode amplifier. For given changes in input potential compute the changes in resistance of the tube. Assuming a resistor in the anode circuit, compare the voltage change with the input change for a variety of resistance values. Plot;
   (a) Resistance as a function of input signal, with constant anode circuit resistance
   (b) Amplification as a function of anode load resistor with a constant input signal

Division XI. Elementary Solid State Physics

A. Units of Instruction
1. The composition of matter
2. The Bohr atom
3. Energy levels, absorption behavior
4. Ways in which energy can be added or removed
5. Radioactivity
6. Alpha and Beta particles
7. Gamma rays
8. Fission
9. Fusion

B. Laboratory projects
1. Use a commercial Geiger counter (or one constructed as a project) to measure or detect radioactivity. Plot response as a function of distance
2. Determine the absorption characteristics of different materials as functions of thickness

Division XII. Sound—Wave Motion

A. Units of Instruction
1. Propagation of a disturbance in a medium
2. Calculation of the speed of a transverse pulse
3. Calculation of the speed of a longitudinal pulse
4. Motion of a wave
5. Mathematical representations of a longitudinal wave
6. Problems
7. Questions
8. Examination

B. Laboratory projects
1. Using the resonance principle and a known frequency, determine the speed of sound in air
2. Using commercial equipment (if available) determine the location of flaws or discontinuities by sonic techniques
3. Determine the length of objects by measuring with an oscilloscope the time required for a higher frequency wave (15,000–20,000 cycle/sec) to pass from one end of a metal rod to the other

Division XIII. Sound—Vibrating Bodies

A. Units of Instruction
1. Boundary conditions for a string
2. Stationary waves in a string
3. Vibration of a string fixed at both ends
4. Harmonic series in a vibrating string
5. Resonance
6. Interference of waves
7. Stationary longitudinal waves
8. Vibrations of rods and plates
9. Problems
10. Questions
11. Examination

B. Laboratory projects
1. Determine the effects of tension and mass of the vibrating body in determining the frequency

Division XIV. The Nature and Propagation of Light

A. Units of Instruction
1. The nature of light
2. The dual nature of light energy
3. Determination of the speed of light, its significance
4. Indices of refraction
5. General principles of refraction
6. Problems
7. Questions
8. Examination

B. Laboratory projects
1. Determine the index of refraction for different glasses and clear plastics. From the index compute the speed of light in each of these media

Division XV. Lenses and Lens Aberrations

A. Units of Instruction
1. The thin lens
2. The thin-lens equation
3. Diverging lenses
4. Converging lenses
5. Lens combinations
6. Graphic methods of describing lenses
7. Problems
8. Questions
9. Examination

B. Laboratory projects
1. Using the parallel-ray technique, determine the focal length of a number of thin lenses, both positive and negative
2. Predict the image size for various conditions and confirm the calculations. Use lenses of the same dimensions and radii of curvature but different indices of refraction

Division XVI. Optical Instruments

A. Units of instruction
1. The magnifying lens and systems of lenses
2. The microscope
3. The camera
4. The telescope
5. The projector
6. Condensing systems
7. Spectrometers, infrared and ultraviolet, absorption characteristics of matter

B. Laboratory projects
1. Study the construc[illegible] of a commercial infrared analyzer

2. Obtain the analysis curve for two or more closely related chemical compounds. Determine the most significant frequencies and the greatest attenuation ratios. Using the maximum response as 100 percent, determine the values of the spectra where marked changes occur
3. Discuss the differences between ultra violet and infrared analyzers

Division XVII. Mirrors

A. Units of instruction
1. Reflection at a plane surface
2. Reflection at a curved or spherical surface
3. Ray treatment of reflection and refraction
4. Internal reflection
5. Refraction

B. Laboratory projects
1. Use both concave and convex mirrors to prove the validity of the mirror equation. Predict the sizes of the images for different conditions and confirm your answers

Division XVIII. Photoelectric—Photoresistive and Photovoltaic Devices.

A. Units of instruction
1. Basic theory
2. Light intensity measurements, photometry
3 Photoresistive applications, auxiliary components and devices
4. Photovoltaic devices, auxiliary components and devices
5. Photo transistors, photo-diodes

B. Laboratory Projects
1. Determine the responses of both photoelectric and photovoltaic cells as functions of intensity and light frequency
2. Design an automatic dimmer for use with automobile headlights. If components are available, test the operation of the design

Division XIX. Diffraction and Polarization

A. Units of Instruction
1. Principles of interference
2. Interference in thin films
3. Diffraction
4. Plane diffraction gratings
5. Diffraction of X-rays by a crystal
6. Polarization principles
7. Polarization by reflection and refraction
8. Optical stress analysis

B. Laboratory Projects
1. Determine the wavelength of a monochromatic light source by the use of a simple diffraction grating
2. Study the methods of producing plane-polarized light, the rotation of the plane of polarization, and interference effects

Texts and References

Beiser. *The Mainstream of Physics*

Blackwood and others. *General Physics*

Orear. *Fundamental Physics*

Resnick and Halliday. *Physics for Students of Science and Engineering*

Sears and Zemansky. *College Physics*

———, *University Physics*

Semat. *Fundamentals of Physics*

Harris and Hemerling. *Introductory and Applied Physics*

Visual Aids

Bausch & Lomb, Inc., Rochester 2, N.Y.
The Compound Microscope. 20 min., 16 mm, color, sound
To Greater Vision. 28 min., 16 mm, black and white, sound

Bell Telephone Business Office (Local)
Crystals—An Introduction. 25 min., 16 mm, color, sound
Domains and Hysteresis in Ferromagnetic Materials. 36 min., 16 mm, color, sound
The Bell Solar Battery. 12 min., 16 mm. color, sound
Brattain on Semiconductor Physics. 30 min., 16 mm, black and white, sound
The Transistor. 10 min., 16 mm, black and white, sound
Similarities in Wave Behavior. 26½ min., 16 mm, black and white, sound

Bray Studios, Inc., 729 7th Ave., New York 19, N.Y.; and Remington Rand, Univac Division, Audio-Visual Engineering Section, Univac Park, St. Paul 16, Minn.
Semi-Conductors. 43 min., 16 mm, black and white, sound

Encyclopaedia Britannica Films, 1150 Wilmette Ave., Wilmette, Ill., *and* U.S. Atomic Energy Commission, Public Information Service, Washington, D.C.
Atom and Industry. 11 min., 16 mm, black and white, sound

Fisher Scientific Co., Audio-Visual Dept., 711 Forbes St., Pittsburgh 19, Pa.
Colorimetry. 14 min., 16 mm, color, sound

General Electric Co., 1 River Road, Schenectady, N.Y., *and* U.S. Atomic Energy Commission, Public Information Service, Washington, D.C.
"A" Is for Atom. 15 min., 16 mm, color, sound

Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif.
The Industrial Atom. 12½ min., 16 mm, black and white, sound

High Voltage Engineering Corp., Burlington, Mass.
High Energy Radiations for Mankind. Produced by Sam Orleans and Associates. 16 min., 16 mm, color sound

Hughes Aircraft Co., Public Relations Dept., Culver City, Calif.
Science in Action. Produced by California Academy of Sciences, 52 min., 16 mm, black and white, sound

Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasedena, Calif.
Deep Space Instrumentation Facility. 19 min., 16 mm, color, sound
Giant Radio Telescope. 17 min., 16 mm, black and white, sound
Inquisitive Giant. 28 min., 16 mm, black and white, sound

McGraw-Hill Book Co., Inc., Text Film Dept., 330 W. 42d St., New York, N.Y.
Doppler Effect. Produced by American Association of Physics Teachers. 8 min., 16 mm, black and white, sound
Nuclear Reactor. Produced by American Association of Physics Teachers. 9 min., 16 mm, black and white, sound
Principles of Chromatography. Produced by Educational Foundation for Visual Aids, 20 min., 16 mm, color, sound
Principles of Transistor. Produced by Educational Foundation for Visual Aids. 20 min., 16 mm, black and white, sound
The Spectrograph. Produced by Educational Foundation for Visual Aids. 20 min., 16 mm, color, sound
X-Ray Crystallography. Produced by Educational Foundation for Visual Aids. 20 min., 16 mm, black and white, sound

Midwestern Instruments, Inc., P.O. Box 7509, Tulsa 18, Okla.
Heart of Instrumentation. 25 min., 16 mm, color, sound

Modern Talking Picture Service, Inc., 3 E. 54th St., New York 22, N.Y.
Gas Chromatography. Produced by Rensselaer Polytechnic Institute under a grant from the Perkin-Elmer Corp. 30 min., 16 mm, color, sound
Infrared Spectroscopy. Produced by Rensselaer Polytechnic Institute. 35 min., 16 mm, color, sound

National Aeronautics and Space Administration, Technical Information Division (Code ET), 1520 H St. NW., Washington, D.C.
High Temperature Materials. 27 min., 16 mm, color, sound

Phillips Electronic Instruments, 750 S. Fulton Ave., Mount Vernon, N.Y.
The Ultimate Structure. Produced by North American Philips Co., Inc., 16 mm, black and white, sound

U.S. Army, Signal Officer, Military District of Washington, Washington, D.C.
Introduction to Radiation Detection Instruments. 17 min., 16 mm, black and white, sound

U.S. Atomic Energy Commission, Public Information Service, Washington, D.C.
Atomic Physics. Produced by J. Arthur Rank, Ltd., England. 90 min., 16 mm, color, sound
Research Reactors. Produced by Lytle Engineering & Manufacturing Co., Los Angeles Division. 38 min., 16 mm, color, sound

Western Electric Co., Inc., Motion Picture Bureau, 195 Broadway, New York 7, N.Y.
Quartz Crystal Growing. 16 min., 16 mm, color, sound
Semi-Conductor Training Course. Filmstrip, 35 mm., color, sound

Auxiliary or Supporting Technical Courses

Electrical Circuits—AC and DC

Hours Required

Class, 3; Laboratory, 6

Course Description

A study of the basic laws pertaining to series and parallel circuits, reactance, impedance, and polyphase systems. Principles of direct current circuits and basic electrical instruments are considered first. Considered simultaneously with the study of materials and temperature and energy relationships, the study of semi-conductors, rectifiers, and transistors stresses mutual interdependencies of knowledge. Simple electron tubes are studied at the same time, and are treated as components which have variable characteristics.

The study of alternating current circuits stresses the vector relationships of voltage and current, inductive and capacitive reactance, and their influence on parallel combinations. This course is not intended to be a complete study of DC and AC, but is designed to equip the student with supporting theoretical information relative to *Measuring Principles II* (Electrical).

Major Divisions

	Hours: Class	Hours: Laboratory
I. Resistance Calculations, Ohm's Law	3	6
II. Series and Parallel Circuits	3	6
III. Networks	6	12
IV. Electric Fields and Capacitance	4	8
V. Magnetic Fields and Inductance	4	8
VI. Meters	3	6
VII. Sine Wave	3	6
VIII. Series Circuits—Alternating Current	8	16
IX. Parallel Circuits—Alternating Current	8	16
X. Polyphase Systems	6	12

Division I. Resistance Calculations, Ohm's Law

A. Units of instruction

1. Resistance calculations
2. The wire tables
3. Temperature effects
4. Commercial resistors
5. Thermistors, positive and negative resistance-temperature coefficients
6. Varistors
7. Strain gages
8. Nonmetallic resistors, voltage sensitivities, etc.
9. Problems
10. Questions
11. Examination

B. Laboratory projects

1. Heat and cool copper, aluminum, and nickel wires. Determine their temperature-resistivity coefficients. From plots of resistance vs. temperature, determine the value of inferred zero. Compare test values with plots for these metals which show their nonlinear responses.
2. Heat and cool both positive and negative coefficient thermistors. Plot resistance vs. temperature. Compare the slopes of the thermistor plots with those of metals.

Division II. Series and Parallel Circuits

A. Units of instruction

1. Series circuits
2. Application of series circuits
3. Parallel circuits
4. Application of parallel circuits
5. Special cases of series and parallel circuits
6. Circuit analysis by assuming a current or a voltage
7. Potential differences in networks
8. Voltage dividers
9. Three-wire systems
10. Problems
11. Questions
12. Examination

B. Laboratory projects

1. Measure current and potentials, and determine resistances for a number of

simple components connected in series. Determine the equivalent resistance and the resistances of the various combinations of components. Verify by checking voltage and current values.

2. Establish a parallel system consisting of three or more branches. Determine the current and the voltage relationships for each branch. Ascertain the equivalent resistance of the entire combination, and of the various branches. Verify your answer from observed or computed values.
3. Establish a three-wire system using both balanced and unbalanced loads. Measure the current in all lines. From meter readings verify the values of current in the neutral lead.

Division III. Networks

A. Units of instruction

1. The superposition theorem
2. Loop analysis—Kirchoff's law
3. Nodal analysis
4. *T* and *pi* networks
5. Thevenin's theorem
6. The maximum power transfer theorem
7. The reciprocity theorem
8. Pads and attenuators
9. Problems
10. Questions
11. Examination

B. Laboratory projects

1. Using four resistors and three sources of potential, prove the validity of the superposition theorem.
2. Using several resistors and two sources of potentials, verify Kirchoff's law for the various current and potential relationships.
3. Using one source of potential and four resistors, so connected that there are at least two parallel paths, establish the validity of Thevenin's theorem.
4. Match a 600-ohm load to a 600-ohm source using:
   (a) *T* attenuator
   (b) Bridged *T* annenuator
   (c) Modified bridged *T* attenuator
   Compute the required values and verify by actual measurement.

Division IV. Electric Fields and Capacitance

A. Units of instruction

1. The electric field
2. Electric flux density
3. Work, energy, and capacitance
4. Capacitors in series and in parallel
5. Capacitance and the dielectric
6. The time-constants of R-C circuits
7. Problems
8. Questions
9. Examination

B. Laboratory projects

1. Determine the equivalent capacitance of a number of capacitors connected in series and then in parallel. Using high impedance meters, relate the voltages in the series case to the capacitances.
2. Using a high resistance meter, determine the voltage across a capacitor which is part of a resistor-capacitor combination which is being charged from a constant-potential source. Vary the value of the resistance and note the effect upon the rate of response. Plot potential vs. time, and indicate the time required to acquire 63 percent of the total change. (This is the time-constant for the pair.)
3. Use a constant-potential source, a resistor, a capacitor, and a neon bulb which is to be connected in parallel with the capacitor, to create one type of timing circuit. Identify the elements which will change the rate of flashing and verify by changing their values or replacing them with other units.

Division V. Magnetic Fields and Inductance

A. Units of instruction

1. An electric current and its fields
2. Magnetic flux theory
3. Magnetic field intensity
4. Magnetism
5. Ferromagnetism
6. Work and energy
7. Magnetic circuits
8. Properties of coils
9. Resistor-inductor combinations
10. Problems
11. Questions
12. Examination

B. Laboratory projects

1. Using a standard inductance for comparison, determine the inductance of a number of coils. If a ballistic galvanom-

eter is used, determine the constant for the system.
2. Using an oscilloscope, determine the hysteresis curve for some common materials.
3. Run a number of saturation curves on magnetic materials used for cores of saturable reactors and for magnetic amplifiers.
4. Determine the time constants for a number of resistor-inductor combinations. Use the same coils as used in Experiment 1. Compare computed values with experimental ones. Explain any discrepancies.

Division VI. Meters

A. Units of Instruction
1. The ballistic galvanometer
2. The d'Arsonval meter movement
3. Current-indicating instruments
4. Potential-indicating instruments
5. Ohmmeters, multimeters
6. Iron vane instruments
7. Electro-dynamometer movements
8. Wattmeters, watthour meters
9. Problems
10. Questions
11. Examination

B. Laboratory projects
1. Convert a d'Arsonval type of galvanometer into a voltmeter of various ranges by computing the necessary resistances. Confirm the computations by laboratory measurements.
2. Convert the same type of galvanometer into an ammeter with at least four different ranges, compute the required resistances and compare computed performance with actual values.
3. Convert a galvanometer into an ohmmeter which has at least four ranges. Compare actual and computed performances.

Division VII. Sine Wave

A. Units of instruction
1. The generation of an AC waveform, the significance of the sine wave.
2. Waveforms
3. Simple harmonic motion
4. The *average* value of a sinusoidal wave
5. The *effective* value of a sinusoidal wave
6. Phase angle, power, and power factor
7. Voltage and current relationships for resistive, inductive, and capacitive circuits
8. Problems
9. Questions
10. Examination

B. Laboratory projects
1. Using a permanent magnet, a coil of wire, and an oscilloscope, determine the output wave, the polarity, relationship to direction of relative motion and speed. By altering the shape of the coil, is it possible to change the wave form? If two or more small coils are connected in series aiding, is it possible to approximate a sine wave by altering the relative positions of the coils with respect to each other?
2. Measure the total power input, the input potential and that of each component, for a series circuit employing resistive, capacitive, and inductive components. Why are the volt-amperes for the various components, and the entire circuit, different from the power?

Division VIII. Series Circuits—Alternating Current

A. Units of Instruction
1. Vector-phasor diagrams
2. Resistors in series
3. Resistive and inductive components in series
4. Resistive and capacitive components in series
5. Series circuits with three or more elements—inductive, resistive, and capacitive
6. Series resonance
7. The effect of frequency, inductance, and capacitance upon resonance
8. Problems
9. Questions
10. Examination

B. Laboratory projects
1. Determine the current, voltage, and power relationships for a circuit which has a resistor, an inductor, and a capacitor in series. If a variable frequency source is available, vary the frequency until the current is a maximum, for a constant input potential. Plot current vs. fre-

quency. With the same capacitor and inductor, determine the effect upon current and resonance peak of decreasing the resistance, increasing the resistance.
2. Using the same components as for the previous experiment, but with constant frequency, produce resonant conditions by changing the value of the inductance. Then, with the original value of the inductor, change the capacitance to produce resonance. Determine the potentials, currents, and powers for the entire circuit as well as each of the components.

Division IX. Parallel Circuits—Alternating Current

A. Units of Instruction
1. Resistors in parallel
2. Resistors and inductors in parallel
3. Resistors and capacitors in parallel
4. Capacitors and inductors in parallel
5. Resistors, inductors, and capacitors in parallel
6. Parallel resonance phenomena
7. Series, parallel resonant circuits
8. Power-factor correction
9. Problems
10. Questions
11. Examination

B. Laboratory projects
1. Determine the potential, current, power factor for each of three different components—resistive, capacitive and inductive, singly and in various parallel combinations. Compare or contrast the impedance of the total combination with the various components. Present the results graphically.
2. Adjust one of the reactive elements of experiment 1 so as to produce parallel resonance. With this modification repeat the previous experiment.

Division X. Polyphase Systems

A. Units of Instruction
1. Two- and three-phase systems
2. Three-phase circuit combinations
3. Wye loads
4. Delta loads
5. Wye-delta transformations
6. Unbalanced loads
7. Three-phase power measurements
8. Phase sequence measurements
9. Polyphase systems other than two- and three-phase
10. Problems
11. Questions
12. Examination

B. Laboratory Projects
1. Using the Scott T connection, provide two-phase power from a three-phase power supply. Meter the load as well as the input. Determine the efficiency of the transformation as well as the balance of the three-load phases. Discuss the advantages and disadvantages of such a system.
2. Parallel single-phase transformers, and then parallel wye and delta secondaries (wye to wye and delta to delta). Determine whether there is any significant circulating current. Use balanced and unbalanced loads.
3. Measure the power to a three-phase motor load using both the two- and the three-wattmeter methods. Compare values. Determine power factors. Evaluate both methods for accuracy, efficiency, power–factor determination for both balanced and unbalanced loads.
4. With the primaries connected both in wye and in delta, determine the angles of phase shift when the secondaries create a six-phase supply. Use an oscilloscope to give visual indications of the phase shift.

Texts and References

ANGUS. *Electrical Engineering Fundamentals*
DAWES. *A Course in Electrical Engineering, Volume I*
——— *A Course in Electrical Engineering, Volume II*
GILLIE. *Principles of Electron Devices*
JACKSON. *Introduction to Electric Circuits*
LURCH. *Electric Circuits*
MORECOCK. *Alternating Current Circuits*
OPPENHEIMER. *Direct and Alternating Current Circuits*
PERRY. *Strain Gage Primer*
STUDER. *Electronic Circuits and Instrumentation Systems*

Electronics I

Hours Required

Class, 3; Laboratory, 6

Course Description

An introduction to the elementary principles and concepts of electronic components, circuits, and devices. Includes a study of vacuum tubes and transistors; tuned circuits and basic circuits for power supplies, detectors, amplifiers, and oscillators; receivers; cathode-ray oscilloscopes; and use of basic test devices and measuring instruments. This course is preparatory to the course *ELECTRONICS FOR INSTRUMENTATION.*

Major Divisions

	Hours: Class	Hours: Laboratory
I. Vacuum Tubes	6	12
II. Semiconductor Characteristics	6	12
III. Power Supplies	5	10
IV. Audio Amplifiers	7	14
V. Tuning Circuits	4	8
VI. Radio-Frequency Amplifiers	4	8
VII. Detector Circuits	5	10
VIII. Electronic Instruments	11	22

Division I. Vacuum Tubes

A. Units of Instruction

1. Diodes
   - (a) Edison effect; electron emission and contact potential
   - (b) Series and parallel filament connections
   - (c) Characteristic curves; saturation, rectification, and detection
2. Triodes
   - (a) Action of control grid
   - (b) Characteristic curves
   - (c) Amplification factor
   - (d) Plate resistance; transconductance
   - (e) Voltage amplification; equivalent circuit
3. Tetrodes and Pentodes
   - (a) Effect of screen grid
   - (b) Characteristic curves, negative resistance
   - (c) Effect of suppressor grid
   - (d) Beam power tubes
   - (e) Characteristic curves of pentodes and beam power tubes

B. Laboratory Projects

1. Tube dissection
   - (a) Experiment to be performed by each student: Cut apart piece by piece several discarded tubes (both metal and glass).
   - (b) Make a freehand sketch of each element, and of the tube's internal structure.
   - (c) Refer to published tube data for symbol and manufacturer's description of each tube.
2. Diode characteristics
   - (a) Determine the voltage-current relationships taken with equipment connected by student crews and checked by instructor. With a duo-diode, curves may be compared for one section and both sections in parallel.
   - (b) Write an informal report with graphs of experimentally obtained data, comparison with published characteristics, and comments on any discrepancies.
3. Triode characteristics
   - (a) Obtain data for transfer curves taken with student-connected apparatus.
   - (b) Write an informal report, as in preceding experiment.
4. Pentode characteristics
   - (a) Observe similar procedure as for triode characteristics. Take separate sets of data for sharp cut-off and for remote cut-off types of pentodes.
   - (b) Write an informal report with data presented on curves that may be compared with those in tube manual.
5. Tube characteristics calculations
   - (a) Calculate amplification factor, plate resistance, and transconductance,

from the curves plotted for triode and pentode tubes.
   (b) Write an informal report showing procedures used and evaluation of units.
6. Demonstrate special tubes. If time permits, attention may be given to special tubes, such as electron-ray indicators and power tubes for transmitters.

Division II. Semiconductor Characteristics

A. Units of Instruction
   1. Semiconductor diode characteristics
      (a) Valence electrons
      (b) Crystal lattice
      (c) Donors and acceptors
      (d) P–N junctions
   2. Semiconductor rectifiers
      (a) Crystal diodes
      (b) Power rectifiers
   3. Transistors
      (a) Point contact transistors
      (b) Junction transistors
      (c) Transistor parameters
      (d) Power transistors

B. Laboratory Projects
   1. Semiconductor diode characteristics
      (a) Obtain measurement for plotting forward and reserve voltage-current relations.
      (b) Give informal report.
   2. Characteristics of junction transistors and surface-barrier transistors
      (a) Examine effects of changing operating voltages and currents.
      (b) Give informal report.
   3. Common-base amplifier characteristics
      (a) Make gain and frequency response measurements.
      (b) Demonstrate biasing methods.
      (c) Give informal report.
   4. Common-emitter amplifier characteristics. Follow procedure similar to experiment 3.
   5. Study bias and stabilization by making measurements in circuits with fixed bias and with self-bias
   6. If time allows, basic transistor receiver circuits may be connected, serving as an introduction to details that will be studied in advanced courses.

Division III. Power Supplies

A. Units of Instruction
   1. Rectifier circuits
      (a) Half-wave and full-wave rectification
      (b) Bridge rectifiers
      (c) Metallic-oxide rectifiers
      (d) Peak inverse voltage
   2. Voltage multipliers; transformerless power supplies
      (a) Doubler circuits
      (b) Triplers and quadruplers
   3. Filter circuits
      (a) Choke input; capacitor input; resistance-capacitance filters
      (b) Voltage dividers; bleeders
   4. Other types of power supplies
      (a) Non-synchronous vibrators
      (b) Synchronous vibrators
      (c) Dynamotors
      (d) Inverter circuits
   5. Voltage regulation
      (a) Ballast tubes
      (b) Glow-tube regulator
      (c) Electronic regulation
      (d) Saturable reactor regulation

B. Laboratory projects
   1. Transformer familiarization
      (a) Examine new or used power transformers—each student should check several units
      (b) Make ohmmeter measurements for lead identification
      (c) Make voltage measurement of windings. Reduced voltage may be applied to the primary as a safety precaution
      (d) Write an informal report showing results, with reference to standard transformer color coding
   2. Demonstration of typical power supply, with student reports of observations
      (a) Study waveforms at various points
      (b) Measure output voltages and ripple with various filters.
      (c) Make measurements of regulation with various filters
      (d) Make a comparison of full-wave and half-wave rectification
      (e) Provide correction of faults in power supplies
      (f) Write an informal report

3. Voltage regulator tubes
   (a) Assemble and connect a voltage regulator tube circuit
   (b) Collect data and graphically show regulator action for conditions for changing line voltage and for changing values of load
   (c) Compare voltage—current curves of 56–51 and B2
   (d) Write an informal report
4. Voltage divider design
   (a) Solve a laboratory problem in figuring resistance and wattage ratings for a divider supplying several loads with different voltages and currents. Check of computations by measurements on the actual circuit
   (b) Write an informal report
5. Vibrators and dynamotors
   (a) Examine and test a vibrator power supply, such as found in car radios
   (b) Examine a dynamotor, generator, or motor, to note construction features of rotating machines.
   (c) Write an informal report

Division IV. Audio Amplifiers

A. Units of Instruction

1. Amplifier classification
   (a) Classification by use—voltage and power amplifiers
   (b) Classification by bias—Class A, Class B, Class AB, and Class C
   (c) Classification by frequency response—audio, intermediate, radio, video, and broad band
2. Distortion in amplifiers
   (a) Frequency distortion
   (b) Phase distortion
   (c) Amplitude distortion
3. Coupling methods
   (a) Resistance-capacitance coupling, equivalent circuits
   (b) Impedance coupling
   (c) Transformer coupling
   (d) Direct coupling—balanced amplifier
4. Feedback amplifiers
   (a) Effects of positive and negative feedback
   (b) Advantages of negative feedback—reduction of noise and distortion, improvement of frequency response, stability and independence of load change
   (c) Negative feedback circuits—current feedback and voltage feedback
5. Phase inverters
   (a) Transformer inverter-phase splitters
   (b) Paraphase amplifiers—inverters
6. Power amplifiers
   (a) Ratings—maximum output, efficiency, power sensitivity
   (b) Power diagrams; load line
   (c) Push-pull amplifiers; graphical analysis
   (d) Output transformers; impedance matching

B. Laboratory Projects

1. Resistance-capacitance coupled amplifier
   (a) Measure frequency response
   (b) Measure voltage amplification
   (c) Determine the effect of load resistance value
   (d) Demonstrate the effect of cathode by-passing
   (e) Write an informal report
2. Impedance-coupled amplifier
   (a) Make a measurement of gain and frequency response
   (b) Write an informal report
3. Transformer coupled amplifier
   (a) Make a measurement of gain and frequency
   (b) Measure the effect of turns-ratio (repeat part (a) with a different transformer)
   (c) Make an informal report
   (d) Test a audio system, giving a demonstration of noise, distortion, and power measurements

Division V. Tuning Circuits

A. Units of Instruction

1. Series resonant circuits
   (a) Impedance variation with frequency
   (b) Applications in electronics
2. Parallel resonant circuits
   (a) Effect of frequency on voltage, current, and impedance
   (b) Uses in tube circuits
3. Resonance curves
   (a) Circuit Q
   (b) Half-power points

4. Selectivity
   (a) Design characteristics
   (b) Fidelity
   (c) L/C ratio

B. Laboratory projects
1. Analysis of capacitive and inductive reactances
2. Audio-frequency power amplifier
   (a) Make a measurement of output transformer turns ratio and impedance ratio
   (b) Make a measurement of power output
   (c) Make a measurement of power sensitivity
   (d) Write an informal report
3. Phase-splitter
   (a) Make a check of signal amplitude and phase relations
   (b) Demonstrate changes due to faults
   (c) Write an informal report
4. Push-pull audio power amplifier
   (a) Demonstrate the balance of the circuit
   (b) Demonstrate output impedance matching
   (c) Illustrate applications of amplifier in troubleshooting
   (d) Write an informal report
5. Audio systems
   (a) Make a demonstration of institutional systems of intercommunications and sound distribution
   (b) Study the selection and interconnection of components of a high-fidelity system
   (c) Make experimental measurements showing variations with frequency
   (d) Demonstrate the effects of series and parallel combinations
6. Alternating current circuit analysis
   (a) Make voltage measurements with capacitance, inductance, and resistance connected across the 60-cycle line
   (b) Write an informal report, with vector analysis of voltages measured
7. Series resonance
   (a) Measure variations of line current with changes in frequency. Current from an audio signal generator to be determined with vacuum tube voltmeter by measuring the voltage acrcss a 100-ohm series resistor
   (b) Make a graph of curves for current variations with capacitor only, inductance only, and their series combination.
   (c) Measure and plot response with a different L/C ratio
   (d) Demonstrate the effect of series resistance on Q
   (e) Write an informal report
8. Parallel resonance
   (a) Make measurements to show effect of parallel tuned circuit, with procedure similar to that in experiment 2 of Division V
   (b) Write an informal report

Division VI. Radio-Frequency Amplifiers

A. Units of instruction
1. Voltage amplification of tuned stages
   (a) Effect of coil Q
   (b) Gain calculations
2. Band-pass coupling
   (a) Critical coupling
   (b) Coupled impedance
3. Multi-stage amplifiers
   (a) Overall response
   (b) Control of undesired regeneration

B. Laboratory Projects
1. Construct a tuned-radio-frequency receiver on breadboard or chassis. Detector laboratory power supply and separate audio amplifier may be used, so that only the tuner need be constructed.
2. Adjust and operate tuner
3. Write an informal report describing adjustments and results

Division VII. Detector Circuits

A. Units of Instruction
1. Diode detection—practical circuits
2. Plate detection
   (a) Operating point
   (b) Cathode bias
3. Grid detection—grid lead-action
4. Heterodyne detection—beat frequencies
5. Regenerative detection—control of feedback
6. Autodyne detection—frequency limitations

7. Superregeneration
   (a) Separately quenched
   (b) Self-quenched circuits
8. Automatic volume control
   (a) Supercontrol tubes
   (b) Delayed control

B. Laboratory Projects
1. Diode detector
   (a) Demonstrate and diagram waveforms of detector in training equipment when fed with modulated signal generator
   (b) Write an informal report of detector action with various values of load
2. Superheterodyne construction
   The receiver for this study may be a kit, or may be a typical superheterodyne assembled with separately obtained parts. Chassis construction should be used. Laboratory power supply units may be utilized, but a self-contained power supply is preferable. Circuit wiring should begin with the power supply and the output stage, working back to the antenna terminals. Students should have a check-list for testing their work themselves before the instructor is asked to locate any errors. Demonstrations of typical circuits for a superheterodyne, using laboratory training aids, may be given by the instructor at appropriate stages of student progress.

Division VIII. Electronic Instruments

A. Units of Instruction
1. Measuring instruments
   (a) Multimeters for measuring resistance, voltage, and current
   (b) Output meters
   (c) Effect of meter loading
   (d) Vacuum tube voltmeters, transistor voltmeters
   (e) High impedance meters
   (f) Digital voltmeters
   (g) Counters
2. Cathode-ray oscilloscope
   (a) Principle of operation
   (b) Interpretation of patterns
   (c) Uses in electronic testing
3. Miscellaneous equipment
   (a) Signal generators
   (b) Sweep oscillators
   (c) Tube and transistor testers
   (d) Capacitor checkers
   (e) Signal tracers

B. Laboratory Projects
1. Test tubes and transistors and other components, as directed.
2. Learn operation of the oscilloscope with particular emphasis on the significance of the lissajous figures, interpretation of patterns and results.
3. Compare the performance of digital voltmeters with the more conventional designs—accuracy, speed, and impedance are to be considered.

Texts and References

DEFRANCE. *General Electronics Circuits*
GENERAL ELECTRIC CO. *Silicon Controlled Rectifier Manual*
——— *Transistor Manual*
GILLIE. *Electrical Principles of Electronics*
HEWLETT-PACKARD. *Microwave Theory and Measurement*
HURLEY. *Transistor Logic Circuits*
KIVER. *Transistors*
KLOEFFLER. *Basic Electronics*
STUDER. *Electronic Circuits and Instrumentation Systems*
TURNER. *Basic Electronic Test Instruments*
——— *Basic Electronic Test Procedures*
WHEELER. *Introduction to Microwaves*
WILCOX. *Basic Electronics*
ZEINES. *Principles of Applied Electronics*

Visual Aids

Bell Telephone Business Office (Local)
The Transistor. 10 min., 16 mm, black and white, sound
Zone Melting. 45 min., 35 mm, color, sound

Bray Studios, Inc., 729 Seventh Avenue, New York, 19, N.Y., *and* Remington Rand, Univac Division, Audio-Visual Engineering Section, Univac Park, St. Paul Minn.
Semi-Conductors. 43 min., 16 mm, black and white, sound

McGraw Hill Book Co., Text-Film Department, 330 West 42nd Street, New York, N.Y.
Principles of the Transistor. Produced by Educational Foundation for Visual Aids. 20 min., 16 mm, black and white, sound

Westinghouse Electric Corp., Motion Picture, Dept., P.O. Box 868, Pittsburgh, Pa.
Semiconductor Training Course. Filmstrip

Technical Reporting

Hours Required

Class, 3; Laboratory, 6

Course Description

This course emphasizes the means for presenting information effectively, using drawings, prints, sketches, outlines, and engineering reports. Much of the subject matter for the course may be necessary reports written for other subjects. The use of graphs, mathematical relationships, and drawings to present significant points clearly is an important portion of the course. Engineering and development work usually employs to a considerable degree sketches and free-hand drawings. A technician should be able to make suitably illustrative rough sketches or drawings to provide adequate information for making a part or to describe some machine, component, system, or circuit.

The student should become proficient in making instrumentation drawings, sketches, and bills of materials. The logical development of ideas and conclusions is of primary importance. The course should be coordinated with *Physics for Instrumentation II* and should build on the experiences of *Communications Skills* (first semester). Each class period should be followed by a laboratory period in which theories and principles are translated into practice.

Major Divisions

	Hours Class	Hours Laboratory
I Diagnostic Tests	3	0
II. Technical Sketching	8	18
III. Dimensioning Drawing	3	6
IV. Pictorial Drawing	5	10
V. Electrical and Electronic Symbols	4	8
VI. Instrumentation Symbols	4	8
VII. Sketch of Simple Instrument Installation	4	8
VIII. Graphical Presentation of Data	6	12
IX. The Oral Report (Using material prepared in class)	3	6
X. The Engineering Report	8	20

Division I. Diagnostic Tests

A. Unit of Instruction

1. Ascertaining the general level of competence in the main areas of sketching, drawing, dimensioning, symbols, and graphs

B. Laboratory Projects

Division II. Technical Sketching

A. Units of Instruction

1. Techniques of freehand sketching
   - (a) Measuring subject
   - (b) Blocking drawing, and proportions
   - (c) Detailing
2. Theory of projection
   - (a) Isometric
   - (b) Oblique
   - (c) Sketching
3. Multiview drawing
   - (a) Principles of multiview drawing
   - (b) Relationship of views
   - (c) Selection of views
   - (d) Treatment of invisible surfaces and center lines
4. Sectional views
   - (a) Types and purposes
     - (1) Symbolic lines
     - (2) Half sections and broken sections
     - (3) Full sections

B. Laboratory Projects

1. Make freehand sketches of simple instrumentation and control element parts to develop skill in estimating distances, proportions, relative sizes, and relationships

Division III. Dimensioning Drawing

A. Units of Instruction

1. General dimensioning
   - (a) Size and location dimensions
   - (b) Fractional and decimal dimensioning
   - (c) Do's and don'ts of dimensioning
   - (d) Procedure in dimensioning
2. Formulation and placement of shop notes
   - (a) Purpose of notes
   - (b) Shop terms of processor
   - (c) How to make measurements of shop operations
3. Tolerances
   - (a) Purpose

(b) Terminology
(c) Classes of fits

B. Laboratory Projects
1. Construct freehand multiview drawings of machine parts requiring simple dimensions and shop notes
2. Construct freehand multiview drawings of more complex machine parts requiring decimal dimensioning and determining and indicating tolerances

Division IV. Pictorial Drawing

A. Units of Instruction
1. Isometric drawing
(a) Position of axes
(b) Non-isometric lines
(c) Steps in construction
(d) 4-center method of constructing ellipses
(e) Advantages and disadvantages
2. Oblique drawing
(a) Choice of positions of axes
(b) Steps in construction
(c) Methods of reducing distortion
(d) Advantages and disadvantages
3. Perspective
(a) General principles
(b) One-point
(c) Two-point
(d) Advantages and disadvantages
4. Shading
(a) Shade lines
(b) Surface shading with lines
(c) Smudge shading
(d) Stippling

B. Laboratory Projects
1. Make an isometric drawing of a pneumatic pressure transmitter, or some similar piece of equipment
Stress correct project and position of axes
Require suitable shading
2. Make an oblique drawing of a similar item
3. Make a perspective drawing of a small building or control panel. Use either one- or two-point perspective

Division V. Electrical and Electronic Symbols

A. Units of Instruction
1. Industrial symbols
(a) Electronic
(b) Electrical
(c) Architectural
(d) Relay
2. Schematic diagrams
(a) Schematic layouts
(b) One-line diagrams
3. Wiring diagrams
(a) Industrial buildings
(b) Power plants
(c) Communication circuits
(d) Data transmission

B. Laboratory Projects
1. Study and learn the symbols commonly used to represent electrical and electronic components and assemblies. Apply them in simple schematic arrangements
2. Construct a simple one-line diagram of an industrial power plant
3. Make a schematic diagram of the same installation

Division VI. Instrumentation Symbols

A. Units of Instruction
1. Industrial symbols
(a) Pneumatic instrumentation
(b) Electric and electronic instruments and controls
2. Schematic diagrams
(a) Pneumatic instrumentation systems
(b) Electronic instrumentation systems

B. Laboratory Projects
1. Using the correct symbols, develop the schematic diagram for some industrial process using pneumatic instrumentation (an air-conditioning system, for example)
2. Using the correct symbolism, create a schematic and a wiring diagram for a relatively simple electronic control system

Division VII. Sketch of Simple Instrument Installation

A. Units of Instruction
1. Preferred ways of presenting pneumatic installations
(a) Single instruments
(b) Multiple instruments
2. Other types of instruments
(a) Single instrument
(b) Multiple instruments

B. Laboratory Projects
1. Sketch the apparatus and piping required for the calibration of pressure gages. Also include a piping sketch

showing necessary fittings and pipe sizes
2. Sketch the instruments required for an industrial control console or panel

Division VIII. Graphical Presentation of Data
A. Units of Instruction
1. Types of graph paper
(a) Rectangular
(1) Inch scale
(2) Centimeter scale
(b) Semi-log
(c) Log-log
(d) Circular
2. Proper scaling of paper
(a) Selection of scales
(b) Broken scales
(c) Double scales
3. Points and lines
(a) Point plotting
(b) Line identification
(c) Name plate
4. Data from graphs
(a) Proper data from graph and calculations
(b) Error points
5. Construction of nomographs
B. Laboratory Projects
1. Plot and obtain information from the following type graphs:
(a) Rectangular
(b) Polar
(c) Semi-log
(d) Log-log
(e) Tri-linear
2. Construct two simple nomographs

Division IX. The Oral Report
A. Units of Instruction
1. Organization of material for effective presentation
2. Formal and informal reports
3. The use of notes
4. The use of slides, exhibits
5. Proper use of the voice
6. Elimination of objectionable mannerisms
7. Introductions
B. Laboratory Projects
1. Present an informal report covering some aspect of instrumentation or its applications
2. Present a formal oral report to the class with the use of slides, graphs, diagrams, or other supporting material

Division X. The Engineering Report
A. Units of Instruction
1. Characteristics of the report
2. Report functions
3. Informal reports
(a) Short-form reports
(1) Memorandum reports
(2) Business letter reports
(3) Outline reports
4. The formal report
(a) Arrangement
(1) Cover and title page
(2) Table of contents
(3) Summary of abstracts
(4) Body of the report
(5) Bibliography and appendix
(6) Graphs and drawings
(b) Preparation
(1) Collecting, selecting, and arranging material
(2) Writing and revising the report
5. Special types of papers
(a) The abstract
(b) Process explanations
(c) The case history
(d) The book review
B. Laboratory Projects
1. Prepare a complete engineering report covering the proposed expansion of some plant or the installation of equipment. It should make full use of graphic means to substantiate its recommendations

Texts and References

AMERICAN STANDARD ASSOCIATION. *Drafting Manual.* ASA-Y14
——— *Graphic Symbols*, ASA-Y32
BAER. *Electrical and Electronics Drawings*
FRENCH. *Fundamentals of Engineering Drawings*
GRACHINO. *Drafting and Graphics*
HOELSCHER. *Engineering Drawing and Geometry*
INSTRUMENT SOCIETY OF AMERICA. *Recommended Practice—Instrumentation Flow Plan Symbols*, ISA-RP5.1
LEVEN. *Graphics with an Introduction to Conceptual Design*
SOUTHER. *Technical Report Writing*

Visual Aids

THE PENNSYLVANIA STATE UNIVERSITY, University Park, Pa.
According to Plan: Introduction to Engineering Drawing, 9 min., 16 mm, sound
Drawing and the Shop, 15 min., 16 mm, sound
Freehand Drafting, 15 min., 16 mm, silent
Shop Drawings, 22 min., 16 mm, sound

General Courses

Communication Skills

Hours Required

Class, 3; Laboratory, 0

Course Description

The course places emphasis throughout on exercises in writing, speaking, and listening. Analysis is made of each student's strengths and weaknesses. The pattern of instruction is geared principally to helping students improve skills in areas where common weaknesses are found. The time allotments for the various elements within major divisions will depend upon the background of the class.

Major Divisions

	Class hours
I. Sentence Structure	6
II. Using Resource Materials	4
III. Written Expression	20
IV. Talking and Listening	12
V. Improving Reading Efficiency	6

Division I. Sentence Structure
- A. Units of instruction
  1. Diagnostic test
  2. Review of basic parts of speech
  3. What makes complete sentences
  4. Use and placement of modifiers, phrases, and clauses
  5. Sentence conciseness
  6. Exercises in sentence structure

Division II. Using Resource Materials
- A. Units of instruction
  1. Orientation in use of school library
     - (a) Location of reference materials, *Readers Guide*, etc.
     - (b) Mechanics for effective use
     - (c) Dewey Decimal System
  2. Dictionaries
     - (a) Types of dictionaries
     - (b) How to use dictionaries
     - (c) Diacritical markings and accent marks
  3. Other reference sources
     - (a) Technical manuals and pamphlets
     - (b) Bibliographies
     - (c) Periodicals
     - (d) *Industrial Arts Index*
  4. Exercises in use of resource materials
     - (a) *Readers Guide*
     - (b) Atlases
     - (c) Encyclopedias
     - (d) Other

Division III. Written Expression (emphasis on student exercises)
- A. Units of Instruction
  1. Diagnostic test
  2. Paragraphs
     - (a) Development
     - (b) Topic sentence
     - (c) Unity of coherence
  3. Types of expression
     - (a) Inductive and deductive reasoning
     - (b) Figures of speech
     - (c) Analogies
     - (d) Syllogisms
     - (e) Cause and effect
     - (f) Other
  4. Written exercises in paragraph
  5. Descriptive reporting
     - (a) Organization and planning
     - (b) Emphasis on sequence, continuity, and delimitation to pertinent data or information
  6. Letter writing
     - (a) Business letters
     - (b) Personal letters
  7. Mechanics
     - (a) Capitalization
     - (b) Punctuation—when to use:

(1) Period, question mark, and exclamation point
(2) Comma
(3) Semicolon
(4) Colon
(5) Dash
(6) Parentheses
(7) Apostrophe

(c) Spelling
(1) Word division—syllabification
(2) Prefixes and suffixes
(3) Word analysis and meaning—context clues, phonetics, etc.

8. Exercises in mechanics of written expression

Division IV. Talking and Listening (emphasis on student exercises)

A. Units of instruction
1. Diagnostic testing
2. Organization of topics or subject
3. Directness in speaking
4. Gesticulation and use of objects to illustrate
5. Conversation courtesies
6. Listening faults
7. Taking notes
8. Understanding words through context clues
9. Exercises in talking and listening

Division V. Improving Reading Efficiency

A. Units of instruction
1. Diagnostic test
2. Reading habits
(a) Correct reading posture
(b) Light sources and intensity
(c) Developing proper eye span and movement
(d) Scanning
(e) Topic sentence reading
3. Footnotes, index, bibliography, cross references, etc.
4. Techniques of summary
(a) Outline
(b) Digest or brief
(c) Critique
5. Exercise in reading improvement
(a) Reading for speed
(b) Reading for comprehension

Texts and References

BAIRD and KNOWER. *Essentials of General Speech*
——— ———. *General Speech: An Introduction*
BORDEAUX. *How To Talk More Effectively*
CROUCH and ZETLER. *A Guide to Technical Writing*
THOMPSON. *Fundamentals of Communication*
WARRINER and GRIFFITH. *English Grammar and Composition: A Complete Handbook*
WITTY. *How To Become a Better Reader*
YOUNG and SYMONIK. *Practical English, Introduction to Composition*

General and Industrial Economics

Hours Required

Class, 3; Laboratory, 0

Course Description

A study of economics designed to impart a basic understanding of the principles of economics and their implications, to develop the ability to follow an informed personal finance program, to aid in the development of intelligent consumption, and to provide an understanding of the underlying relationship of cost control to success in industrial enterprise. The programs or problems worked upon by an instrumentation technician in either research or production ultimately must be measured by a cost analysis. Awareness of this fact and a knowledge of elementary economics prepare the student for the cost-conscious environment of his future employment. It is suggested that the instruction in this course be based on this pragmatic approach and that students be encouraged to study examples from industry as they learn about industrial cost analysis, competition, creation of demand, economic production, and related aspects of applied economics.

Major Divisions

		Class hours
I.	Introduction	2
II.	Economic Forces and Indicators	3
III.	Natural resources—The Basis of Production	3
IV.	Capital and Labor	3
V.	Business Enterprise	7
VI.	Factors of Industrial Production Cost	8
VII.	Price, Competition, and Monopoly	5
VIII.	Distribution of Income	2
IX.	Personal Income Management	2
X.	Insurance, Personal Investments, and Social Security	3
XI.	Money and Banking	3
XII.	Government Expenditures, Federal and Local	3
XIII.	Fluctuations in Production, Employment, and Income	2
XIV.	The United States Economy in Perspective	2

Division I. Introduction

1. Basic economic concepts

Division II. Economic Forces and Indicators

1. Economics defined
2. Modern specialization
3. Increasing production and consumption
4. Measures of economic activity
   (a) Gross national product
   (b) National income
   (c) Disposable personal income
   (d) Industrial production
   (e) Employment and unemployment

Division III. Natural Resources—The Basis of Production

1. Utilization and conservation of resources
2. Renewable resources
3. Non-renewable resources
4. Future sources

Division IV. Capital and Labor

1. Tools (Capital)
   (a) The importance of saving and investment
   (b) The necessity for markets
2. Large-scale enterprise
3. Labor
   (a) Population characteristics
   (b) Vocational choice
   (c) General education
   (d) Special training
   (e) Management's role in maintaining labor supply

Division V. Business Enterprise

1. Forms of business enterprise
   (a) Individual proprietorship
   (b) Partnership
   (c) Corporation
2. Types of corporate securities
   (a) Common stocks
   (b) Preferred stocks
   (c) Bonds
3. Mechanics of financing business
4. Plant organization and management

Division VI. Factors of Industrial Production Cost

1. Buildings and equipment
   (a) Initial cost and financing
   (b) Repair and maintenance costs
   (c) Depreciation and obsolescence costs

2. Materials
   (a) Initial cost and inventory value
   (b) Handling and storage costs
3. Processing and Production
   (a) Methods of cost analysis
   (b) Cost of labor
   (c) Cost of supervision and process control
   (d) Effect of losses in percentage of original product compared to finished product (yield) in chemical operations
4. Packaging and shipping
5. Overhead costs
6. Taxes
7. Cost of selling
8. Process analysis, a means to lower costs
9. Profitability and business survival

Division VII. Price, Competition, and Monopoly

1. Function of prices
2. Price determination
   (a) Competitive cost of product
   (b) Demand
   (c) Supply
   (d) Interactions between supply and demand
3. Competition, benefits, and consequences
   (a) Monopoly and oligopoly
   (b) Forces that modify and reduce competition
   (c) History of government regulation of competition
4. How competitive is our economy?

Division VIII. Distribution of Income

1. Increasing real incomes
2. Marginal productivity
3. Supply in relation to demand
4. Incomes resulting from production
   (a) Wages
   (b) Interest
   (c) Rents
   (d) Profits
5. Income distribution today

Division IX. Personal Income Management

1. Consumption—the core of economics
2. Economizing defined
3. Personal and family budgeting
4. Analytical buying
   (a) Applying quality standards
   (b) Consumer's research and similar aids
5. The use of credit
6. Housing—own or rent

Division X. Insurance, Personal Investments, and Social Security

1. Insurance defined
2. Life insurance
   (a) Group, industrial, and ordinary life policies
   (b) Types of policies—their advantages and disadvantages
3. Casualty insurance
4. Investments
   (a) Savings accounts and Government bonds
   (b) Corporation bonds
   (c) Corporation stocks
   (d) Annuities
   (e) Pension plans
5. Social Security
   (a) Old-Age and Survivors Insurance
   (b) Unemployment Compensation

Division XI. Money and Banking

1. Functions of money
2. The Nation's money supply
3. Organization and operation of a bank
   (a) Sources of deposits
   (b) The reserve ratio
   (c) Expansion of bank deposits
   (d) Sources of reserves
4. The Federal Reserve System
   (a) Service functions
   (b) Control of money supply
5. Federal Deposit Insurance Corporation

Division XII. Government Expenditures, Federal and Local

1. Economic effects
2. Functions of Government
3. Analysis of Government spending
4. Future outlook
5. Financing Government spending
   (a) Criteria of sound taxation
   (b) Tax revenues in the United States
   (c) The Federal and State personal income tax
   (d) The corporate income tax
   (e) The property tax
   (f) Commodity taxes

Division XIII. Fluctuations in Production, Employment, and Income

1. Changes in aggregate spending
2. Output and employment
3. Other factors affecting economic fluctuations
   (a) Cost-price relationships

(b) Fluctuations in demand for durable goods
(c) Involuntary fluctuation of supply of commodities
(d) Economic effects of war
(e) Inflation and deflation of currency value
(f) Economic effects of inventions and automation

4. Means of implementing fiscal policy
5. Government debt
   (a) Purposes of Government borrowing
   (b) How burdensome is the debt
   (c) Problems of debt management

Division XIV. The United States Economy in Perspective

1. Recent economic changes
   (a) Increased productivity and well-being
   (b) Effects of war and depression
   (c) New products and industries
   (d) Increase in governmental controls
2. Present economic problems of U.S. economy
   (a) The world market—a community of nations
   (b) International cooperation
   (c) Maintenance of prosperity and progress
   (d) Economic freedom and security
3. Communism
   (a) Nature and control by Soviet State
4. Fascism
5. British socialism
6. Problems common to all economic systems
7. Special economic problems of the United States

Texts and References

One of the books on the following list may be selected for a text. Others may be used for reference.

ARIES *and* NEWTON. *Chemical Engineering Cost Estimation.*
BLODGETT. *Comparative Economic Systems*
Business Week Magazine
Consumers' Research Report
Consumers' Union Reports
DONALDSON *and* PFAHL. *Personal Finance*
GORDON. *Economics for Consumers*
POND. *Essential Economics: An Introduction*
SAMUELSON. *Economics: An Introductory Analysis*

Visual Aids

McGraw-Hill Book Co., Inc., 330 West 42d Street, New York, N.Y.
- *Basic Economic Concepts.* 35 mm., filmstrip-set of 4 filmstrips. Average 40 frames each.
- *Savings and Investment.* 35 mm., filmstrip
- *Supply and Demand.* 35 mm., filmstrip
- *Money, Prices, and Interest.* 35 mm., filmstrip
- *Business Cycles and Fiscal Policy.* 35 mm., filmstrip

Industrial Organizations and Institutions

Hours Required

Class, 3; Laboratory, 0

Description

A description and analysis of the roles of labor and management in the economy of the United States is presented. Approximately half of the classroom time is devoted to labor-management relations, including the evolution and growth of the American labor movement and the development and structure of American business management. A study is made of the legal framework within which labor-management relations are conducted and the responsibilities of each in a democratic system of government. The second half of the course pertains to labor-economics as applied to the forces affecting labor supply and demand, problems of unemployment and wage determination on the national, plant, and individual levels. Emphasis centers upon current aspects of industrial society with historical references intended only as background.

Major Divisions

	Class hours
I. Labor in an Industrial World	9
II. Management in an Industrial Society	9
III. The Collective Bargaining Process	12
IV. Dynamics of the Labor Market	8
V. Wage Determination	7
VI. The Balance Sheet of Labor-Management Relations	3

Division I. Labor in an Industrial World

1. The nature and scope of the Industrial Revolution
   - (a) The factory system
   - (b) Occupational trends
   - (c) Mechanisms of adjustment
2. The evolution of American labor unions
   - (a) Nature of early unions: basic system of craft unions
   - (b) Organizations by unions for solving problems
   - (c) Emergence of business unionism
   - (d) The changing role of government
3. Structure and objectives of American unions
   - (a) Objectives in collective bargaining
   - (b) Political objectives and tactics
   - (c) Structure of craft and industrial unions
   - (d) Movement toward unity—the AFL–CIO merger

Division II. Management in an Industrial Society

1. The rise of big business
   - (a) Economic factors
   - (b) Dominance of the corporate firm
   - (c) Government, public policy, and big business
2. The Managerial Revolution
   - (a) Changing patterns of ownership and management
   - (b) Scientific management
   - (c) Twentieth century trends
3. Structure and objectives of American Industry
   - (a) Production for profit: an Affluent Society
   - (b) Structure of industry—organizational forms
   - (c) Ethics in a competitive economy

Division III. The Collective Bargaining Process

1. Legal framework
   - (a) Common law provisions
   - (b) The growth of statute laws
     - (1) The antitrust laws: aid to emergence of collective bargaining
     - (2) The Addamson and LaFollette Laws
     - (3) Norris-LaGuardia
     - (4) Wagner Act
     - (5) Taft-Hartley
     - (6) Landrum-Griffin and beyond
2. Management and collective bargaining
3. Bargaining procedures and tactics, including conciliation and mediation process
4. Issues in collective bargaining
   - (a) Security issues
   - (b) Working conditions
   - (c) Safety provisions and safety education
   - (d) Money matters
5. Strikes and lockouts: tactics and prevention
6. Evaluation of collective bargaining

Division IV. Dynamics of the Labor Market
1. Labor supply and the market
   (a) Level and composition of the labor force
   (b) Changing patterns of employment
   (c) Some questions about labor supply and the market
2. Reduction and control of unemployment
   (a) Types of unemployment
   (b) Proposed schemes of employment stabilization
   (c) Continuing problems
3. Labor mobility
   (a) Types of labor mobility
   (b) Deterrents to labor mobility
   (c) Suggested programs to improve labor mobility

Division V. Wage Determination
1. Wages, process, and employment
   (a) Meaning of wages
   (b) Wages and the productive process
   (c) The problem of inflation
2. Wages and the national income
   (a) Concepts of measurement and productivity
   (b) Determinants of productivity
   (c) The distribution of national income
3. Wage structures
   (a) Occupational differences
   (b) Geographic patterns
   (c) Industry patterns
   (d) Wage determination: plant level, individual wages

Division VI. The Balance Sheet of Labor-Management Relations
1. The control and elimination of poverty in a modern industrial State
   (a) The extent of poverty
   (b) The attack on poverty
   (c) Trends and portents
2. Justice and dignity for all in an industrial democracy
   (a) The worker—status and goals
   (b) Management—rights and responsibilities
   (c) The future of capitalisitc society

Texts and References

One of the books on the following list may be selected for a text. Others may be used for reference.

BLOOM and NORTHRUP. *Economics of Labor Relations*
CHAMBERLIN. *The Economic Analysis of Labor Union Power*
ELLS. *The Meaning of Modern Business: An Introduction to the Philosophy of Large Corporate Enterprise*
FAULKNER. *American Economic History, 8th Ed.*
GEARY. *The Background of Business, 2d Ed.*
GREGORY. *Labor and the Law, 2d Ed.*
GRIMSHAW and HENNESSEY. *Organizational Behavior—Cases and Readings*
KERR and others. *Industrialization and Industrial Man*
LEISERSON. *American Trade Union Democracy*
MCGREGOR. *The Human Side of Enterprise*
PFIFFNER. *Administrative Organization*
PHELPS. *Introduction to Labor Economics*
REYNOLDS. *Labor Economics and Labor Relations*
RICHBERG. *Labor Union Monopoly, A Clear and Present Danger*
SLICHTER, HELAY, and LIVERNASH. *The Impact of Collective Bargaining on Management*
SULTAN. *Labor Economics*
TAFT. *Economics and Problems of Labor*
U.S. DEPARTMENT OF LABOR. *The American Worker Fact Book*
——— BUREAU OF LABOR STATISTICS. *Interim Revised Projections of U.S. Labor Force*

Visual Aids

The Brookings Institution, Washington, D.C.
   Big Enterprise in the Competitive System. 40 min., 16 mm, color, sound
Coronet Films, Inc., Coronet Bldg., Chicago
   Labor Movement: Beginnings and Growth in America. 13½ min., 16 mm, sound
Encyclopeadia Britannica Films, Inc., 1150 Wilmette Ave., Wilmette, Ill.
   Productivity—Key to Plenty. 22 min., 16 mm, sound
   Working Together (A Case History in Labor Management Cooperation). 24 min., 16 mm, sound
McGraw-Hill Book Company, Inc., New York, N.Y.
   Internal Organization. 10 min., 16 mm, sound
   Job Evaluation and Merit Rating. 13 min., 16 mm, sound
Teaching Film Custodians, 25 West 43d Street, New York, N.Y.
   Bargaining Collectively. 10 min., 16 mm, sound
University of Indiana, Bloomington, Ind.
   Decision: Constitution and the Labor Union. 29 min., 16 mm, sound

FACILITIES, EQUIPMENT, AND COSTS

Planning of Facilities

Laboratories and related classrooms, offices, and storage facilities required for teaching instrumentation technology do not present special or unusual conditions peculiar to the technology. Any well-constructed building with suitable utilities may be used.

If possible, the main instrument shop should be on the ground floor where there is a solid foundation for the drill press and grinder, where suitable floor drains may be installed, and where such moderately heavy items as oxygen and acetylene bottles may be received or dispatched conveniently.

A classroom near the instrument shop and instrument laboratory is desirable. Classrooms and laboratories should be well lighted with a recommended minimum of 50-foot candles of light at the table or desk tops. Fluorescent lighting is satisfactory.

Hot and cold water, compressed air and steam service lines to instrument laboratories should be planned for the shortest length of piping consistent with laboratory arrangement. They should be hidden as far as practicable, but control points should be planned for safety, accessibility and ease of maintenance. It is recommended that *each laboratory* have a master control panel with shut-off valves for each utility. This master control panel should have a door with lock so that utilities can be controlled at a central point and locked up. Because of intermittent use of steam, a small capacity boiler may be located in or near the laboratory to operate independently of the heating system. A boiler of 10 to 15 h.p. capacity probably would be adequate.

Fuel gas is required in the laboratories. Gas lines should be installed with care, and should be protected to avoid damage.

Electrical services should provide both 110- and 220-volt single-phase electrical service for instrumentation laboratories. Most equipment used in the laboratory requires 110 volts; occasionally a 220-volt single-phase current is required.

In connecting electrical service to laboratory benches, it is suggested that each be connected to a separate circuit breaker, and the circuits be designed with ample capacity so that when a number of students in the laboratory are using electrical apparatus, the lines will not become overloaded. Each laboratory should have a separate master distribution control panel for electrical circuits.

The drawings and layouts which follow are suggested as examples of satisfactory classrooms laboratories for instrumentation technology. Since no one classroom and laboratory layout meets every need, three arrangements, figures 8, 9, and 10, are offered. Each layout provides individual features which may prove advantageous in light of such factors as already existing facilities, local industry needs, available funds, and size of classes. Each layout offers certain features which may assist in the design of a laboratory to satisfy the needs of a particular institution's program.

Figure 11 shows the construction of a typical student work bench, and figure 12 shows electric and pneumatic connections for the back panel of the bench.

Equipment, tools, and supplies.—Building and equipping adequate laboratories for the teaching of instrumentation is expensive. It may be feasible to build laboratories, install permanent work stations, and necessary initial equipment; and to provide the *minimum of laboratory equipment* required to begin the teaching program. This allows the program to be started with a minimum outlay of funds, and permits the cost of additional necessary or desirable equipment to be spread over a period of time during which laboratory equipment may be brought up to the level of a *well-equipped* facility.

Experience has shown that the department head or instructor should make final decisions on the choice of laboratory equipment because of his knowledge of technical details. The instructor can avoid costly mistakes which often result if non-technical personnel attempt to equip a scientific laboratory.

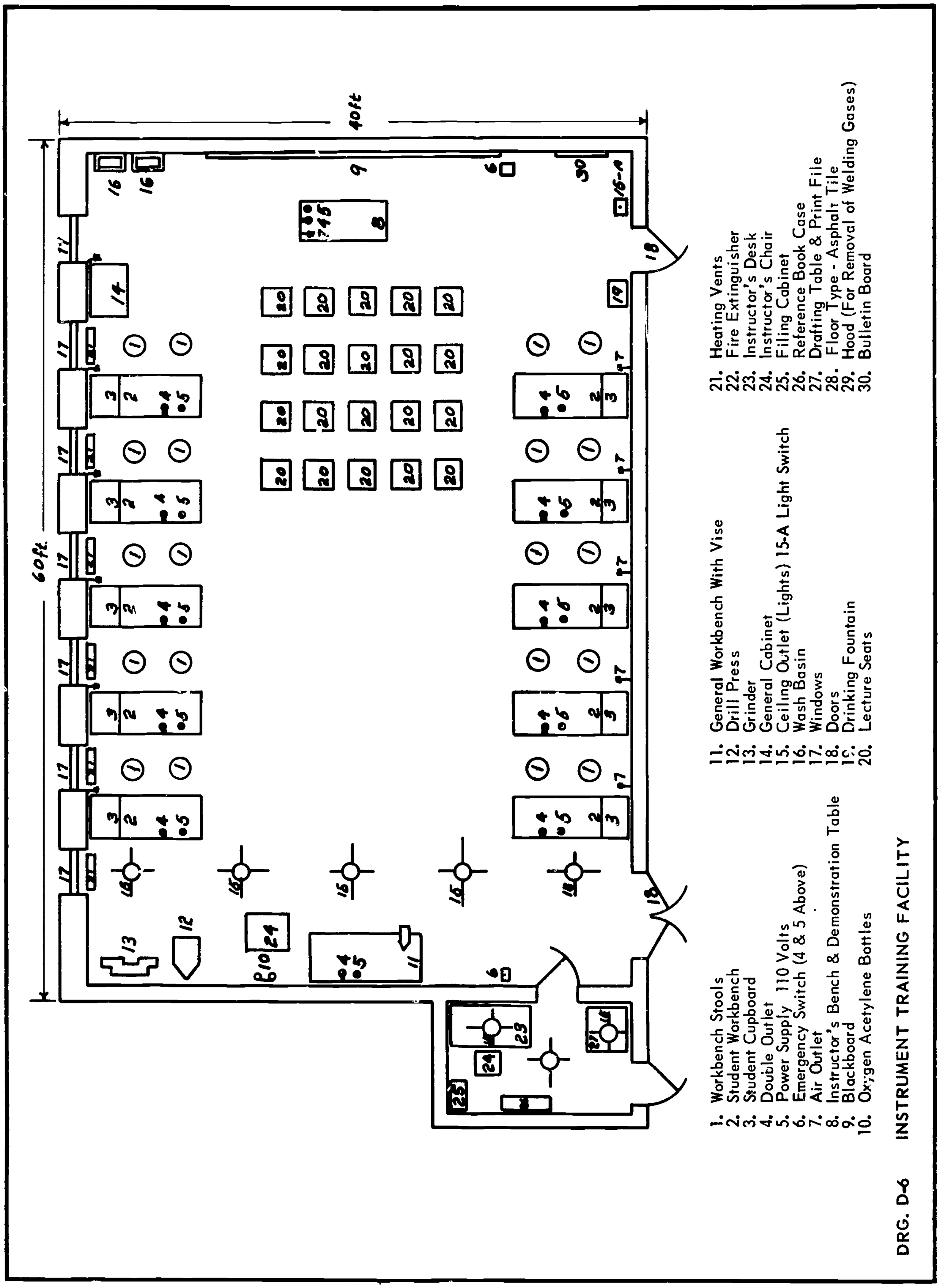


Figure 8
Instrument Training Facility.

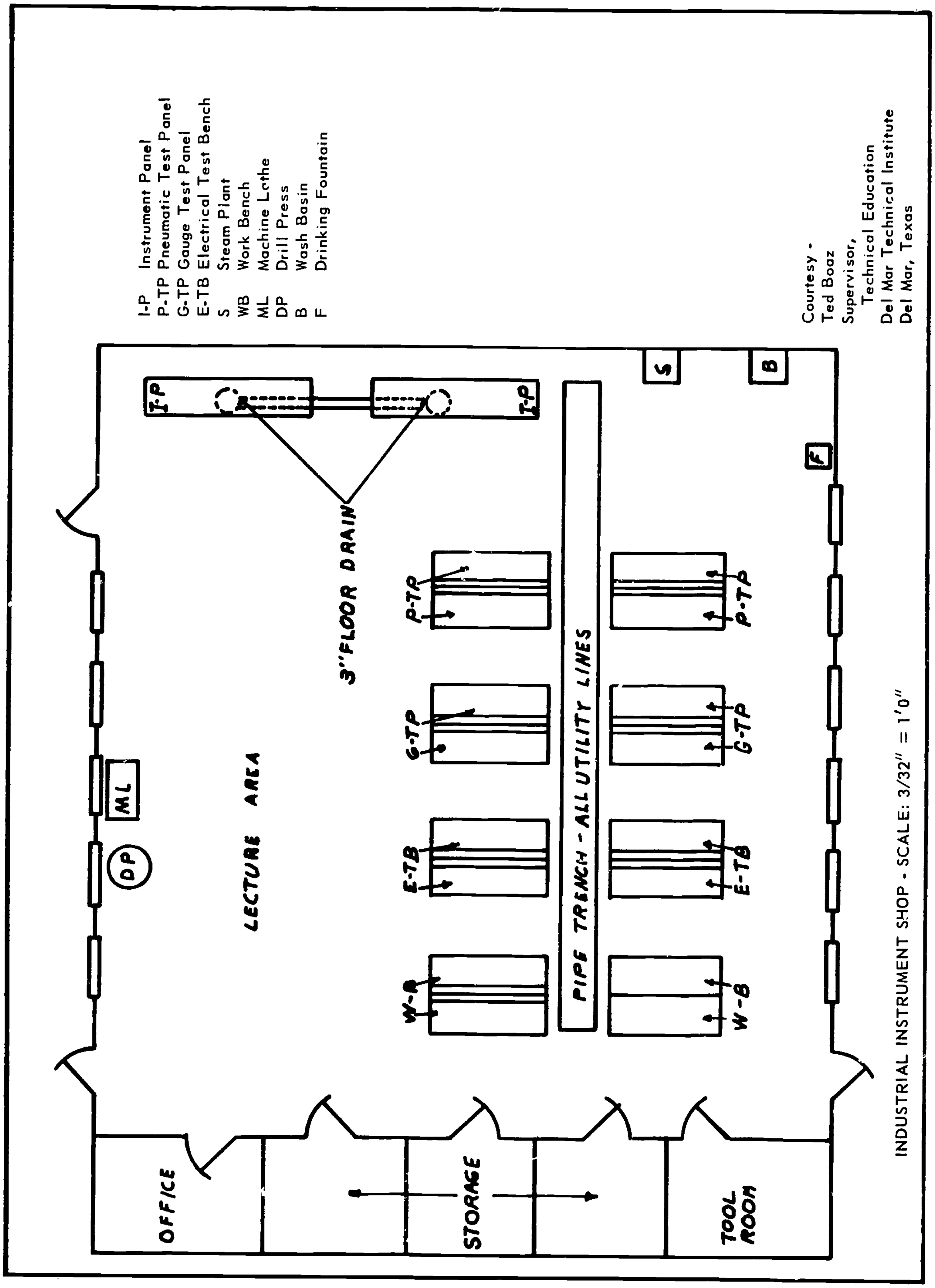


Figure 9
Industrial Instrument Shop.

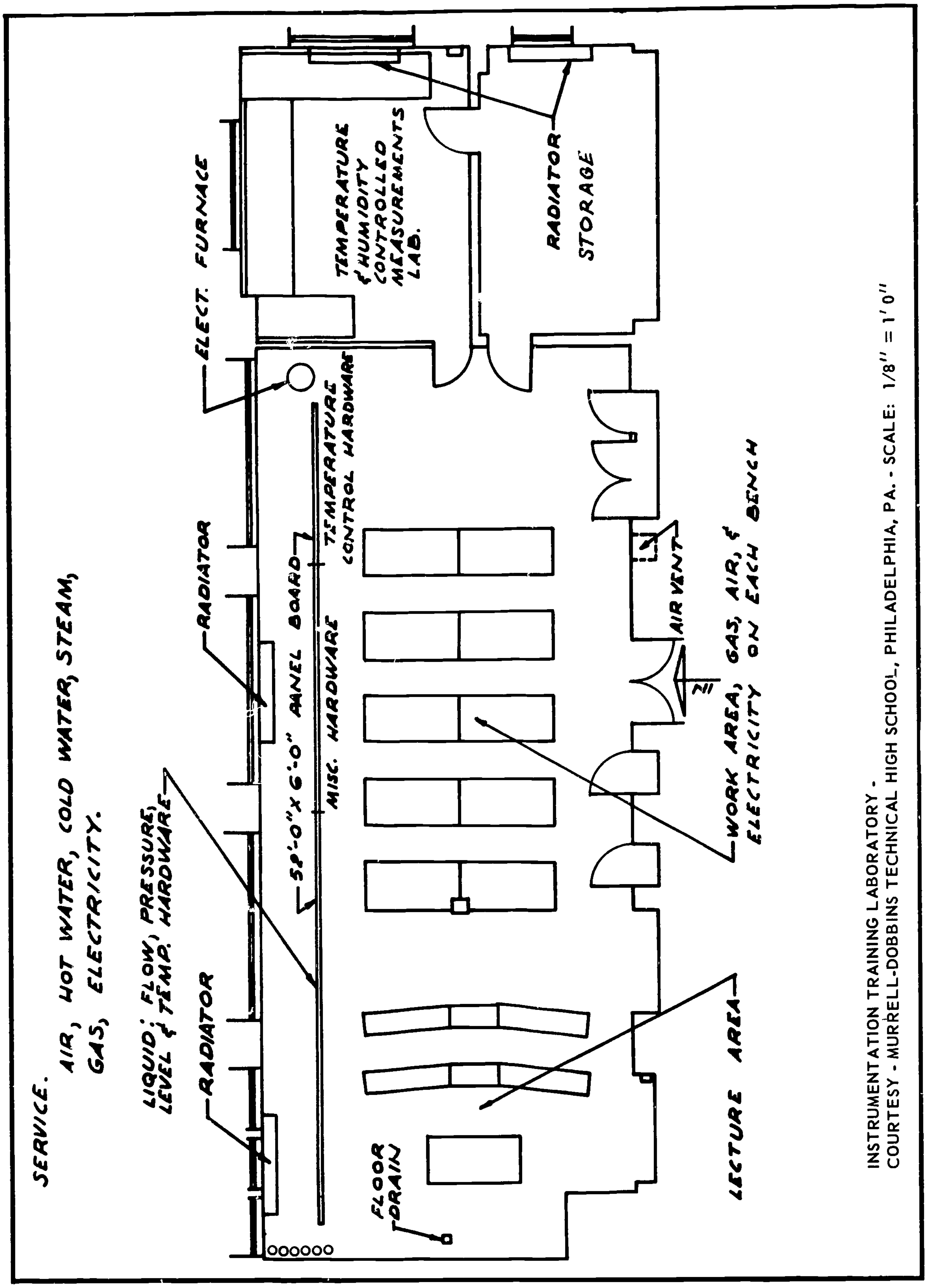
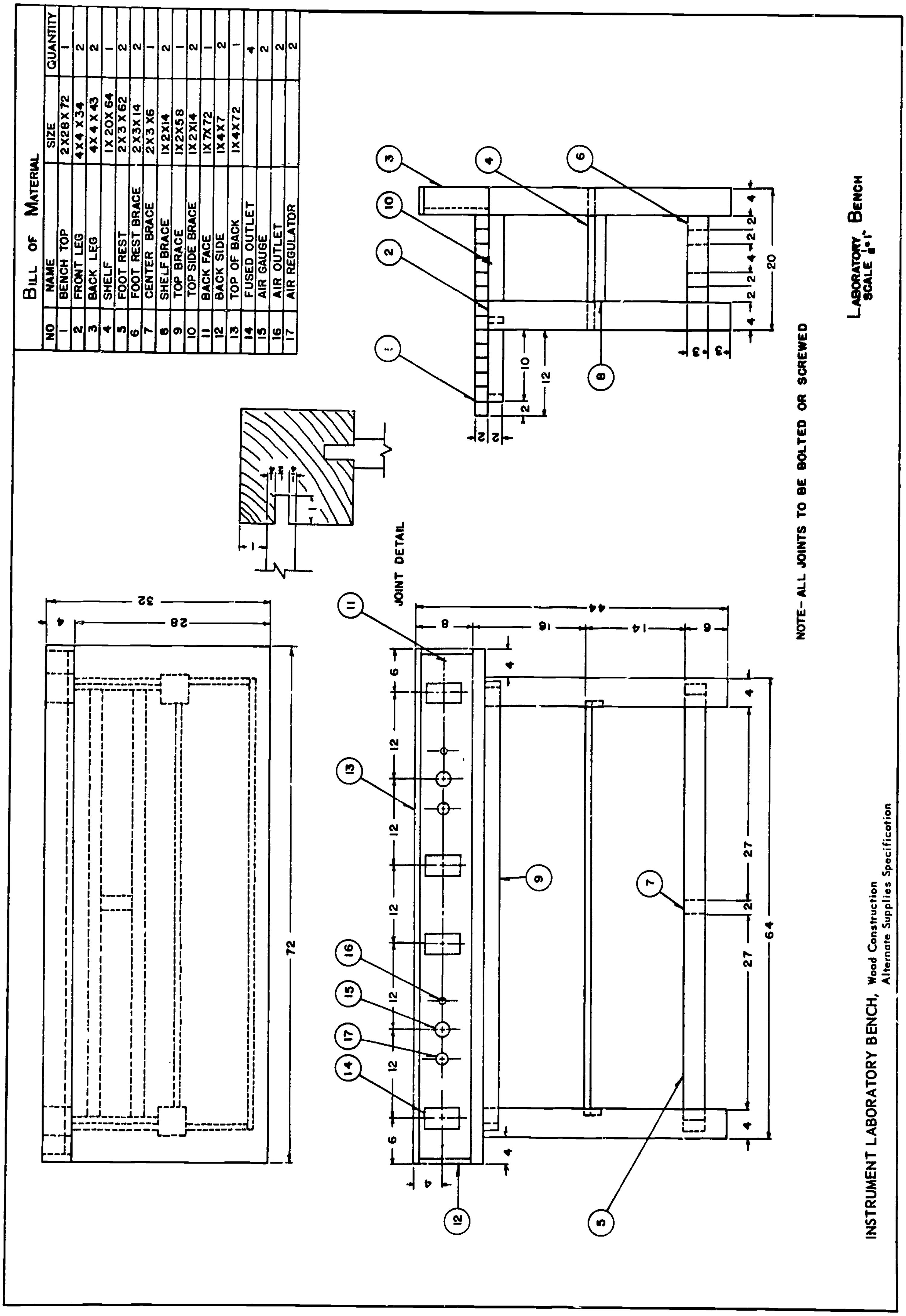


Figure 10
Instrumentation Training Laboratory.



Bill of Material

NO	NAME	SIZE	QUANTITY
1	BENCH TOP	2X28X72	1
2	FRONT LEG	4X4 X34	2
3	BACK LEG	4X 4 X 43	2
4	SHELF	1X 20X 64	1
5	FOOT REST	2X 3 X 62	2
6	FOOT REST BRACE	2X3X14	2
7	CENTER BRACE	2X3 X6	1
8	SHELF BRACE	1X2X14	2
9	TOP BRACE	1X2X58	1
10	TOP SIDE BRACE	1X2X14	2
11	BACK FACE	1X 7X72	1
12	BACK SIDE	1X4X7	2
13	TOP OF BACK	1X4X72	1
14	FUSED OUTLET		4
15	AIR GAUGE		2
16	AIR OUTLET		2
17	AIR REGULATOR		2

Figure 11
Instrument Laboratory Bench.

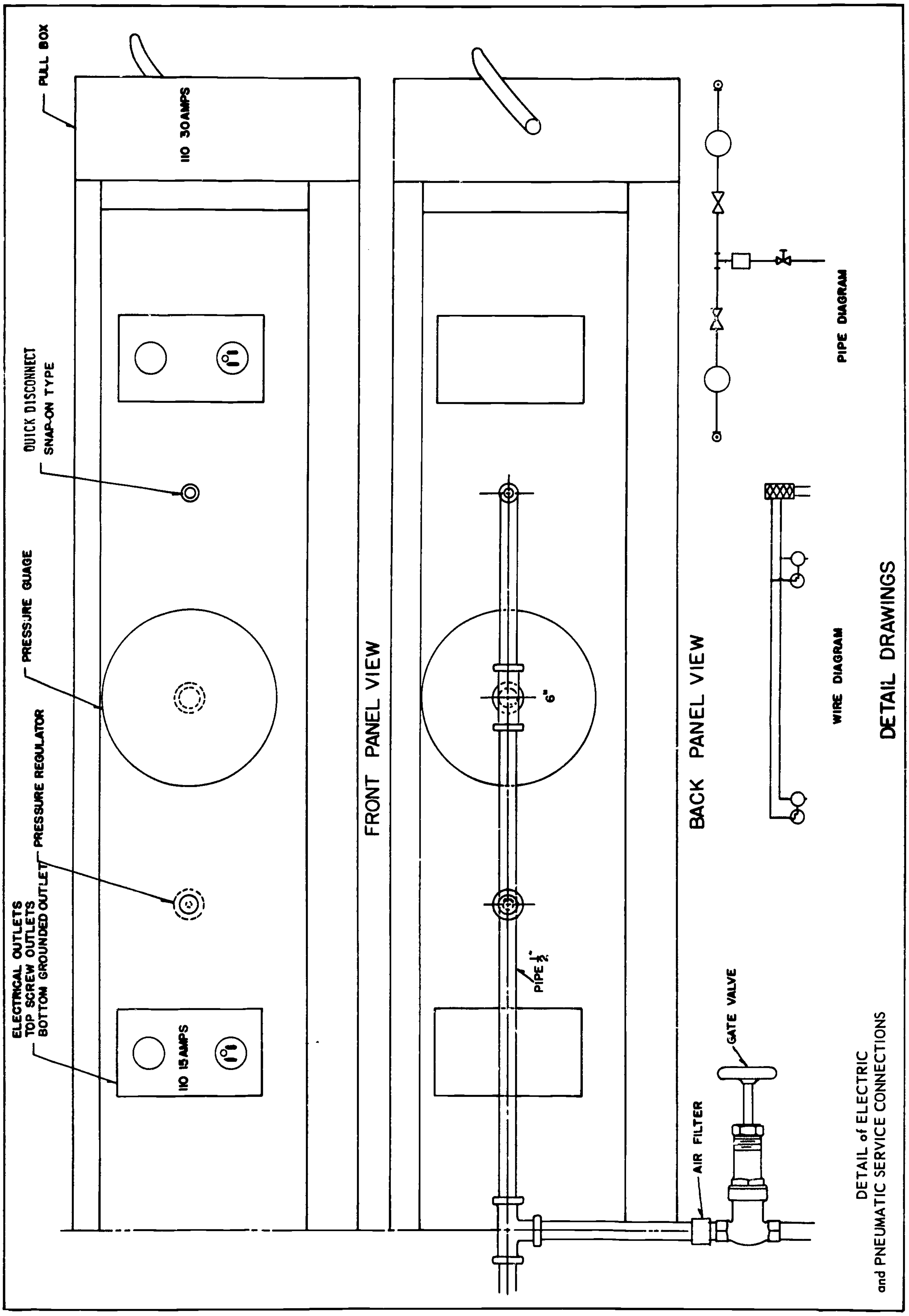


Figure 12

Detail of Electric and Pneumatic Service Connections (for bench in figure 11).

Simple, low-cost, basic mechanisms (commercially made or prepared in the school laboratory) may sometimes be used instead of complete, self-contained assemblies of instrumental units. The extent of their use depends on the depth of the teacher's industrial experience and ingenuity. However, experience has shown that maximum student contact with and reference to, commercially available equipment in the laboratory will accelerate the student's use of acquired knowledge and skills in industry upon completion of the curriculum.

The cost of establishing, equipping, and operating a department for teaching instrumentation technicians will be found to vary somewhat, depending upon whether its location is near or far from major suppliers, the size of the department, the quality and the quantity of equipment or supplies purchased at a given time, and the method of purchasing. If the equipment can be bought as a part of a large purchase of scientific equipment through a central purchasing agency, the total price of equipment and supplies may be somewhat less than if the items are purchased separately. Small purchases of scientific supplies or equipment usually are not subject to the supplier's discounts that are applied to purchases of larger quantities of the same supplies or equipment.

When plans to establish, enlarge, or re-equip an instrumentation department progress to the point which requires a detailed and precise estimate of costs, it is suggested that the services of major suppliers be obtained so the cost estimates may be complete and sufficiently accurate for current budgetary purposes. Prior to a major purchase of equipment, a thorough examination should be made of the potential suppliers by department head or instructors, because in instrumentation, as in other technologies, major changes are constantly taking place. The purchase of up-to-date equipment of good quality is the best preparation for a successful program for instrumentation technicians.

In initiating an instrumentation program, individuals planning the facilities and purchasing the instrumentation laboratory equipment should consider what is already available. If electrical, electronics, mechanical design, or chemical technology programs are already established in the institution, joint use of laboratory facilities may prevent duplication of expensive equipment.

However, joint use of these facilities requires carefully coordinated planning with the other departments, since it is essential that each department have sufficient equipment for its own needs. Consideration must also be given to whether or not existing equipment in other departments will be compatible in instrument range or power requirements with that planned for the instrumentation program. If existing units are not compatible, they will not serve in the systems in which they must function for teaching instrumentation.

Demonstrators and simulators for teaching various concepts, processes, principles, devices, and interrelations in systems are available for teaching instrumentation. In setting up an instrumentation program, however, the planners of the teaching program and laboratory equipment should make a thorough study of simulation and demonstration units and systems available *at that time.*[1]

There is an increasing number of manufacturers of these units. The pertinence, excellence, and effectiveness of their products provide an attractive means of placing pre-assembled equipment systems in the instrumentation laboratory as a teaching unit, thus saving considerable time and effort for the instructor who otherwise would have to build or assemble these systems for his laboratory.

Examples of some demonstrators and simulators designed for teaching are:

1. A valve kit-trainer unit, designed to aid in the study of valves and their function
2. An industrial process dynamic demonstrator, figure 13
3. An industrial temperature process and control simulator, figure 14
4. An industrial process flow, level, pressure simulator, figure 15
5. A pneumatic principles, device, process, and control demonstrator, figure 16
6. An instrumentation principles demonstrator, figure 17
7. An electrical phenomena demonstrator
8. A pneumatic bridge demonstration unit, figure 18
9. Control process simulation unit, figure 19
10. An instrumentation function demonstrator

[1] The units are a combination of instruments and mechanisms built as a compatible and self-contained system designed for the teaching and demonstration of a specific set of principles or phenomena.

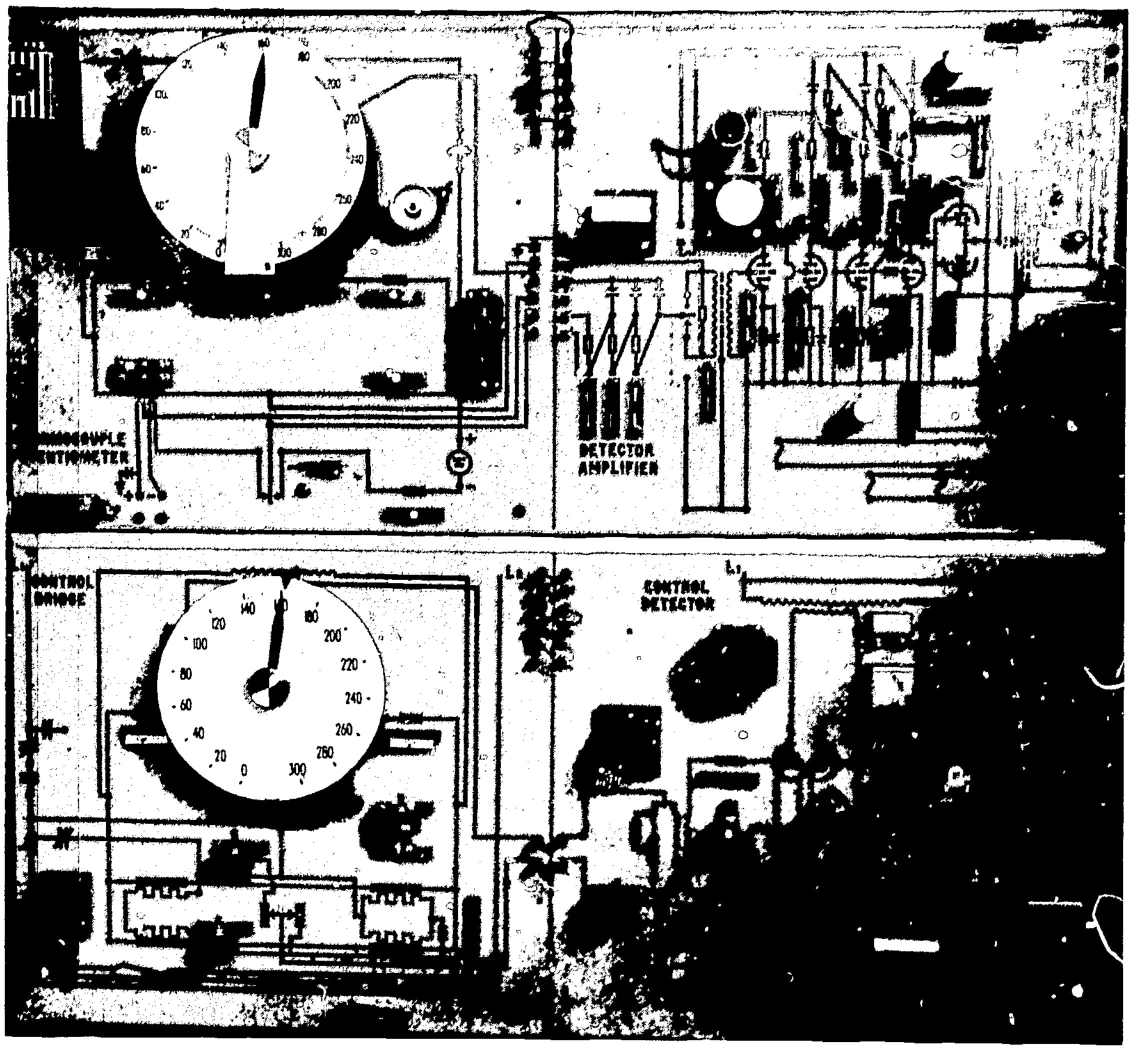


Figure 13
Industrial Process Dynamic Demonstrator.

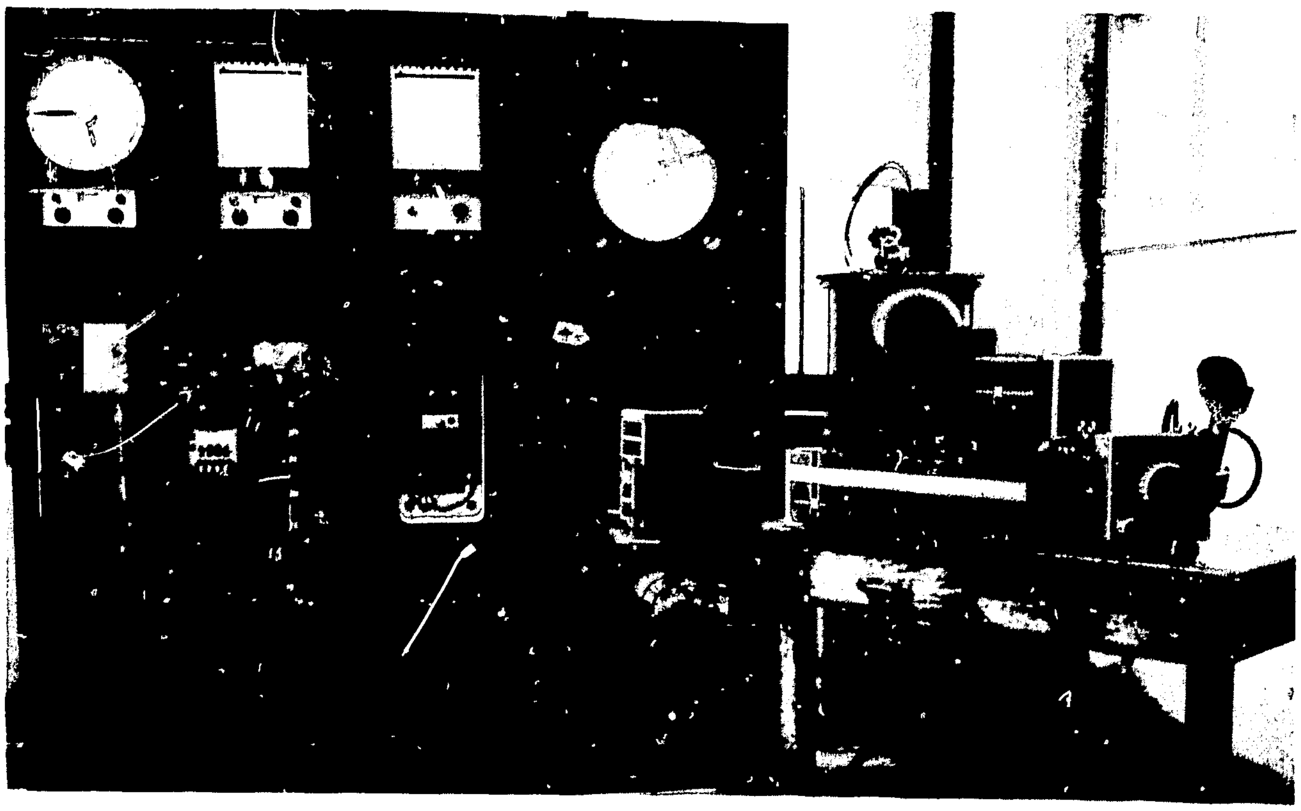


Figure 14
Industrial Temperature Process Simulator.

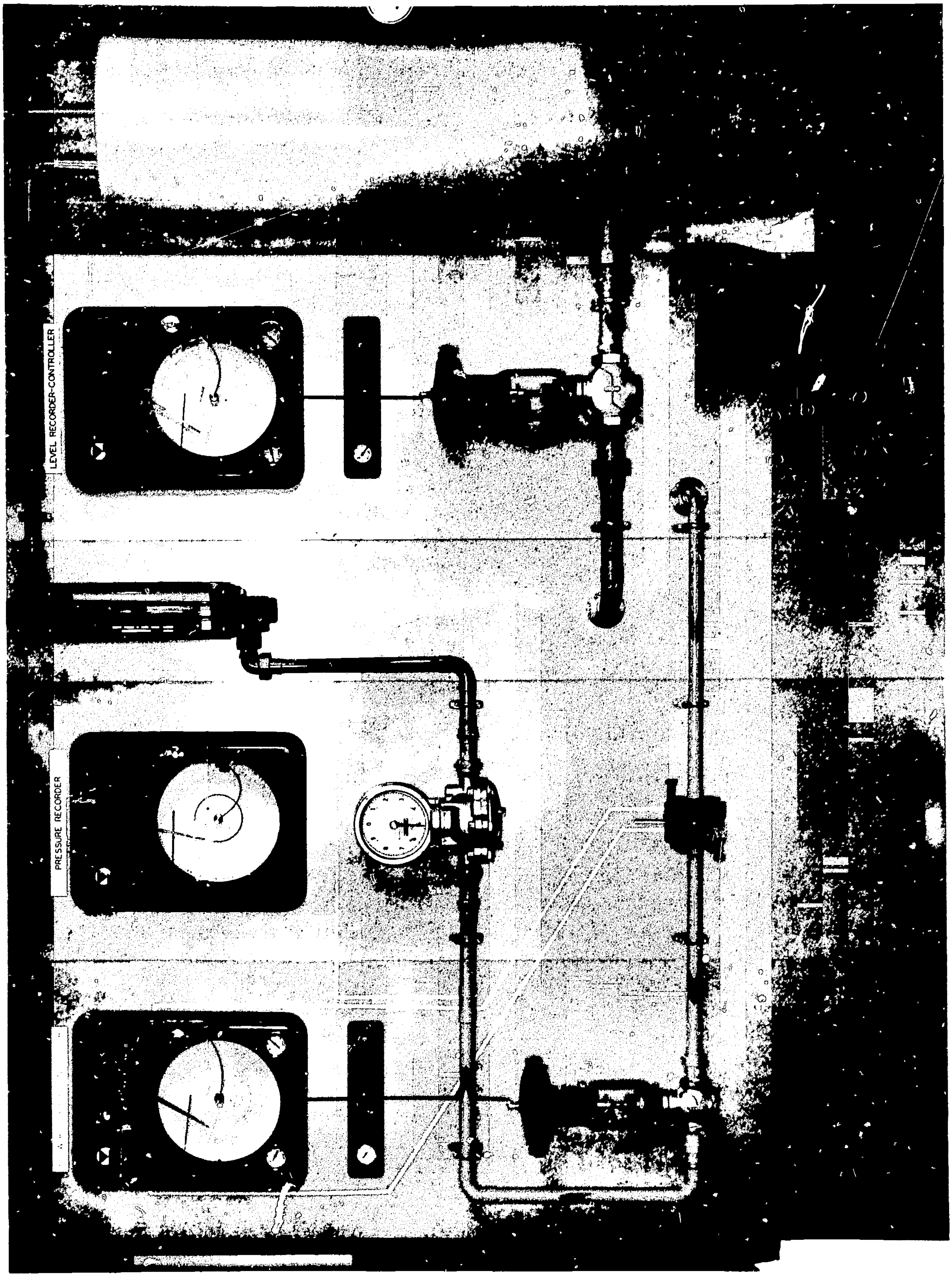


Figure 15
Industrial Process Simulator, Flow-Level Pressure.

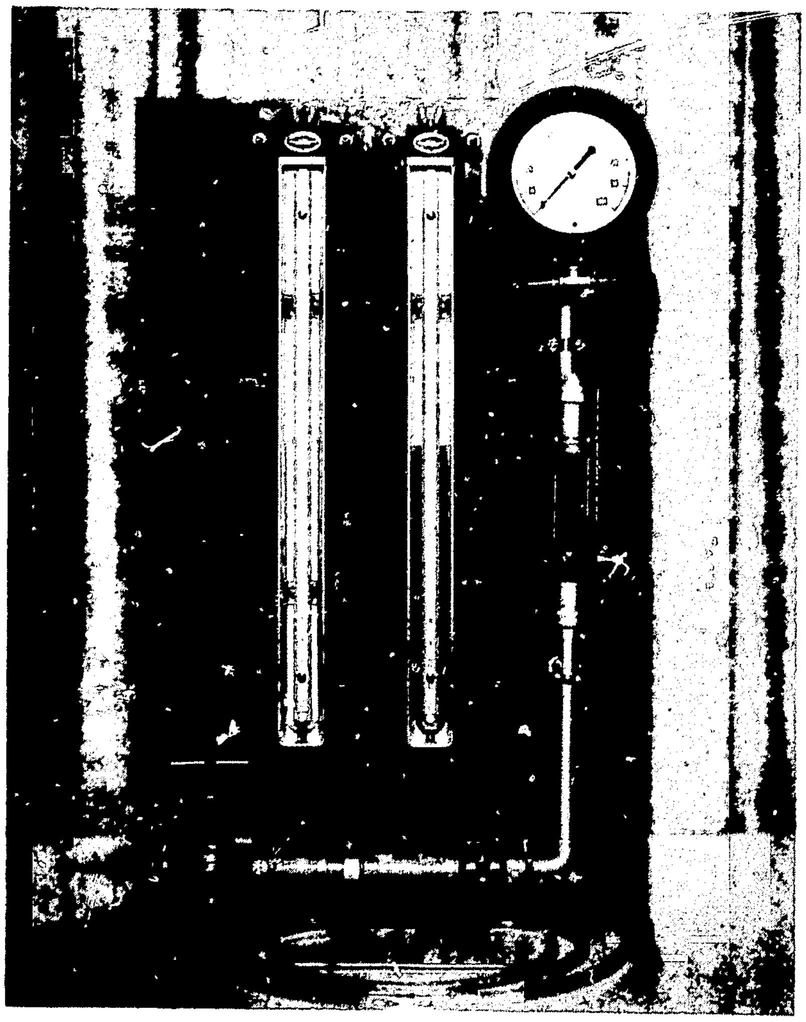


Figure 16
Pneumatic Bench Demonstrator.

11. An instrumentation electronic console demonstrator, figure 20
12. A tape-controlled automatic process control demonstration unit
13. A control system analog demonstrator, figure 21
14. A pneumatic computer demonstrator, figure 22

Some of the foregoing examples of demonstration and simulation equipment designed for teaching cost a few hundred dollars; others are complex demonstration units with wide applicability in teaching instrumentation, costing up to several thousand dollars.

Suppliers of simulation and demonstration equipment may be found in scientific equipment suppliers' lists, purchasing directories (such as *Thomas' Register*), telephone directories, and in advertisements in educational and trade journals. Experience shows that well-equipped instrumentation teaching laboratories include simulators or demonstrators for at least some of the sytems or phenomena listed above. A budget for the purchase of such initial teaching equipment would probably require from $15,000 to $20,000. The department head or instructor should select the specific demonstration or simulator units considered most suitable.

The specifications for laboratory equipment listed in this section are offered as an assistance to the instructor or department head who may have the responsibility for purchasing the equipment. They are typical specifications for equipment for use in teaching programs. Quantities suggested are intended for a class of 20–25 students for optimum instructional conditions.

The equipment listed will provide only the necessary items for student instruction and practice. It includes a number of individual items which can be used for a variety of experiments and laboratory projects. Other pieces of equipment have been grouped together in package-form to insure system-compatibility. Examples of package systems include: DC Electrical Measurements, Analytical Measurements, Industrial Temperature Measurements, Industrial Automatic Control, and Analog Computation. In the case of specified packages of components or equipment, it is imperative that the grouped items have system compatibility.

The best method of procuring a truly compatible series of components for a set of measurements is to obtain bids on complete systems or subsystems having the suggested specifications such as: components for performing a series of DC Electrical Measurements, components for performing a series of analytical experiments as outlined, or suggested calibration facilities contained in the list. The awarding of bids on the basis of lowest cost for each individual piece of equipment *may not provide* required system accuracies or signal matching characteristics—expressed as compatibility.

Groups of equipment, tools, and supplies are shown in separate lists with an estimated total cost for each list. Total estimated costs are summarized at the end of this section.

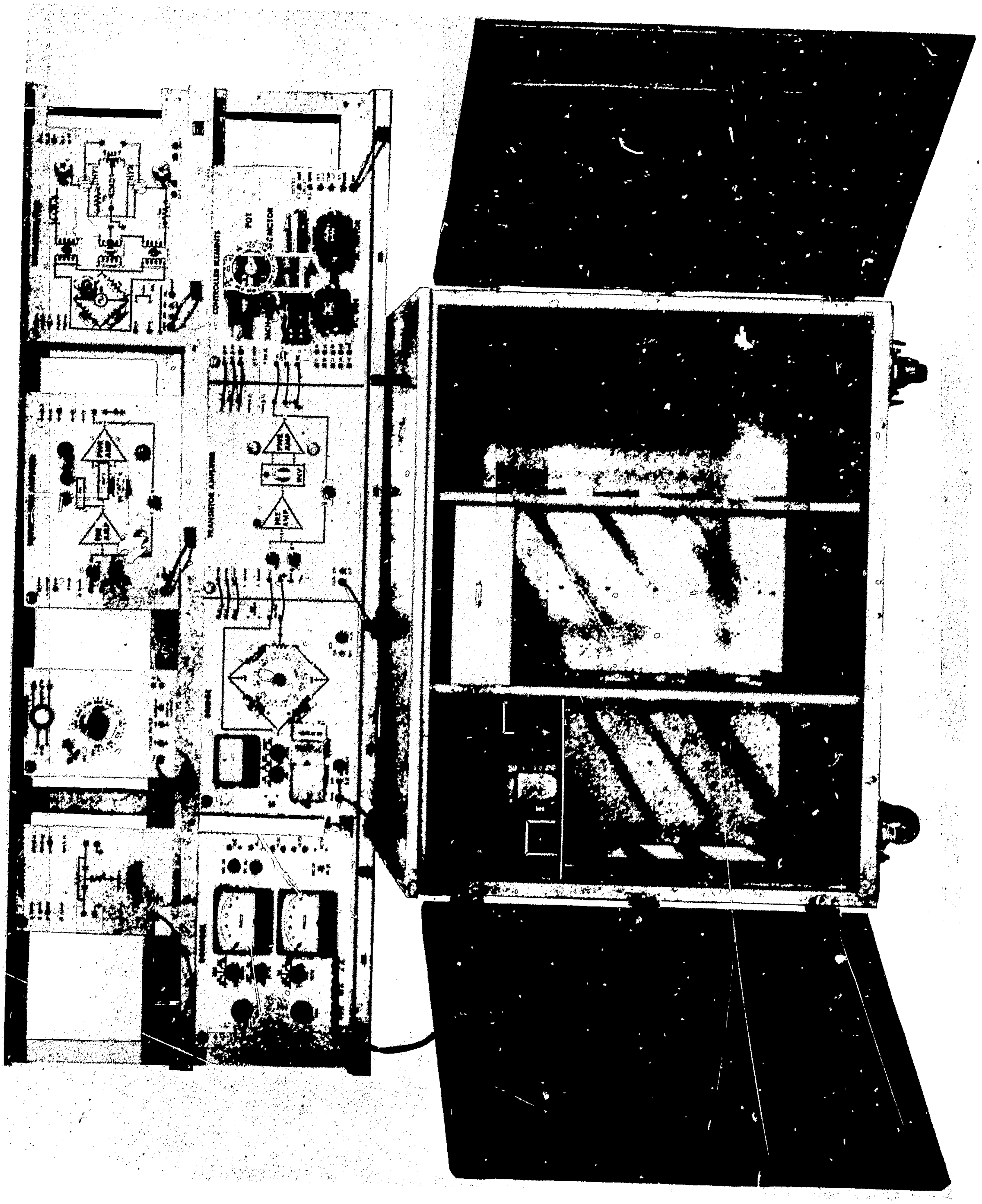


Figure 17
Instrumentation Demonstrator.

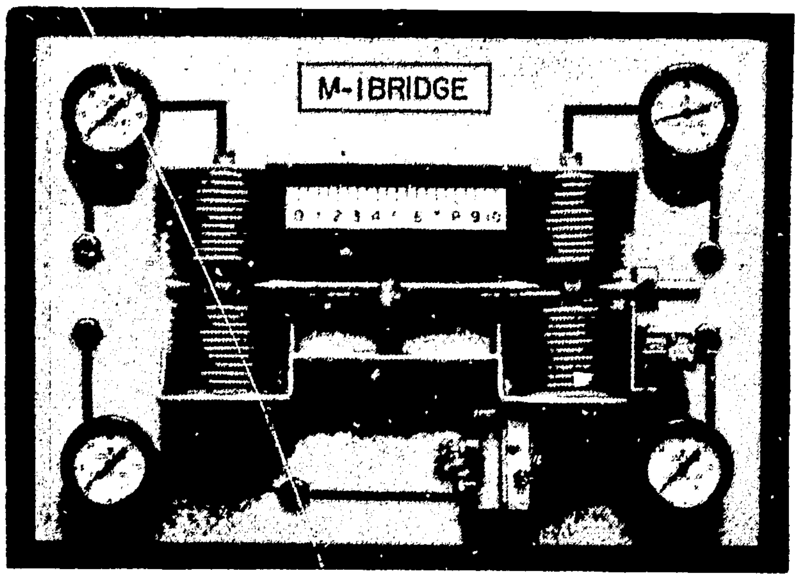


Figure 18
Pneumatic Bridge Unit.

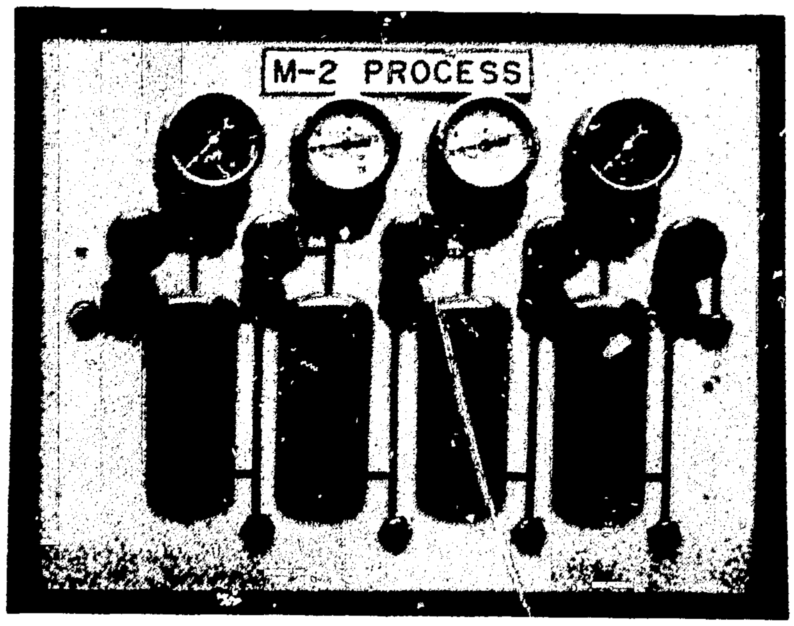


Figure 19
Process Simulator Unit.

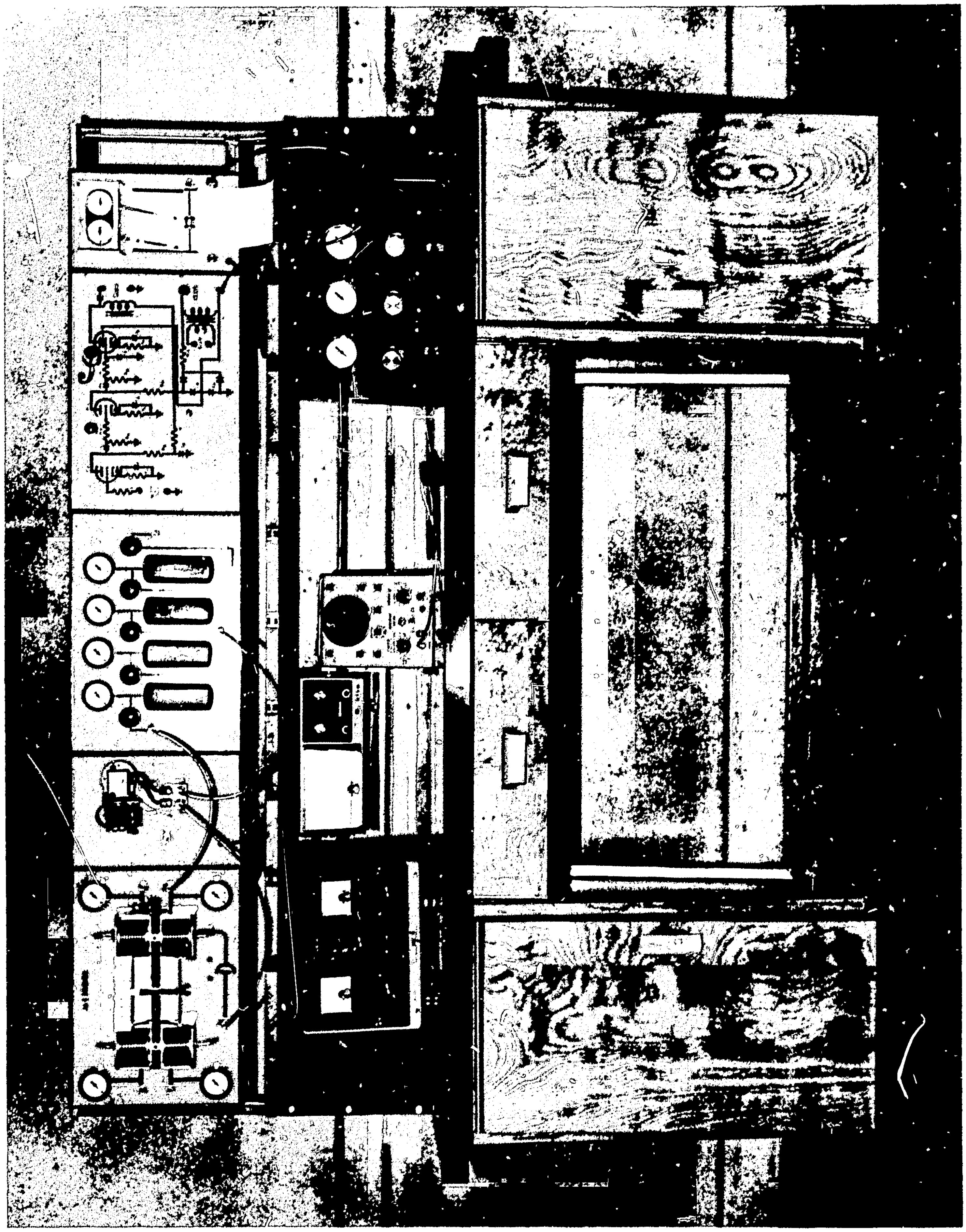


Figure 20
Instrumentation Electronic Console Demonstrator.

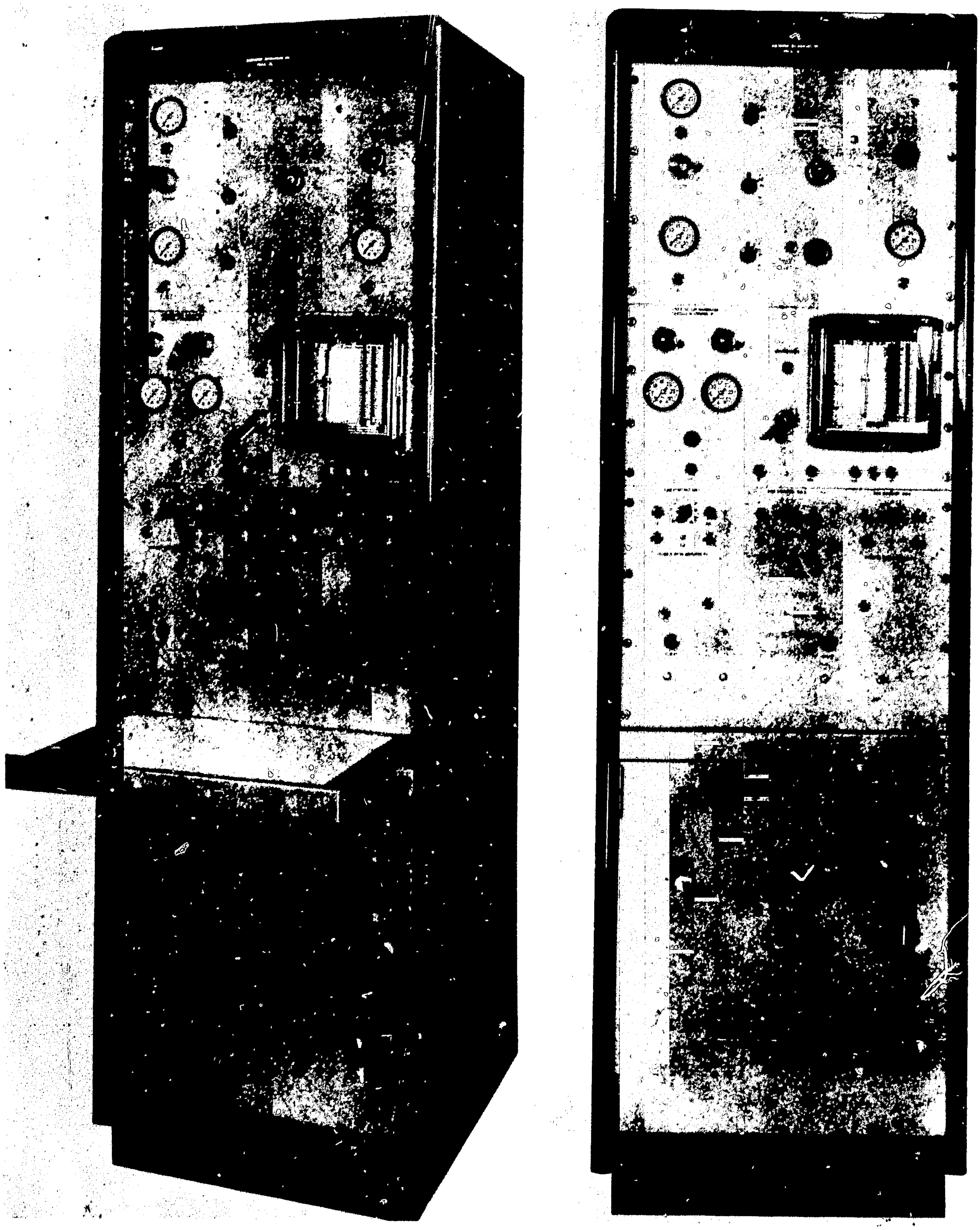


Figure 21
A Control System Analog.

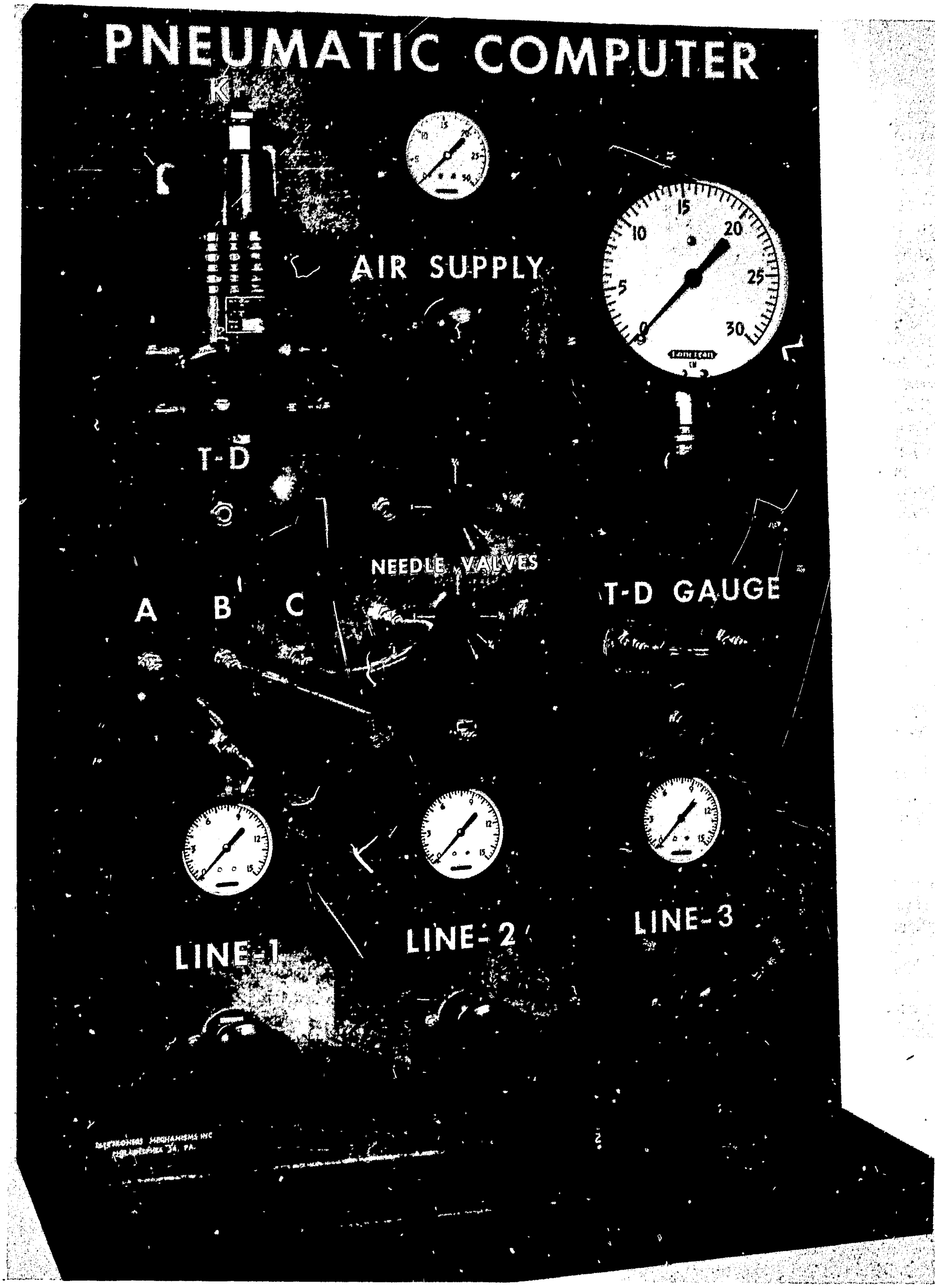


Figure 22
A Pneumatic Computer.

Basic Equipment

Specification	Quantity
Millivoltmeter-Type Temperature Indicator	1
Range: 0–2000 F (Type K), Chromel-Alumel thermocouple.	
Voltage & Frequency: 115 v., 60 cycles.	
Control: S.P.D.T. time proportioning control.	
Single-Point Circular Chart Recorder with Pneumatic Proportioning Control	1
Range: 0–1000 F (Type J), Iron-Constantan thermocouple.	
Chart Speed: 24 hours per revolution electric chart drive.	
Voltage & Frequency: 115 v., 60 cycles.	
Control: Pneumatic control proportional band and automatic reset.	
Single Seated Diaphragm Air-Control Valve	1
Size: ½ inch.	
Body: Cast iron, 125 pound screwed ends.	
Trim: Stainless steel.	
Packing: Nonlubricated type teflon.	
Control Action: air to close.	
Pneumatic Motor—Bottom Mounted Level-Type with positioner by-pass and gages	1
Precision Regulator—Pneumatic Low-Pressure Type	2
Air Filter—Low-Pressure Type	2
Air Compressor	1
2.0 cfm delivery; ½ horsepower; 20-gallon tank; single belt drive unit; 120 or 240 v., 60 cycles, single phase, complete with reducing valve.	
Single-Point Strip-Chart Recorder with Position-Proportioning Control	1
Range: 0–2000 F (Type K), Chromel-Alumel thermocouple.	
Chart Speed: 2 inches per hour electric chart drive.	
Voltage & Frequency: 115 v., 60 cycles.	
Control: Adjustable proportional band, reset rate and rate time.	
Motorized Power Stat	1
Input Voltage: 120 v., 60 cycles.	
Output Voltage: 0–120 or 0–140 volts, 20 amps, 2.4 or 2.8 kva, single phase.	
16-Point Strip-Chart Recorder	1
Range: 0–2000 F (Type K), Chromel-Alumel thermocouple.	
Chart Speed: 2 inches per hour with gear changes for 4, 6, and 8 inches per hour.	
Printing: Plus and number, single color.	
Voltage & Frequency: 115 v., 60 cycles.	
High-Range Radiation Pyrometer Assembly	1
Narrow angle 20–1 distance factor; pyrex lens (RH); maximum calibration values approximately 3,400 F; maximum target temperatures approximately 4000 F; rear sighting lens.	
Support Fitting for High-Range Radiation Pyrometer Assembly	1
Complete with machined seats and adjustable clamp.	
Open-End Inconel Sighting Tube for High-Range Radiation Pyrometer	1
Complete with mounting flange assembly; 12 inches long.	
Portable Millivolt Potentiometer, Dual Range	5
Ranges: High 20–60 mv, Low 0–20 mv.	
Portable Temperature Potentiometer, Dual Range	3
Range: 0–2000 F (Type J), Iron-Constantan thermocouple 0–2400 F (Type K), Chromel-Alumel thermocouple.	
Thermal Temperature Recorder Circular Chart	3
Range: 0–1000 F.	
Chart Speed: 4 hours per revolution, electric chart drive.	
Voltage & Frequency: 115 v. 60 cycles.	
Thermal System: Mercury-filled, self-compensating.	
Copper-Constantan (Type T) Thermocouple Assembly	1
Protecting Tube: full-length carbon steel.	
Length: 24 inches.	
Terminal Head: general purpose with ½-inch N.P.T. conduit connection.	
Mounting Attachment: adjustable mounting flange on protecting tube.	
Iron-Constantan (Type J) Thermocouple Assembly.	
Protecting Tube: full-length inconel.	
Length: 24 inches.	
Terminal Head: general purpose with ½-inch N.P.T. conduit connection.	
Mounting Attachment: adjustable flange on protecting tube.	
Chromel-Alumel (Type K) Thermocouple Assembly	1
Protecting Tube: full-length atmosphere-resistant.	
Length: 24 inches.	
Thermal Head: general purpose with ½-inch N.P.T. conduit connection.	
Mounting Attachment: adjustable flange on protecting tube.	
Platinum-Platinum, 13% Rhodium (Type R) Thermocouple Assembly	1
Protecting Tube: full-length double type.	
Primary Tube: sillimanite.	
Second Tube: silicon carbide.	

Specification	*Quantity*
Length: 24 inches.	
Terminal Head: general purpose with ½-inch N.P.T. conduit connection.	
Mounting Attachment: Adjustable flange.	
Platinum-Platinum, 10% Rhodium (Type S) Thermocouple Assembly	1
Protecting Tube: full-length double type.	
Primary Tube: sillimanite.	
Secondary Tube: silicon carbide.	
Length: 24 inches.	
Terminal Head: general purpose with ½-inch N.P.T. conduit connection.	
Mounting Attachment: adjustable flange.	
Mechanical Flow Meter—Bellows Type, Circular Chart Recorder	1
Range: 0–100 inches water differential pressure.	
Chart: graduated 0–100 square-root graduations.	
Chart Speed: 4 hours per revolution with mechanical integration.	
Voltage & Frequency: 115 v. 60 cycles.	
Meter Body: Bellows type rated at 100 psi static pressure.	
Accessories: to include 3-valve manifold.	
Circular Chart Pressure Recorder	3
Range: 0–100 psig.	
Chart Speed: 24 hours per revolution electric chart drive.	
Voltage & Frequency: 115 v. 60 cycles.	
Pressure Element: stainless steel spiral.	
Accessories: to include mounting bracket.	
Decade Resistance Box	3
Range 10 times (1000+100+10+1+.1).	
Limit of Frror: 1 or more ohms: 0.1%; 0.1 ohm: 0.25%.	
Portable Wheatstone Bridge	2
Range: 1 ohm to 9.9999 megohms.	
Limit of Error: 0.1%.	
Heating Thermostat	6
Range: 56 to 94 F.	
Control Action: circuit closes with temperature drop.	
Voltmeter	3
Range: 3–15–150 volts DC.	
Voltmeter	3
Range: 15–30 volts AC.	
Ammeter	3
Range: 5 amperes DC.	
Ammeter	3
Range: 1 to 50 amperes AC.	
Milliammeter	3
Range: .15–1.5–15 milliamperes DC.	
Milliammeter	3
Range: 0–30 milliamperes AC.	
Wattmeter	1
Range: 75–150 watts DC and Single phase AC.	
Portable Tube Tester	1
Multimeter, Portable (Volt-Ohm-Milliammeter)	20
Ranges: Volts, 0–5000 AC and DC; Millivolts, 0–250 DC; Microamperes, 0–50 DC; Milliamperes, 0–500 DC; Amperes, 0–10 DC; Resistance, 0–20 megohms.	
Accessories: to include test leads.	
Flow Meter—Current-Propeller Type, with mechanical readout	1
Flow Meter—Rotating-Vane Type, with electronic readout	1
Flow Meter—Nutating Type, with mechanical readout	1
Pressure Gage, 0–15, 6 inches H_2O.	10
Pressure Gage, 0–60 psi, 6 inches H_2O.	10
Pressure Gage, 0–100 psi, 6 inches H_2O.	10
Pressure Gage, 0–300 psi, 6 inches H_2O.	1
Pressure Gage, 0–600 psi, 6 inches H_2O.	1
Thermos Bottle, Stainless Steel, 1 Quart	20
Precision Potentiometer	3
Range: 0–1.6 volts, including less range.	
Oscilloscope, dual-trace	3
Precision Wheatstone Bridge Facility includes guarded DC null detector, DC power source, housed in cabinet	1
Temperature-Checking and Calibration Facility	1
Range: Approx. 300–2000 F.	
Operating Voltage: 115/230 volts AC, system includes:	
Checking furnace (approx. upper limit: 2000 F.) with equalizing blocks and reference temperature source (° C.).	
Temperature control panel containing recorder, duration adjusting-type controller and controlled power source.	
Precision Potentiometer Facility, includes guarded DC potentiometer, guarded DC null detector, standard cell, DC power source, housed in cabinet	1
Fundamentals of DC Electrical Measurement *System*	2
Includes compatible components for:	
A. DC Resistance Measurement by the Wheatstone Bridge Method, consisting of—	
Guarded Wheatstone Bridge:	
Range: 001 ohm to 1.111 megohms.	
Limit of Error: ±(0.05%±0.001 ohm) up to 100 megohms; ±0.5% above 100 megohms.	
1 Guarded DC Null Detector:	
Period: 2 seconds up to 1000 ohms source resistance, 4 seconds at 100,000 ohms source resistance.	
Input Resistance: 25,000 ohms.	
External Resistance: up to 100,000 ohms.	
Sensitivity: 0.30μ v/scale division up to 20,000 ohms.	

Specification	Quantity
1 Dry Cell:	
Voltage Rating: 1.5 volts DC.	
1 10-ohm Standard:	
Limit of Error: ±0.02% at 0.3 ampere; ±0.005% at 0.1 ampere.	
B. Precision Low-Resistance Measurements with a Kelvin Bridge, consisting of—	
1 Kelvin Bridge:	
Range: 0.00001 to 1 ohm.	
Limit of Error:	
Ratio resistors: ±0.05%.	
Fixed standards: ±0.05%.	
Adjustable standard: +0.2 scale division.	
1 Tapping Key: Single contact and short circuit key.	
1 Dry Cell:	
Voltage Rating: 1.5 volts DC.	
Self-Contained Galvanometer:	
Sensitivity: 0.005μ amp/mm.	
Period: 2.5 seconds.	
CDRX: 300 to 500 ohms.	
System Resistance: 25 ohms.	
1 Resistor (Shunt):	
Resistance: absolute ohms (0.1).	
Current Rating: 15 amperes.	
Limit of Error: ±0.04%.	
C. Precision DC Voltage and Current Measurements by the Potentiometer Method, consisting of—	
1 Potentiometer:	
Range: 0 to 1.6 volts.	
Limit of Error:	
High range: ±0.0005 volt.	
Medium range: ±0.0001 volt.	
Low range: ±0.00001 volt.	
1 Standard Cell:	
EMF: within 1.01884 to 1.01964 absolute volts at 20 C.	
Limit of Error: ±0.01% of certified value.	
1 Dry Cell:	
Voltage Rating: 1.5 volts DC.	
1 Tapping Key: Single contact and short circuit key.	
1 Pinch-Type Switch (DPDT).	
1 Self-Contained Galvanometer:	
Sensitivity: 0.0055 μ amp/mm.	
Period: 2.5 seconds.	
CDRX: 300 to 500 ohms.	
System Resistance: 25 ohms.	
1 Adjustable DC Resistor:	
Resistance: 0 to 999.9 ohms.	
Decade Steps: 9 (0.1+1+10+100).	
Limit of Error: ± (0.1%+0.01 ohm).	
1 Shunt Box:	
Range: 0.075, 0.15, 0.3, 0.75, 1.5, 3, 7.5, and 15 amps.	
Output: 150 millivolts.	
Limit of Error: ±0.02%.	
1 Volt Box:	
Range: 15, 150, and 300 volts.	
Resistance: 750 ohms/volt.	
Output: 150 millivolts.	
Limit of Error: 0.02%.	
Fundamentals of Analytical Measurements System	2
Includes compatible components for:	
A. pH and Redox Measurements with Stabilized pH Indicator, consisting of—	
1 Stabilized pH Indicator:	
Ranges:	
0 to 14 pH.	
0 to +700 millivolts.	
0 to +1400 millivolts.	
Limit of Error: ±0.07 pH.	
Readability: 0.02 pH.	
1 Carton of Accessories and Supplies, containing:	
Glass Measuring Electrode (20–60 C).	
Calomel Reference Electrode.	
Electrode Holder.	
Reference Buffer Solution 6.86 pH (1 pint).	
Potassium Chloride (4 ounces).	
Glass-Electrode Bulb Guard.	
B. Electrode for Redox Measurements, consisting of—	
1 Platinum Measuring Electrode.	
C. Electrolytic Conductivity Measurements by Conductivity Monitor, consisting of—	
1 Portable Conductivity Monitor:	
Scale Range:	
Linear from 0 to 100.	
Microhms per centimeter (multiply reading by cell constant).	
Power Supply: Operates on 120 volts, 60 cycles, AC	
1 Dip-Type Cell for Portable Indicator:	
Cell Constant: 10.	
Depth of Immersion: 4 to 6½″.	
D. Gas Analysis Measurement by the Thermomagnetic Method, consisting of—	
1 Thermomagnetic Oxygen Analyzer for Direct Indication of Percent Oxygen:	
Sensitivity: Better than ±0.05% O_2.	
Accuracy of Indicating Meter: ±1.0% of span.	
Output Signal: 0–5 mv DC.	
Accuracy of Output: Equivalent to ±0.15% O_2 or 1.5% of span (whichever is greater).	
Response time:	
Initial: 2 seconds.	
Time constant: 15 seconds.	
90% of final value: 35 seconds.	
Fundamentals of Industrial Temperature Measurements *System*	2

Specification *Quantity*

Includes compatible components for:

A. Radiation Method Using an Electronic Null Balance Potentiometer Indicator, consisting of—

1 Potentiometer Indicator:

Type: Round chart electronic indicator.

Measuring Circuit: DC Potentiometric.

Range: 800–1800 F.

Accuracy: ±0.3% of span for spans greater than 2 mv; ±0.5% for spans from 1 to 2 mv.

Maximum Source Impedance: 2500 ohms.

Span Step Response Time Rating: 5 seconds nominal, full scale.

Measuring Circuit Current Source: AC rectified, and regulated by Zenerdiode circuit.

Power Supply: 120 volts, 60 or 50 cycles.

1 Heat-Radiation Detector:

Complete assembly consisting of detector and mounting assembly.

Temperature Range: 800–1800 F.

1 25-Foot Coil, Copper Leadwire, 14-gage, Duplex, stranded, with asbestos insulation and asbestos braid overall.

B. Thermocouple Method Using an Electronic Null Balance Potentiometer Indicator, consisting of—

1 set of parts to convert potentiometer indicator (above) from radiation detector to thermocouple-type temperature measurements:

Range Card: 0–2000 F type K.

Scale: 0–2000 F type K.

1 Thermocouple Element Type K 14-gage, 18″ long, with double-hole insulators.

1 Thermocouple Terminal Connector.

1 25-Foot Coil, Type K Extension Wire, with enamel asbestos insulation.

C. Resistance Thermometer Method Using an Electronic Signaling Controller, consisting of—

1 Controller:

Range: 0–1000 F for 25 ohm platiuum resistance thermometer.

Accuracy of Adjustment: 0.3%.

Control Sensitivity: ±0.5 F.

Control Element: SPDT Relay 0.75 amps make or break action on 120 volts AC.

Power Supply: 120 volts; 60, 50, 25 cycles, as specified.

1 Resistance Thermometer, consisting of—

Resistance Element, 25 ohm platinum: (25 ohms at 32 F), hermetically sealed, 3 lead.

Length: 18 inches.

Limit of Error:

±1.5 F, 32–250 F.

±3 F, 250–1000 F.

Response Time: 15 seconds for 90% of temperature change in stirred water moving approx. 1 foot per second.

1 25-Foot Coil, Stranded Copper Wire, Three Conductor, 18-gage:

Insulation: Neoprene overall, with heat-resistant rubber on each conductor.

Resistance: Conductors to be matched in resistance.

D. Optical Pyrometer Method Using the Disappearing Principle, consisting of—

1 Optical Pyrometer:

Range: 1400–3200 F.

Double Scale: 1400–2250 F and 1950–3200 F.

Measuring Circuit: Null balance principle.

Objective Lens Assembly: Standard focal length of 2 inches (permits focusing upon objects 1/32 inch or larger at a distance of 7 inches or more from the lens holder).

Fundamentals of Analog Computation *System*_____ 2

Includes compatible components consisting of—

1 Computation Assembly, with power supply and four functional switches for performing multiplication, division, square-root extraction, and signal conversion:

Operational Amplifier:

Input Signal: 0 to 4 ma or 1 to 5 ma DC into approx. 300 ohms minimum impedance.

Output Signal: 0 to 10 volts DC maximum into 1500 ohms minimum load resistance, 0 to 4 ma maximum into 2500 ohms maximum load resistance.

Isolation: Input-output isolation provided for all input signals except high input impedance.

Repeatability: Better than 0.1% of full-scale output.

Signal Rejection: Common mode, 10,000 to 1 or better.

Function: Signal conversion and isolation; summing of voltage signals and as a function generator.

Power Supply: 107 to 120 volts, 50 cycles, or 107 to 127 volts, 60 cycles; 4 voltamperes.

1 Square-Root Extractor:

Input Signal: 0 to 4 ma or 1 to 5 ma DC into approx. 300 ohms minimum impedance.

Specification	*Quantity*
Output Signal: 0 to 10 volts DC into 1500 ohms minimum load resistance, 0 to 4 ma into fixed 2500 ohm load resistance.	
Isolation: Input-output isolation provided for all input signals except 0 to 2.6 volts high input impedance.	
Repeatability: Better than 0.1% of full-scale output.	
Adjustment: Adjustable zero and span.	
Function: Accepts square law input and provides linear output.	
Power Supply: 107 to 120 volts, 50 cycles or 107 to 127 volts, 60 cycles; 4 voltamperes.	
1 Multiplier/Divider.	
Input Signal: No isolation between input signals and common; Input $E_1 = 0$ to -10 volts DC, maximum source current 1.2 ma. Input voltage source impedance not to exceed 30 ohms for stated accuracy. Input $E_2 = 0$ to -10 volts DC maximum source current 3.0 ma. Input $E_3 = -5$ to -10 volts DC maximum source current 3.0 ma. Source impedance to be less than 20 ohms.	
Output Signal: 0 to 10 volts DC maximum into 2000 ohms minimum load resistance.	
Isolation: Input-output isolation provided by means of magnetic amplifier.	
Repeatability: Better than 0.1% of full scale.	
Signal Rejection: Amplifier only, common mode, 10,000 to 1 or better. Transverse 40 to 1 for 0 to 20% range or better.	
Function: Multiplication and division ($E_1 \times E_2/E_3$).	
1 Electronic Strip Chart Recorder:	
Range: 0–50 mv DC.	
Measuring Circuit: Null balance, potentiometric.	
Chart Width: 10 inches nominal.	
Chart Speed: 60 inches hour.	
Fundamentals of Industrial Automatic Control System	2
Provides a means of experimental determination and calibration of final control action associated with various control modes and process deviations. Contains compatible components as follows:	
1 Strip-Chart Two-Pen Recorder.	
Type: Strip chart electronic recorder.	
Measuring Circuit: Automatically balanced DC potentiometer.	
Range Span: 0–50 mv for both pens.	
Accuracy Rating: ±0.3% of range per American Standards Association Specification C39.4.	
Dead Ban: 0.15% of electrical span.	
Record: Continuous line; calibrated chart width is nominal 10 inches.	
Chart Speed: 60 inches/hour.	
External Circuit Resistance: 2500 ohms maximum.	
Span Step: Response time rating 1 second nominal.	
Control Element: Control setter operated switches and 100% slidewire for use with three action current output-type control unit.	
1 Three-Action (Proportional, Rate and Reset): Current Adjusting-Type Control Unit.	
Current Output: 0–5 ma DC, with load impedance of 3000 ohms or less.	
1 Voltage Divider Network (To convert current output of control unit to millivoltage signal for recorder):	
Consists of Two Resistors: 1 @ 2000 ohms and 1 @ 10 ohms.	
Resistor Accuracies: ±0.05%+0.003 ohms.	
1 Variable Voltage Source:	
Output Voltage: Variable from 0 to 50 millivolts DC by motor-driven slidewire.	
Time of Complete Slidewire Traverse: 10 minutes.	
Switches: Starting and stopping motor-driven slidewire and reversing direction.	
Output Voltage: Adjustable by manual setter.	
Small Power Drill Press	1
Small Power Grinder	1
Steam Boiler, approximately 25# pressure, approximately 10 H.P	1
Small Air Compressor	1
Basic Equipment Estimated Total Cost $50,000 to $55,000.	

	Suggested quantity
Screwdriver, Plastic Handle, 3-Inch Blade	7
Screwdriver, Plastic Handle, 4-Inch Blade	7
Screwdriver, Plastic Handle, 8-Inch Blade	7
Screwdriver, Jeweler's Type, Set of 5	7
Screwdriver, Split Tip	7
Screwdriver, 6-Inch Offset	7
Pliers, Side Cutting, 8 Inches	7
Pliers, Long Nose, 6 Inches	7
Pliers, Slip Joint, 9½ Inches	7
Pliers, Combination, 5½ Inches	7
Pliers, Diagonal Cutting, 6 Inches	7
Wrenches, Open End Set, ½ to 2 Inches	1
Wrench, Adjustable, 6 Inches	7
Wrench, Adjustable, 8 Inches	1
Pipe Wrench, 6 Inches	1
Pipe Wrench, 8 Inches	1
Hex, Wrenches, Set	7

	Suggested quantity
Spline Wrenches, Set	7
Files, Assorted	21
File, Round, 10 Inches	1
File, Flat, 10 Inches	1
File, Square, 10 Inches	1
File, Triangular, 8 Inches	7
Emery Cloth, Fine, Package	7
Sandpaper, Assorted, Package	3
Crocus Cloth, Package	3
Hammer, Ball Peen, 16 Ounces	1
Punch, Center	2
Punch, Pin	2
Punch, Starting	2
Chisel, ¾-Inch Cold	2
Hacksaw Frame, Adjustable, 12 Inches	2
Hacksaw Blades, Package, 18 Teeth, 12 Inches	1
Hacksaw Blades, Package, 24 Teeth, 12 Inches	1
Knife, Electrician's, with Locking Screwdriver Blade	7
Volt-Ohm Milliammeter, Miniature, including Flexible Probe Jaws and Leads for Direct and Adjacent VOM Measurements	7
Fuse Puller, Pocket-Type	1
Painter's Sash Brush, 1 Inch	7
Oil Can, Straight Nozzle, ½ Pint	2
Friction Tape, 8-Ounce Roll	25
Tape, Plastic Electrical, 60-Inch Roll	25
Flaring Tool Kit, Heavy Duty	7
Torch, Propane	2
Soldering Iron, 100 Watts, 16 Ounces, 110 v. 60 Cycles	7
Soldering Iron Tips, Set, ⅛-Inch to ⅞-Inch Size	1
Soldering Gun, Instant Heat, 90 watts, 110 v. 60 cycles	3
Wire Brush	1
Magnifying Glass	4

Supplies

	Suggested quantity
Storage Cabinet—Small Parts 24 drawers, 3 drawers high, overall size: 33⅞ inches wide x 17⁵⁄₁₆ inches deep x 10¹¹⁄₁₆ inches high	1
Storage Cabinet, Steel, four shelves adjustable on 2-inch centers, 2 doors, over-all size: 30 inches x 18 inches x 72 inches	1
Filing Cabinet, all steel legal size, four locking drawers	1
Single Conductor, Copper, Thermoplastic Insulated Wire, No. 12 Gage, 1 Length (200 feet)	1
Single Conductor, Copper Thermoplastic Insulated Wire, No. 14 Gage 1 Length (200 feet)	1
Single Conductor, Copper, Thermoplastic Insulated Wire, No. 16 Gage 1 Length (200 feet)	1
Single Conductor, Copper, Thermoplastic Insulated Wire, No. 18 Gage 1 Length (200 feet)	1
Connecting Wire, Thermoplastic Insulation, Black, No. 20 Gage Stranded, 1 Spool (75 feet)	1
Connecting Wire, Thermoplastic Insulation, Red, No. 20 Gage Stranded, 1 Spool (75 feet)	1
Connecting Wire, Thermoplastic Insulation, Green, No. 20 Gage Stranded, 1 Spool (75 feet)	1
Connecting Wire, Thermoplastic Insulation, Blue, No. 20 Gage Stranded, 1 Spool (75 feet)	1
Connecting Wire, Thermoplastic Insulation, Yellow, No. 20 Gage Stranded, 1 Spool (75 feet)	1
Connecting Wire, Thermoplastic Insulation, White, No. 20 Gage Stranded, 1 Spool (75 feet)	1
Terminals, Spade Tongue, 14- to 20-Gage	100
Terminals, Ring Tongue, 14- to 20-Gage	100
Terminal Kit, Assorted	1
Wire Solder, 50/50 1 Spool (5 pounds)	1
Wire Solder, Resin Core 50/50, 1 Spool (5 pounds)	1
Soldering Flux, Paste-Resin 1 container (5 pounds)	1
Range-Change Kit for Single-Point Strip-Chart Recorder, to change range from 0–2000 F Chromel-Alumel to 1000–2400 F, Chromel-Alumel, includes necessary resistors, reference junction compensation, and chart and scale	2
Platinum Wire, Bare, 20-Gage ... feet	10
Platinum-10% Rhodium Thermocouple Wire, Bare, 20-Gage ... feet	5
Platinum-13% Rhodium Thermocouple Wire, Bare, 20-Gage ... feet	5
Thermocouple Wire, Matched, Bare Copper-Constantan (Type T), 20-Gage ... feet	100
Thermocouple Wire, Matched, Bare Iron-Constantan (Type J), 8-Gage ... feet	100
Thermocouple Wire, Matched, Bare Iron-Constantan (Type J), 14-Gage ... feet	100
Thermocouple Wire, Matched, Bare Chromel-Alumel (Type K), 14-Gage ... feet	100
Thermocouple Wire, Copper-Constantan (Type T), Duplex, 20-Gage, Glass Silicon Insulation ... feet	100
Thermocouple Wire, Iron-Constantan (Type J), Duplex, 14-Gage, Asbestos Insulation ... feet	100
Thermocouple Wire, Chromel-Alumel (Type K), Duplex, 20-Gage, High Temperature Glass Refrasil Insulation ... feet	100
Thermocouple Insulator, Ceramic Round, 4-Hole, 1-Inch Long, for 20-Gage Wire	1, 000
Thermocouple Insulator, Ceramic Round, 4-Hole, 1-Inch Long, for 14-Gage Wire	1, 000
Thermocouple Insulator, Ceramic Round, Double-Bore, 2 Inches Long, for 20-Gage Wire	1, 000
Thermocouple Insulator, Ceramic Round, Double-Bore, 1-Inch Long, for 14-Gage Wire	1, 000
Thermocouple Insulator, Ceramic Round, Double-Bore, 1-Inch Long, for 8-Gage Wire	1, 000
Thermocouple Insulator, Ceramic Oval, Double-Bore, 1-Inch Long, for 14-Gage Wire	1, 000
Thermocouple Insulator, Ceramic Oval, Double-Bore, 1-Inch Long, for 8-Gage Wire	1, 000
Thermocouple Insulator, Fish-Spine Type, Ceramic, Single-Hole, Approximately 0.140-Inch Long, for 14-Gage Wire	4, 870
Thermocouple Insulator, Fish-Spine Type, Single Hole, Approximately 0.226-Inch Long, for 8-Gage Wire	3, 190
Thermocouple Extension Wire, Copper-Constantan (Type TX), 16-Gage, Polyvinyl Plastic over Polyvinyl Plastic Insulation ... feet	100

	Suggested quantity
Thermocouple Extension Wire, Iron-Constantan (Type JX), 16-Gage, Lead Sheath over Polyvinyl Plastic Insulation ---------- feet --	100
Thermocouple Extension Wire, Chromel-Alumel (Type KX), 16-Gage Asbestos over Enamel Insulation ---------- feet --	100
Thermocouple Extension Wire, Platinum, Rhodium (Type SX), 16-Gage, Asbestos over Enamel Insulation ---------- feet --	100
Range Spring (Range of 0–25 Inches of Water Differential Pressure) for Bellows-Type Mechanical Flow Meter ----------	1
Range Spring (Range of 0–50 Inches of Water Differential Pressure) for Bellows-Type Mechanical Flow Meter ----------	1
Range Spring (Range of 0–200 Inches of Water Differential Pressure) for Bellows-Type Mechanical Flow Meter ----------	1

	Suggested quantity
Orifice Plate—Size: 1/8 inch x 3 inches, 304 stainless steel, eccentric bored (optional) ----------	1
Orifice Plate—Size: 1/8 inch x 3 inches, 304 stainless steel, concentric bored ----------	1
Orifice Plate—Size: 1/8 inch x 3 inches, 304 stainless steel, segmental bored (optional) ----------	1
Thermometer, Mercury-In-Glass, Pocket Type, Range: −10 C to +110 C ----------	7
Thermometer, Mercury-In-Glass, Range: −20 C to +140 C ----------	7
Thermometer, Mercury-In-Glass, Range: 0 F to +250 F ----------	7
Thermometer, Mercury-In-Glass, Range: 0 F to +400 F ----------	2
Thermometer, Mercury-In-Glass, Range 0 F to +760 F ----------	2

Supplies, total estimated cost -- $1,000 to $1,500

Summary of Costs

The listed equipment is basic and does not include items for specialized programs. In addition to the basic equipment, an additional sum of $10,000–15,000 should be earmarked and included in initial equipment cost estimates for the purchase of equipment to meet the needs for some local or regional program specialty such as aerospace instrumentation, chemical-petroleum instrumentation, or bio-medical instrumentation.

Beyond specific equipment expenditures, an initial fund of approximately $3,000–5,000 should be provided for the purchase of expendable materials and replacement parts.

Therefore, the total initial cost of equipping for an instrumentation technology program, based on prices in 1964, may be estimated as follows:

Basic Equipment	$50, 000– 55, 000
Benches, fixtures, and storage cabinets installed	15, 000– 22, 000
Suggested instrumentation equipment for local or regional specialization	10, 000– 15, 000
Suggested allowance for demonstrators and simulation equipment	15, 000– 20, 000
Tools (as listed)	1, 000– 1, 500
Supplies (as listed)	1, 000– 1, 500
Initial replacement parts and expendable materials	3, 000– 5, 000
Total	95, 000–120, 000

The foregoing estimates do not provide for the cost of the building, which, if constructed for the program, may be calculated at $11 to $13 per square foot of unfurnished laboratory space. Such space with special utilities and built-in furnishings, without portable equipment, may be estimated at $24 to $29 per square foot.

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APPENDIX A

A Selected List of Scientific or Technical Societies Concerned With Instrumentation and Its Application

A list of some of the scientific and technical societies concerned with instrumentation and its applications may provide a helpful source of library content, instructional information, and reference data.

The list which follows [1] is not a complete listing of all such organizations; neither does inclusion imply special approval of an organization, nor does omission imply disapproval of an organization. Details regarding local chapters or sections of these societies have been omitted.

Instructors and others desiring information from the organizations listed may address their inquiry to the Executive Secretary of the organization.

- Instrument Society of America (ISA)
- Institute of Electrical and Electronic Engineers (IEEE)
- American Institute of Aeronautics and Astronautics (AIAA)
- American Institute of Physics (AIP)
- American Chemical Society (ACS)
- American Society for Testing Materials (ASTM)
- Society for Nondestructive Testing, Inc. (SNT)
- Society for Experimental Stress Analysis (SESA)
- American Society of Mechanical Engineers (ASME)
- American Nuclear Society (ANS)
- Electrochemical Society, Inc.
- Society of Automotive Engineers, Inc. (SAE)
- American Society of Tool and Manufacturings Engineers (ASTME)
- American Society for Metals (ASM)

A brief description of each, giving headquarters address, history, purpose, membership, and publications follows:

Institute of Electrical and Electronics Engineers (IEEE), Box A, Lenox Hill Station, New York 21, N.Y.

History: Merged with Institute of Radio Engineers, Inc., as of January 1, 1963, to form the new society. 200 sections.

Purpose: Engineers and scientists in electrical engineering, electronics, allied fields; membership includes 20,000 students. Holds numerous meetings and special technical conferences. Conducts lecture courses at the local level on topics of current engineering and scientific interest. Assists student groups. Awards medals, prizes, and scholarships for outstanding technical achievement.

Total Membership: 156,500.

Publications: Proceedings of the IEE, monthly; *Electrical Engineering,* monthly; *IEEE Student Journal,* bi-monthly; *Transactions of Professional Technical Groups,* irregular; *IEEE Directory,* biennial.

Instrument Society of America, 530 William Penn Place, Pittsburgh 19, Pa.

History: Organized August 7, 1939, as American Society of Instrument Engineers; reorganized November 1939, as American Society for Measurement and Control; incorporated and name changed to present title 1946. 101 geographic sections in the United States and Canada.

Purpose: To advance the arts and sciences connected with theory, design, manufacture, and use of instruments in the various sciences and technologies.

Total Membership: 15,500.

Publications: Journal, monthly; *ISA Transactions,* quarterly; *Automation and Remote Control,* monthly; *Industrial Lab,* monthly.

American Institute of Aeronautics and Astronautics, 1290 Avenue of the Americas, New York, N.Y.

History: Organized in 1962 by merger of American Rocket Society, Inc. (founded in 1930) and Institute of the Aerospace Sciences, Inc. (founded in 1932). More than 50 geographic sections in the United States.

Purpose: To advance the arts and sciences of aeronautics and astronautics and related science and technology.

Total Membership: More than 25,000.

Publications: Abstracts, bimonthly; *Journal,* monthly.

American Institute of Physics, 335 East 45th Street, New York 17, N.Y.

History: Founded 1931 by the following member societies: Acoustical Society of America, American Association of Physics Teachers, American Physical Society, Optical Society of America, and Society of Rheology, reorganized 1946 to provide membership for other organizations and for individuals.

Purpose: To advance and diffuse knowledge of the science of physics and its applications to human welfare.

Total Membership: Associated societies, institutions, and organizations, and individual members include more than 20,000 persons.

Publications: Physical Review, semimonthly; *Reviews of Modern Physics,* quarterly; *Bulletin of the American*

[1] Selected in part from *Scientific and Technical Societies of the United States and Canada,* 7th edition, National Academy of Sciences-National Research Council, Washington, D.C., 1961.

Physical Society, eight times a year; *Physical Review Letters*, semimonthly; *Journal of the Optical Society of America*, monthly; *Journal of the Acoustical Society of America*, monthly; *Noise Control*, bimonthly; *American Journal of Physics*, nine times a year; *Astronomical Journal*, ten times a year; *Review of Scientific Instruments*, monthly; *Journal of Chemical Physics*, monthly; *Journal of Applied Physics*, monthly; *Physics of Fluids*, bimonthly; *Journal of Mathematics Physics*, bimonthly; *Physics Today*, monthly; and numerous AIP Translation Journals.

American Chemical Society, 1155 16th Street, N.W., Washington, D.C., 20036.

History: Organized 1876. 164 geographic sections.

Purpose: To encourage the advancement of chemistry in all its branches; to promote research in chemical science and industry; to improve qualifications of chemists through education; and to disseminate chemical knowledge by meetings, contacts, and publications.

Total Membership: More than 96,000.

Publications: Abstracts, semimonthly; *Analytical Chemistry*, monthly; *Chemical and Engineering News*, weekly; *Industrial and Engineering Chemistry*, monthly; *Journal of Chemical Education*, monthly; 11 other regular publications covering special fields.

American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa.

History: Organized 1898 as the American Section of the International Association for Testing Materials.

Purpose: To promote the knowledge of the materials of engineering, and to standardize specifications and methods of testing.

Total Membership: 11,500.

Publications: Book of ASTM Standards (10 parts) and supplements to above; *Bulletin*, 8 issues per year; *Proceedings*, annual.

Society for Nondestructive Testing, Inc., 914 Chicago Ave., Evanston, Ill.

History: Organized October 1941 and incorporated in Massachusetts as the American Industrial Radium and X-Ray Society; name later changed to present title.

Purpose: To promote the art and science of nondestructive testing; to assist industry in supplying better quality products at less cost through the efficient use of nondestructive testing; and to publish material for the benefit of members of the Society.

Total Membership: 3,600.

Publications: Nondestructive Testing, bimonthly.

Society for Experimental Stress Analysis, 21 Bridge Square, Westport, Conn.

History: Organized 1943. 16 local sections.

Purpose: To promote and encourage knowledge pertaining to experimental stress analysis; to hold conferences, meetings, and symposia for the exchange of ideas and exhibition of equipment; and to publish and distribute papers or articles on stress analysis.

Total Membership: 2,080.

Publications: Proceedings, biennial.

American Society of Mechanical Engineers, 345 East 47th Street, New York 17, N.Y.

History: Organized 1880; incorporated 1881. 96 sections (one in Canada and one in Mexico).

Purpose: To promote the art and science of mechanical engineering and the allied arts and sciences; to encourage original research; to foster engineering education; to advance the standards of engineering; to promote the intercourse of engineers among themselves and with allied technologists; and to broaden the usefulness of the engineering profession.

Total Membership: 47,564.

Publications: Mechanical Engineering, monthly; *Transactions* (5 subdivisions), quarterly; *Applied Mechanics Reviews*, monthly; *PMM-Journal of Applied Mathematics and Mechanics* (translation of *Russian Journal*), bimonthly.

American Nuclear Society, 244 East Ogden Ave., Hinsdale, Ill.

History: Founded October 1954; in 1958–59 three divisions authorized: Hot Laboratory Division, Isotopes and Radiation Division, and Reactor Mathematics and Computations Division. 16 local sections.

Purpose: To integrate and advance the knowledge of nuclear science and technology.

Publications: Nuclear Science and Engineering, monthly; *Transactions*, semiannual; *Nuclear News*, monthly.

Electrochemical Society, Inc., 20 East 42nd St., New York N.Y. 10017

History: Organized April 3, 1902. 21 local sections.

Purpose: To advance the theory and practice of electrochemistry, electrometallurgy, electrothermics and allied subjects through meetings for reading and discussion of professional and scientific papers on these subjects; the publication of such papers, discussions, and communications as may seem expedient; and cooperation with chemical, electrical, and other scientific and technical societies.

Total Membership: 3,182.

Publications: Journal, monthly.

Society of Automotive Engineers, Inc., 485 Lexington Ave., New York 17, N.Y.

History: Organized 1904; merged with the American Society of Aeronautical Engineers and the Society of Tractor Engineers under present title in 1916.

Purpose: To promote the arts, sciences, standards, and engineering practices connected with the design, construction, and utilization of self-propelled mechanisms, prime movers, components thereof, and related equipment.

Total Membership: 25,000.

Publication: Transactions, annual.

American Society of Tool and Manufacturing Engineers, 10700 Puritan Avenue, Detroit 38, Mich.

History: Founded 1932 as American Society of Tool Engineers. 167 chapters in the United States and foreign countries.

Purpose: To advance scientific knowledge in the field of tool and manufacturing engineering; and, through its members, engage in research, writing, publishing, and disseminating such information.

Total Membership: More than 40,000.

Publications: Tool Engineer, monthly; *Scope*, bimonthly; *News for Metalworking Executives*, monthly.

American Society for Metals, Metals Park, Novelty, Ohio

History: Founded 1920 as the American Society for Steel Treating; name changed to present title 1935. 114 chapters in United States and Canada.

Purpose: To serve members in the metal producing and consuming industries through dissemination of technical information on the manufacture, treatment, and use of metals.

Total Membership: 31,500.

Publications: Metal Progress, monthly; *Metals Review*, monthly; *Transactions*, annual; *Review of Metal Literature*, monthly; Handbook, *Metals*.

APPENDIX B

Suggested Procedure for Laboratory Report Writing

General Characteristics

Tests of equipment are usually summarized in the form of reports. In most cases, these reports are submitted to individuals who have not been actively engaged in the tests: hence, the reports must be clear and concise enough to leave no doubt concerning the method of test and the interpretation of the results. Data should be summarized and shown graphically whenever diagrams, charts, or graphs simplify its comprehension or interpretation.

The report should be written in the past tense and in the third person. It should be impersonal throughout. The report must be complete in itself so that it can be followed by a reader without extensive knowledge of the test under consideration. A good report is thorough, orderly, neat, and grammatically correct.

Specifications

1. Write with ink or use a typewriter.
2. Use 8½- x 11-inch paper (ruled paper for handwriting).
3. Write on one side of the paper only.
4. Draw all illustrations, circuit diagrams, and curves neatly and carefully.
5. Letter or type all information on drawings, circuit diagrams, and curves. Do not mix lettering styles.
6. Assemble the sheets in the order given in the following report outline. Submit the material in a standard report folder with the brads inserted through the back cover only, with the heads on the outside.

Report Outline

The material should be arranged in the following order:

- I. Title Page
- II. Introduction
- III. Method of Investigation
  - A. Procedure
  - B. Circuit diagrams
- IV. Results
  - A. Data
    1. Nameplate data of equipment
    2. Observed and calculated data
  - B. Sample calculations
  - C. Curves
- V. Analysis of Results
- VI. Questions

(Not more than one of the above six divisions should be included on a single page. Omit Roman numerals.)

Discussion of Report Outline

I. Title Page

On this page should appear the name of the school, the course number and title, the date performed, the date submitted, the name of the student reporting, and the name of co-worker or co-workers. This page may be omitted if the form printed on the report folder includes these items.

II. Introduction

The introduction should be a concise statement setting forth the aim and scope of the investigation.

III. Method of Investigation

A. *Procedure.* In this section, a general description of the procedure should be given. It should be comprehensive but brief. The enumeration and detailed description of routine mechanical operations and their sequence—such as closing switches, reading instruments, turning knobs, and so forth—should in general be avoided. However, when a specific method of mechanical operation is necessary to assure the validity or accuracy of the test data, it is important that the essential details be included in the description.

B. *Circuit Diagrams.* Each diagram should have a figure number, and should be referred to in the text material by that number. Each figure should have a descriptive title. Small diagrams may be included in the body of the description, or several may be drawn on one separate sheet if the result is not crowded. Standard symbols should be used.

IV. Results

A. *Data.* The first item under results should be the nameplate data—or equivalent identification—of the apparatus tested. The original observed data and the calculated data should be presented in tabular form. If the observed data require corrections, these should be made before tabulation. Instrument identification numbers and ranges need not be copied from the original laboratory data sheet.

B. *Sample Calculations.* This section should consist of a sample of a complete calculation of each type involved in the determination of calculated data and the solution of problems. When a succession of calculations is required in order to reach a final result, the same set of observed data should be used in carrying through the successive sample calculations; i.e., the same sample figures that are selected from a data column should be used in all calculations involving that set of data.

C. *Curves.* All curve sheets should conform to the following specifications:

1. Use "twenty to the inch" coordinate paper, 8½ x 11 inches, for rectangular plots.
2. Plot the first quadrant where only one quadrant is needed.
3. In general, make the axes intersect within the sectioned part of the paper. Leave the curve sheet margins blank.
4. Plot the independent variable as abscissa and the dependent variable as ordinate.
5. In general, start the scale of the dependent variable, but not necessarily the scale of the independent variable, at zero.
6. Choose scales that are easy to use and that do not allow points to be plotted to a greater accuracy than that justified by the accuracy of the data.
7. Indicate points plotted from data by visible dots or small circles.
8. Draw a smooth average curve through the plotted points except in cases in which discontinuities are known to exist. Use a French curve in drawing the curves.
9. Place a title containing all pertinent information on each curve sheet. The title should be lettered or typed. Label the axes and show the units in which they are marked.
10. Draw only related curves on the same sheet.
11. Insert curve sheets in the report so that they can be read from the bottom or right side.
12. Use ink for everything on the sheet except the curves themselves; these should be drawn with a colored pencil.

V. Analysis of Results

The analysis of results is the most important section of the report. As the name implies, it should be a complete discussion of the results obtained.

Part of the discussion should deal with the accuracy or reliability of the results. It is suggested, where applicable, that this section consist of a careful treatment of the effect on the results of the following:

(1) Errors resulting from the necessity of neglecting certain factors because of physical limitations in the performance of the test
(2) Errors in manipulation
(3) Errors in observation
(4) Errors in instruments

An important part of the discussion should be a comparison of the results obtained with those which would reasonably have been expected from a consideration of the theory involved in the problem. Whenever the theory is apparently contradicted, the probable reasons should be discussed.

When results are given in graphical forms as curves, the shape of each curve should be carefully explained. Such an explanation should state the causes for the particular shape the curve may have.

Any original conclusions drawn as a consequence of the laboratory procedure and a study of the results obtained should be included in this section.

VI. Questions

In this section should be included answers to any questions which are given as a part of the test.

APPENDIX C

Sample Instructional Materials

Instructional materials for Instrumentation Technology should be designed to make the best possible use of laboratory equipment. Very little published material in the form of workbooks or laboratory experiments is available. Instrumentation textbooks are incomplete and thus have limitations for classroom work; also, material for demonstration and project work must be designed and prepared by instructional personnel experienced in the field of instrumentation. This material should be designed to serve as a guide and a significant share of the conclusions and results should be left to student resourcefulness.

Typical Material for a Unit of Instruction

A full-time technical instructional program gains great strength from coordinated learning activities. Such activities include classroom instruction, directed study, demonstrations, examinations, problems, laboratory experiences, and reports. The multiple approach method of learning includes: Classroom lecture outline, Reading references, Problem assignment, Laboratory projects, and Examination.

Sample Laboratory Report

The formal laboratory report is an extremely effective part of the teaching and learning process. It is a form of recitation that demands an organized systematic approach and leads to a logical conclusion. Its educational value goes well beyond the absorption of facts and technical understanding. If properly used, it can promote clear thought; it will strengthen the skills of communication; and it can develop that most important of all motivation factors, personal pride. Not all laboratory experiments, however, should be the subject of complete or formal laboratory reports because of the time required for such reporting. The instructor must exercise judgment in requiring formal reports or shorter summary reports in light of the reasonable availability of the student's time.

The form suggested for the formal laboratory report, contained in Appendix B follows accepted practices of technical reporting. It should be made clear to the student that the detailed information in the report is equal in importance to results and conclusion.

Text and Reference Material

The selection of text materials should normally be made by those who teach the subject matter of the curriculum. Good textbooks and reference materials are indispensable in formal classroom instruction. In general, references should provide both a simplified exploration of the subject being studied and an extensive treatment for special reports.

Teaching Guide

Course: PHYSICS FOR INSTRUMENTATION I (First Semester), Division IX—Transfer of Heat Energy

Topics:

- Lecture 1—Thermal Resistance
- Lecture 2—Thermal Capacitance
- Lecture 3—Time Constant Responses (Frequency Response)

Lecture Time: Three 50-minute periods

Laboratory Time: Two 110-minute periods

Quiz Time: 45 minutes

Lecture Outlines

Lecture 1—Thermal Resistance

References:

- A–24 Blackwood, Oswald H.; Kelly, William C.; *and* Bell, Raymond M. *General Physics*, 3d ed., New York: John Wiley and Sons, 1963
- A–123 Resnick, Robert *and* Halliday, David. *Physics for Students of Science and Industry.* New York: John Wiley and Sons, 1960
- A–133 Semat, Henry. *Fundamentals of Physics*, 3d ed., New York: Holt, Rinehart and Winston, 1963

I. Definitions

II. Factors involved
- A. Temperature difference
- B. Time
- C. Number of heat units transferred

III. Units of resistance
- A. Different systems of temperature measurement
- B. Units of heat

IV. Factors affecting thermal resistance
- A. Liquids, gases, solids
- B. Agitation, turbulence
- C. Insulating films
- D. Area
- E. Thickness

V. Methods for minimizing thermal resistance
- A. Increase contact area
- B. Decrease thickness of insulating film
- C. Increase relative speed of fluids and heat exchanger

VI. Problem assignment
 A. Compute thermal resistances for a number of situations
 B. From assigned experiment, determine thermal resistance based on initial rate of change of temperature.

Lecture 2—Thermal Capacitance

References:

A-24 Blackwood, Oswald H.; Kelly, William C.; *and* Bell, Raymond M. *General Physics*, 3d ed., New York: John Wiley and Sons, 1963

A-123 Resnick, Robert *and* Halliday, David. *Physics for Students of Science and Industry.* New York: John Wiley and Sons, 1960

A-133 Semat, Henry. *Fundamentals of Physics*, 3d ed., New York: Holt, Rinehart and Winston, 1963

I. Definition
 A. Relate to other types of capacitance
 B. Distinguish between *capacitance* and *capacity*

II. Factors involved
 A. Change in *level*
  1. Temperature
  2. Pressure
  3. Level
 B. Change in *quantity* with respect to level change

III. Computation of thermal capacitance
 A. Effect of total weight
 B. Effect of specific heat—relate to thermal capacitance per pound of material

Lecture 3—Time-Constant Responses (Frequency Response)

References:

A-24 Blackwood, Oswald H.; Kelly, William C.; *and* Bell, Raymond M. *General Physics*, 3d ed., New York: John Wiley and Sons, 1963

A-123 Resnick, Robert *and* Halliday, David. *Physics for Students of Science and Industry.* New York: John Wiley and Sons, 1960

A-133 Semat, Henry. *Fundamental of Physics*, 3d ed., New York: Holt, Rinehart and Winston, 1963

I. Definition of time constant
 A. Plot temperature response to step change. Demonstrate by experiment in class
 B. Draw tangent to initial part of the curve
 C. Show that time for tangent to reach the final value is actually time required to attain 63% of a step change.
 D. Use exponential $\left(1-e^{\frac{-t}{RC}}=0.63\right)$ when $\frac{t}{RC}=1$.

II. Show that the product of R and C contains time units.

III. Assume values for R and C and d.
 A. Determine time for step change to be completed if the initial rate of heat transfer prevails.
 B. Compute the number of time-constants required to complete 95%, 98%, 99%, and 99½% of a step change.

IV. Compare answers from Step 3 with the values attained in Step 1.

V. Stress typical responses to single resistor-capacitor combinations.

VI. Explain the result of having two resistor-capacitor combinations in series. Illustrate with typical response curves.

Laboratory Procedures

Laboratory 1—Thermal Resistance and Capacitance

Purpose: To compare the effects of fluid speed and turbulence upon thermal resistance.

Discussion: Thermal resistance is reduced whenever heat can be transferred more rapidly to or from a material for any given temperature differential. Rapid transfer requires at the interface the maximum temperature differential between the fluid and the solid object. If the fluid is relatively stagnant, the fluid soon approaches the temperature of the object, and little heat is transferred. Because movement prevents this stratification, thermal resistance should decrease with increases in the relative speed. Because gases under moderate pressures can store less heat per unit of volume than can most liquids, gases are less capable of accepting or giving up heat than are most liquids. Consequently, thermal resistance should be much greater when gases are involved, and lower when liquids are used to transfer the heat. When equal thermal capacitances undergo different rates of change, the different time constants are created by dissimilar resistances.

Equipment Required:
 4 thermometers—0° to 100° C
 4 identical test tubes filled with equal amounts of water at about 0° C
 1 fan
 2 tanks of water at room temperature

Procedure:
1. Place thermometers in all test tubes after recording weight of tube and weight of water.
2. Record time and place one test tube in room where air is still.
3. At the same time, place another tube and thermometer in front of fan.
4. Record times and temperatures for both tubes until within ½ degree of room temperature.
5. Repeat, but place the two remaining tubes in water at room temperature. Immerse to same depth. Keep one in still water but agitate water for the second.

Laboratory Report Data:
1. Plot temperatures vs. time. From the initial tangent to the curves, determine the time constants.
2. Compute the thermal capacitances of the tube, water, and thermometer. Using the time constants obtained from the experiment, determine the actual resistance for each of the four different conditions. Compare actual results with the theoretical determinations.
3. Compare relative resistances.
4. Discuss practical significance of results.

Laboratory 2—Time-Constant and Frequency Response Determination

Purpose: To determine the frequency response of a thermal resistor-capacitor combination.

Discussion:

The controllability of systems is largely dependent upon the behavior of the components. One of the most useful, yet simple, methods of analysis employs the frequency response of each component. The time constant of a unit furnishes a clue to its behavior.

If a sinusoidal input of various frequencies is employed, the temperature of the test unit will generally stay in step with changes in the input when the cycles are long. But as the frequency—not the magnitude—is increased, the maximum and minimum temperatures will not attain their former values. Neither will they be in step with the thermal input.

If the frequency is made high enough, there will be virtually no variation from a constant value.

If the ratios of output to input are plotted on log-log paper, the tangent to the plot for low frequency response and that for the high frequency response will intersect. The frequency at which the intersection takes place is termed the *corner* frequency, and the actual response output should be

70.7% of the input. At this frequency $1=\frac{1}{2\pi f T}$.

Consequently, the time constant can be computed. Conversely, if one knows the time constant, the corner frequency can be computed.

Equipment Required:

1 thermometer—0° to 100° C

1 two-to-three-quart container (source of hot and cold water, and control valves)

Procedure:

1. By experiment, determine approximate valve openings to change the flow of constant-temperature hot water so that its flow rate varies sinusoidally with the valve position. By timing the movement of the valve, the flow can be made to vary sinusoidally with *time*. Determine six or seven valve positions between maximum and minimum flow.
2. Provide for a constant flow of water at fixed temperature (room temperature is satisfactory) into a two- or three-quart container into which the controlled hot water can also flow.
3. Adjust both water sources so that at the maximum hot water flow rate, it will be about twice that of the cold source.
4. Using a cycle of 3 or 4 minutes, plot the temperature response of the mixture of hot and cold water. Take twice as long for the cycle, and repeat. If both maximum temperatures are about the same, consider them to be the *zero frequency response;* all other temperatures can be compared with it.
5. Cut the time for each cycle by a factor of *two*, completing three cycles at each frequency. Record time, temperatures, and valve position so that the heat input and water temperature can be compared. Continue to increase the frequency (i.e., decrease the time for a cycle) until the maximum response is only 20% that of the maximum temperature rise.

Laboratory Report Data:

1. Plot on log-log paper the ratios of actual maximum temperature to maximum temperature attained in Step 4 above. Draw tangents to both straight portions of the plot.
2. Determine the corner frequency on plot. What is the ratio for this frequency?
3. On semi-log paper (use log scale for abscissa), plot the delay between the maximum input and the maximum water temperature. Determine the angle of lag at the corner frequency. (Each cycle consists of 360°.)
4. Discuss the method for determining the frequency response for a mechanical component.

Examination

Course: PHYSICS FOR INSTRUMENTATION I (First Semester)

Division IX—Transfer of Heat Energy

Examination Topics: Thermal Resistance, Thermal Capacitance, Time Constants, and Frequency Response

Time: 45 minutes

1. Identify and discuss the important factors involved in determining thermal resistance.
2. What is the relationship of thermal resistance to other types of resistance, such as electrical? friction?
3. What is the relationship of a response to a step change as compared to the response to other types of change? Explain.
4. Outline at least two different ways to determine time constant, based on the response to a step change.
5. Why has a quantity undergone 63% of a step change at the end of the first time-constant period?

   How much of a change does it experience during the second time constant?
6. Why is a step change not complete at the end of a specified number of intervals of time?
7. For all practical purposes, how many time-constant periods must elapse before the value of the variable approaches a final value (that is, within ½%)?
8. What are the relative advantages of determining step changes and frequency responses when predicting the response of a number of components?
9. What is the maximum angular lag which can be introduced by a resistor-capacitor unit?
10. What is the relationship of the corner frequency to the time constant of the component?

    What is the relationship of the time constant to the corner frequency?

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