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RESEARCH HIGHLIGHTS

OF THE

NATIONAL BUREAU OF STANDARDS

ANNUAL REPORT

UNITED STATES DEPARTMENT OF COMMERCE
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Research Highlights
of the
National Bureau
of Standards

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The National Bureau of Standards, Washington, D.C., laboratories (top) and Boulder, Colorado, laboratories (bottom).

Contents

1. GENERAL REVIEW

During the past year the National Bureau of Standards continued efforts to strengthen its basic research activities in accordance with urgent national needs. With increased funds provided by the Congress, the Bureau was able to initiate new or expanded research programs in a number of areas, such as ultra high pressures and plasma physics, that are coming to be recognized as critical to national defense and technological progress.

In these frontier areas the Bureau is concerned primarily with advancing the science of measurement. As new fields of science and technology become active, new standards must be developed, new instrumentation devised, and appropriate calibration services provided. To keep pace with these rapidly advancing needs, an imaginative and vigorous research program must be conducted in most branches of the physical sciences.

The Bureau recognizes that its principal research mission is to provide the central basis within this country for a complete system of physical measurement matched to the dynamic requirements of American sicence and industry. Within the limits of its budget and facilities, the Bureau has been making a concentrated effort to meet this challenge.

The Bureau's measurement mission is implicit in the functions assigned it by legislation. Most basic of these functions is the custody, development, and maintenance of the national standards of physical measurement. Through a complex chain of calibration extending into the shops of industry, these very precise standards provide a firm basis for accurate measurement in the mass production of interchangeable parts, in the development of new products and devices, in the commercial exchange of goods, and in the determination of scientific quantities.

A second major function, closely related to the standards activity, is the precise measurement of the properties of matter and materials. The Bureau determines fundamental physical constants, like the acceleration of gravity, to provide the accurate values needed by scientists and engineers. It also develops data on the properties of materials, such as metals and plastics, to afford a sound basis for their use in science and industry.

The background in measurement science provided by the basic work in standards and properties of materials enables the Bureau to serve the Government and the Nation in a variety of other ways: In devising methods of testing materials, in developing specifications for Government purchase, in developing building and safety codes, and in rendering advice on technical problems to other Federal agencies. These activities are, however, subordinate to the principal research effort, which continually seeks to advance the science of measurement.

(For statement of NBS mission, see page 150.)

Progress on Measurement's Frontiers

When the Bureau was established in 1901, it had custody of two primary standards of physical measurement—the meter for length and the kilogram for mass. Since that time it has been necessary to provide hundreds of other standards, together with appropriate measurement methods, in newly opened areas. Recent developments in some of today's more critical fields of measurement are discussed in the following paragraphs.

Length. The control of dimensions in mass production industries goes back to the national standard meter, the distance between two fine lines on a platinum-iridium bar kept in a vault at the Bureau. For example, the mass production of uniform pistons in the automotive industry depends initially on calipers and micrometers used in the shop. These instruments are checked by the company against its master gage blocks, which in turn are periodically calibrated against standards linked through a measurement process to the standard meter.

As the mass production industries have advanced, the dimensions of interchangeable parts have become increasingly critical. During World War I tolerances of machined parts accurate to 1 part in 10,000 were extremely rare. But today there is a pressing need to control the tolerances of many important and critical elements such as fuel injectors, bearings, gyroscopes, and transistors to tolerances expressed in hundred-thousandths or even millionths of an inch. The master standards must be even more precise as some accuracy is lost at each stage of calibration.

This need has caused machine tool manufacturers to request that the National Bureau of Standards develop procedures for calibrating their master gage blocks on a regular basis to 1 part in 10 million. The Bureau had been calibrating master gage blocks to an accuracy of 1 part in 1 million, that is, to the nearest millionth of an inch for inch-long blocks. Because of the extreme importance of the work, a number of industrial firms have made funds available to supplement available appropriations so that the necessary research can be carried out as soon as possible.

During 1960 significant progress was made in the development both of highly stable gage blocks and of ultraprecise measuring techniques. Three types of gage blocks, produced in the Bureau's metallurgy laboratories, showed dimensional stability considerably greater than that of the best commercial blocks. One type of gage block, nitrided for surface hardness, expanded only 0.0000002 inch per inch of its length in a year. Sixteen gage block materials are now under investigation and have been given a total of 42 different metallurgical treatments.

For the first time in its history, the Bureau certified the accuracy of length measuremcnts on two commercial gage blocks to better than 1 part in 5 million. The measurements were made on a 16-inch and an 18-inch gage block by two independent methods, one of which gave the lengths in terms of wavelengths of light and the other directly in terms of the standard meter bar. The results agreed to the nearest millionth of an inch or better

for both gage blocks. The NBS measurements also agreed within 2 millionths of an inch with independent measurements made by the National Physical Laboratory in England. Another gage block, 4 inches in length, was certified to one part in 4 million, and this result agreed with the measurements of two other national laboratories to 1 millionth of an inch.

In another aspect of dimensional measurement, progress was made in relating the length of the national standard meter to the wavelength of

On October 14, 1960, the 11th General Conference on Weights and Measures, meeting in Paris, adopted the wavelength of Krypton-86 orange light as the new international standard on which all length measurements will be based. The definition of the meter as 1,650,763.73 wavelengths of the orange-red line of Kr^{86} replaces the platinum-iridium meter bar which has been kept in Paris as an international standard of length since 1889 under the Treaty of the Meter (pages 4 and 31).

orange-red light emitted by the isotope krypton-86. This wavelength has been proposed for adoption* as the new international standard of length in place of the international standard meter, which is kept at the International Bureau of Weights and Measures in Sèvres, France. Measurement science is now moving away from the use of arbitrary prototypes as standards and toward a dependence on natural atomic constants. These unchanging properties of the atom have the advantages of being reproducible in the laboratory at any time. Their use as standards can thus release science from dependence upon the characteristics of a particular object that might be destroyed or slowly change in value.

Attempts to define the meter in terms of an unchanging property have been under way for many years. Krypton-86 lamps can furnish standards which should be reproducible to 1 part in 100 million—a significant improvement over the precision that can be obtained with the meter bar. However, to keep the standardizing laboratories of the various countries well ahead of the requirements of science and technology, the development of more precise standards must continue. At the same time, the problems involved in utilizing this greater precision in the calibration of material standards must be solved. The Bureau is therefore continuing to conduct research on the development of better wavelength standards for use in length measurement. This work has produced three devices using mercury atoms which provide extremely narrow spectral lines—about one-tenth as wide as is given by the proposed krypton-86 standard. At some future time these narrow lines could make possible very precise standards of length based on wavelengths of mercury radiation.

Force. Force measurements are widely used in industrial fields such as weighing, materials testing, and automatic control of equipment. Today there is a need for precisely measuring larger forces than ever before. Especially urgent is the need for determining the thrust of the more powerful rocket engines now being developed. It has been estimated that by increasing the accuracy of large force measurements, millions of dollars now being spent for experimental firings of rocket engines could be saved.

As a step toward this goal, the basic designs were completed during the year for dead-weight force measuring machines of 300,000- and 1,000,000-lb capacity to be installed at the Bureau's new site at Gaithersburg, Md. These machines will be used to calibrate force-measuring devices that are used, in turn, to calibrate other devices and machines for measuring and applying large forces. Their large capacities should greatly accelerate the extension of modern force-measuring methods. Designed to provide accuracies better than 0.01 percent, they will not only make possible the direct calibration of most existing force measuring devices, but they will also make it possible to develop new and improved portable secondary standards which are greatly needed as working standards in other laboratories.

Pressure. The use of very high pressures offers great promise as a means of developing materials to meet severe requirements in military and in-

*Kr^{86} wavelength was adopted on October 14, 1960, see photograph on page 3.

dustrial applications. For example, high pressures cause chemical changes that form new compounds such as polyethylene and boron nitride, and crystalline changes such as occur when graphite is changed to diamond, or quartz to Coesite. Tungsten carbide more than doubles in strength when subjected to a hydrostatic pressure of 400,000 pounds per square inch.

However, these high pressures cannot be utilized effectively without a well-defined scale of pressure, standard measurement methods, and precise data on properties of materials at various regions on the pressure scale. In 1960 a special program was therefore begun to develop standards, measurement techniques, and data on properties in the very-high-pressure field.

Improvements have already been made in both accuracy and range of pressures covered. New equipment is now in operation for developing ultra-high pressures. With this equipment it has been possible to reach pressures as high as 2 million lb/in.^{2} It is now being used in exploratory studies of reactions which take place at high pressures and which may serve as calibration points on the pressure scale. The first of such reactions has been the conversion of graphite to diamond. This reaction demonstrated that it is possible to heat a sample to 1,500 °C while a pressure of over 1 million lb/in.^{2} is being applied.

As part of the general program in pressure measurements, a Vacuum Standards Laboratory has been set up to concentrate on developing standards for extremely low pressures. The program will include a study aimed at the generation of more reproducible pressures in this range to serve as fixed points. Efforts will also be made to effect necessary improvement in accuracy of vacuum measurements by different organizations and scientific workers.

High-vacuum pressures correspond to the pressures encountered many miles above the earth's surface, and there is a growing need for precise measurement in this pressure range. Improved measurement of extremely low pressures also is needed in investigating adsorption phenomena and other surface properties of materials, as well as in operating equipment such as particle accelerators used in studies of nuclear reactions.

Temperature. Another vital measurement frontier is that of temperature, especially the extremes of temperature. Recent requirements for high-temperature materials, high speeds and frictions, and increased propulsion efficiencies have placed a premium on the upward extension of the temperature scale and temperature measuring techniques.

Present-day research requires instrumentation for making careful laboratory and field experiments to test high-heat systems under operating conditions. Under controlled laboratory conditions high-temperature measurements can be made up to about 4,000 °C, with an uncertainty of about 40 degrees at the top of the range; at 15,000 °C, this measurement uncertainty has increased to about 1,000 degrees. Yet today scientists are discussing million degree temperatures and the possibility of controlled fusion furnaces.

At the other end of the temperature scale there is a similar measurement challenge. Within 4 degrees of absolute zero, there lie the vast field of

cryogenic (extremely low-temperature) research and new prospects of low-temperature production processes; yet there are no fully adequate reference points in this segment of the temperature scale.

The Bureau is making vigorous efforts to extend its temperature measurement capabilities in both directions on the temperature scale, particularly into the extreme high-temperature region. Recent advances include the development of a photoelectric optical pyrometer which greatly reduces the human element in calibrations up to 4,000 °C, and the design of a special type of high-temperature resistance thermometer having a precision 10 times greater than previous instruments for calibration in the 630 to 1063 °C range. A great deal of research has been done to produce a high-temperature source that will be both stable and reproducible. This work has resulted in a high-current density arc with a number of new features, which operates in the region from 10,000 to 20,000 °C; this arc has been tested up to 15,000 °C, and appears promising as a standard, optically thin, high-temperature source. Temperatures in the arc are being determined by measuring the intensity and shape of the spectral lines it produces.

The low-temperature research program has been expanded in an effort to provide high-precision thermometry in the range from 90 down to 20 °Kelvin (−183 to −253 °C) and to develop a calibration service for secondary thermometers from 20 down to 2 °K. At present the International Temperature Scale does not go below 90 °K. However, development of precise, repro ducible measuring techniques should make it possible to extend the International Temperature Scale down to these lower temperatures.

Radio and Electronics. Electronics is now the fifth largest industry in this country. It has been predicted that it will step into first place within 10 years. With this rapid growth has come the problem of accurately measuring the basic radio and electronic quantities so as to insure the unfailing performance of an ever-increasing variety of components and equipment.

Such fields as space exploration, automation, and miniaturization are subjecting electronic equipment to new and complex uses as well as extreme environments. In these applications the need for accuracy on the production line becomes increasingly important. In the missile field, for example, it is estimated that reliability above 90 percent can be achieved only if each component has not more than a 1-to-1,000 probability of failure. To produce components having the necessary uniformity and accuracy requires a chain of calibration leading from the assembly line back ultimately to the precise electrical standards maintained by the National Bureau of Standards.

In an effort to meet these measurement needs, the NBS Radio Standards Laboratory at Boulder, Colo., has been expanding its calibration services and its research program on radio standards. In so far as possible, it is seeking to provide the improved standards and measurement methods that are needed for all radiofrequency and microwave quantities.

At the present time, standards are being established and improved measure-

ment techniques developed for frequency, power, attenuation, voltage, impedance, noise, field strength, interference, conductivity, and magnetics. During the year, for example, a microvolt console was completed for calibrating voltage generators in the high-frequency region, a portable low-frequency antenna calibration system for field use was designed and constructed, calibration systems for four additional waveguide sizes were made ready, instrumentation for impedance measurement in the X-band was completed, sensitive techniques were devised to measure reflections and losses of waveguide joints and connectors, and a microwave noise standard having an accuracy of 0.01 decibel was developed.

For several years the Bureau has been carrying on an intensive research program to establish atomic standards for frequency and time measurement. Based on an unchanging property of the atom, such standards would have significant advantages over the present standard, a specific period of the earth's revolution about the sun. During the past year, two cesium beam atomic standards for frequency and time interval measurement were put into operation, making it possible to refer the national standard of frequency to an atomic resonance with an accuracy better than 2 parts in 100 billion. The standard radiofrequencies broadcast by the Bureau are monitored with reference to this standard.

Work also progressed on a special atomic frequency standard for use in a satellite flight to check the gravity-dependent frequency shift predicted by Einstein's general theory of relativity. A prototype standard using the atoms in rubidium vapor was constructed and found to be stable to 1 part in 100 billion over a period of a month. Ultimately it will be miniaturized to a volume of about 1 cubic foot for use in the satellite. Exposure to radiation corresponding to that in the Van Allen radiation belts produced no observable change in measurement accuracy.

Many defense agencies engaged in weaponry development have reached a point where their timing and frequency calibration requirements far exceed the accuracies that can be provided by the Bureau's short-wave radio stations, WWV at Beltsville, Md., and WWVH on Maui, Hawaii. Signals from these stations are propagated by alternate reflections between the earth and inosphere (the electrically charged layers of the upper atmosphere) to reach the receiver. As transmitted, they are accurate to better than 1 part in 100 million; but the height and density of the ionosphere change constantly, and this creates small, erratic changes in the frequencies as they are received. Errors introduced by these changes were insignificant 10 years ago; today they are very important in such areas as the tracking of missiles and satellites.

To provide greater accuracy in the received signal, the Bureau began experimental broadcasts of a standard radiofrequency at the very low frequency of 20 kilocycles from a new station near Boulder, Colo. This station has the call letters WWVL. At this frequency radio waves follow the curvature of the earth, with the ionosphere and the ground acting as upper and

lower limits of a gigantic duct to guide the signals over the globe. The new station supplements earlier experimental broadcasts at 60 kilocycles; both broadcasts are intended to provide much more stable transmissions than are possible from WWV or WWVH.

Radiation. In recent years the invention and development of high-energy electron accelerators have extended the frontier of available X-rays to the region of thousands of millions of electron volts. The unique properties of these high-energy X-rays have made them extremely useful not only in nuclear physics but in radiation therapy and industrial radiography. At present many new fields of technology are being opened up by the availability of intense electron beams which are also produced by the accelerators. Industry has already begun to use such beams to sterilize pharmaceuticals and food, polymerize plastics, and vulcanize rubber.

Safe and effective application of the new high-energy radiations requires the development of basic data on the radiations and the provision of precise standards, measurement techniques, and calibration procedures. Research conducted during the year made significant progress in this general field. For example, the technology of absorbed dose measurements was improved by the development of a dose calorimeter having increased stability and sensitivity. A portable instrument standard for measuring the absolute intensities of X-rays up to 180 million electron volts was calibrated by the standard intensity calorimeter and this calibration was in turn transferred to portable instruments in four European laboratories. An electron spin resonance detector was developed for the measurement of magnetic fields that vary with space and time as in an accelerator. This detector can measure a 3,000-gauss magnetic field to an accuracy of 1 part in 1,000.

To keep pace with the new fields opened up by the availability of intense electron beams, a new high-intensity accelerator was designed for the Bureau's Gaithersburg site. This accelerator will produce one of the world's most intense electron beams, with energies continuously variable from 10 to 100 million electron volts. Its power output—about 40,000 watts—will be about 100,000 times that now obtained in this energy range at the Bureau. The resultant increase in intensity will make it possible for the Bureau to enter new areas in nuclear and atomic physics, and through such studies to develop standards, measuring techniques, and shielding requirements for the high dose rates now being applied in industry and the armed services.

Fundamental Constants Measured

For some time a program has been under way to obtain more accurate values for basic constants, such as the velocity of light, the acceleration of gravity, and the various atomic constants. These constants of nature, when determined to extremely high accuracy, provide invariant bases for the reproduction of standards of many physical quantities such as length, time, and electric current. They thus serve to lock present standards and units of physical measurement into the phenomena of science.

The Bureau is engaged in a series of measurements aimed at providing an improved value for the acceleration of gravity. This value is fundamental to almost every relationship in the field of mechanics. It is one of the constants which determine the standards for the volt and the ampere, and it directly affects the standards of temperature (pages 8 and 45).

An achievement of the program during the past year was the determination of an improved value for the faraday by a new experimental process. The increased accuracy afforded by this determination is of major importance in both physics and chemistry, where the faraday enters into the determination of other fundamental constants.

To obtain the faraday, the electrochemical equivalent of silver was first determined by measuring the mass dissolved by one coulomb of electricity. This quantity, together with the atomic weight of the silver used in the experiments, gave the new value of the faraday: 96516.5 ± 2.1 coulombs on the physical scale.

In connection with the work on the faraday, a new value of the atomic weight of silver was determined with the cooperation of the Atomic Energy Commission. The new value (107.8731 ± 0.0020 on the chemical scale and

107.9028±0.0013 on the physical scale) results directly from a highly accurate evaluation of the absolute abundance ratio of silver using the techniques of mass spectrometry. The atomic weight of silver plays a key role in determining atomic weights of other elements. It also plays an important part in the assignment of values to other fundamental constants such as Avogadro's number and the gas constant.

Plasma Physics and Astrophysics

One of the most rapidly developing fields of physics deals with an ionized gas, often at high temperature and departing from local thermodynamic equilibrium. The nature and behavior of such a gas is still very poorly understood. Yet, many branches of technology in which there is growing interest—such as thermonuclear power, space physics, hypersonic aerodynamics, and ionospheric physics—have in common a dependence upon the solution of problems in this general field.

At present, many of the laboratories attempting to apply plasma physics to practical objectives are forced to rely on costly and inefficient empirical methods for lack of precise measurement techniques and basic data on the fundamental properties of this gaseous medium. To help solve this problem, the Bureau began a special research program to unify and strengthen its work in plasma physics and astrophysics. In this program it will attempt to develop the necessary measurement standards, basic data, theoretical guidance, and interpretive techniques for determining the relevant properties of hot gases and for the solution of pressing problems in modern astrophysics. Many long-standing Bureau programs are contributing, such as atomic spectroscopy, ionospheric and solar physics, and high-temperature physics. The program will draw upon such fields as gaseous electronics, astrophysics, atomic physics, microwave physics, spectroscopy, statistical mechanics, chemical physics, and hydrodynamics.

The most pressing demand for these Bureau services arises in the space sciences, where the coming of satellite-borne observatories promises to place enormously increased demands upon basic data for interpreting astronomical observations. New problems will result from the opening of the vacuum ultraviolet region of the spectrum to the earth-bound observer, since this spectrum arises from stellar regions that are likely not to be in local equilibrium. To cope with these problems, a greatly expanded effort in atomic and high-temperature physics and in modern fluid mechanics is required.

Emphasizing the importance of this program to the national space effort, the Space Science Board of the National Academy of Sciences-National Research Council transmitted the following resolution to the Secretary of Commerce:

> "The Board foresees that a strong limitation to progress in physical interpretation of experiments and observations of the terrestrial, planetary, solar and stellar atmospheres is the lack of sufficient understanding of basic physics of atoms and molecules in the environment which they encounter in these atmospheres. The Board feels that

basic work on atomic cross sections, reaction rates and interaction with radiation fields both individually and cooperatively should be encouraged wherever interest exists or may be stimulated.

"The Board is aware of the excellent work in various such aspects of laboratory and theoretical astrophysics done by groups at the National Bureau of Standards, and, as a supplement to the above, believes that the Government should recognize in a formal way this potential in a federal laboratory for a coordinated and relatively comprehensive approach to these problems which are so important to space science."

To meet these needs, a number of new programs were initiated during the year. Theoretical and experimental research programs to measure transition probabilities were started at the Washington laboratories. The first phase of this work will utilize high-current wall-stabilized arcs. In the near future the research will be extended into the higher temperature range through use of electromagnetic shock tubes, and attempts will be made to measure atomic lifetimes directly. This program is closely coordinated with an expanded research effort in plasma thermometry. Objectives of this effort are to develop stable plasma sources, to investigate the accuracy of methods of determining plasma temperatures, and to study the characteristics of plasmas that are not in local thermodynamic equilibrium.

New research programs were also started in the field of low-energy atomic collision cross sections. Crossed-beam methods are being developed for the determination of collision cross sections between electrons and atoms and between electrons and ions. Studies of the photoionization of negative ions are being extended into the ultraviolet, and work on the photoionization of atoms and molecules is being planned.

In an attempt to make fundamental data on the properties of the atomic constituents of hot gases more readily available, the Bureau is collaborating with the Office of Naval Research in the establishment of a center to collate and publish critical compilations of data on transition probabilities and low-energy atomic collision cross sections. The initial effort will be devoted primarily to transition probabilities.

In the analysis of atomic spectra, considerable progress has been made on the very complex spectrum of thorium, of which 15,000 spectral lines have been observed and their wavelengths measured with a precision of about two parts per million. Other rare earth elements on which work has been started include ytterbium, cerium, praseodymium, and thulium. Plans have been made to expand research in vacuum ultraviolet spectroscopy, greatly needed for interpretation of new rocket spectra of the sun.

An important contribution has been made to the diagnostics of high-density plasmas. Physicists studying thermonuclear plasmas have been handicapped by their inability to use conventional microwave probe methods to determine extremely high electron densities in plasmas. Using the British thermonuclear machine Zeta, a group of scientists from the Boulder Laboratories successfully demonstrated a method that permits accurate determination of the internal magnetic field and gives promise of accurate determinations of both electron density and electron temperature in extremely dense plasmas. This line of research is being extended at the Boulder Labora-

tories, where additional studies have been stimulated by problems in the physics of the exosphere of the earth and solar corona, and by fundamental studies of the interaction of radio waves with matter in the plasma state.

Finally, a small group of theoretical astrophysicists in Boulder are working in collaboration with astrophysicists of other institutions in the interpretation of astronomical observations obtained with rockets and satellites. In this work they are using new methods developed for the treatment of energy transfer problems in nonequilibrium plasmas.

New Developments in Materials

The discovery of a series of materials that show simultaneously both ferroelectric and ferrimagnetic properties aroused considerable industrial interest. Ferroelectric materials have electrical properties analogous to the magnetic poperties of ferromagnetic materials such as iron and nickel. Ferrimagnetic materials are magnetic materials that cannot be magnetized as strongly as the more common ferromagnetic materials.

Ceramics with magnetic properties have been known for a long time, but until now none has been found to show both ferroelectric and magnetic properties at the same time. As the two properties seem to be mutually dependent in the composition studied, these materials should find application in new electronic components where a coupling between dielectric and magnetic effects is desirable or where a magnetic material having a high dielectric constant would be useful.

Research is currently under way to provide quantitative data on the physical properties of these unusual materials. This work will be extended to modify the compositions further by crystallographic substitutions.

A great deal of interest was also shown in a vapor deposition process for plating high-purity tungsten on metal surfaces, which was developed for the Navy. The method involves reducing gaseous tungsten hexafluoride with hydrogen by passing it over the heated object to be plated.

Tungsten is one of the few metals that possess structural strength at temperatures above 2,000 °C. However, until recently the high-temperature properties of tungsten could not be effectively utilized. Its brittleness and hardness prevented it from being machined by conventional methods while its weight restricted its use in aeronautical equipment.

With the vapor deposition method, it is now possible to coat numerous simple and complex surfaces for high-temperature use as in rocket and missile nozzles and jet engine parts. The technique also lends itself to the fabrication of tungsten articles; simple tungsten shapes for use in vacuum tubes have already been fabricated in this way.

Under the sponsorship of the Department of Defense, a program has been undertaken to obtain high-temperature thermodynamic data on the light elements—lithium, magnesium, aluminum, and beryllium—and their compounds. These data are essential for the prediction of chemical reactions at high temperatures and for a systematic evaluation of prospective high-energy

solid propellants for rockets. The light elements are of particular value for rocket fuels because they generate large amounts of power per unit weight and lose relatively little power through exhaust products. For several aspects of the program special equipment has been devised for measurements under unusual conditions. The basic data obtained in this work, combined when necessary with data from other laboratories, are most useful in the form of tables of the fundamental thermodynamic properties up to high temperatures. New tables of this kind have now been machine-computed for over 100 substances.

Within the past 10 years radio and microwave technology has been greatly stimulated by the introduction of new semiconducting, magnetic, and dielectric materials. However, the application of these materials is still limited by a lack of knowledge concerning the relation between properties on the one hand and structure and composition on the other. During the past year notable advances were made in this area through development of techniques and instruments for highly accurate characterization, analysis, and evaluation of such materials. These developments included, for example, apparatus for determining complex tensor permeability as a function of frequency, a magnetometer for measuring spontaneous or saturation magnetization, a method for measuring extremely high dielectric constants, a technique that permits low-loss magnetic measurements, and a technique for making complex conductivity measurements without applying electrodes to the material.

At present the most critical problems in the field of materials are those of developing materials of ultra high purity in sufficient quantity and with sufficient control to further research and development and, in a number of cases, to satisfy production requirements. Such pure substances can be basic tools both for understanding materials and for engineering materials of such precisely known properties that their performance under specified conditions can be reliably predicted.

Recognizing the need for a national program on high-purity materials, the Bureau initiated an expanded program in this field during fiscal 1960. Thus far emphasis has been placed on the preparation of high-purity materials. Much work must be done to characterize such materials precisely and to determine their fundamental properties.

Radio Propagation Research

Within the Federal Government the Bureau's Central Radio Propagation Laboratory has been given the primary responsibility for collecting, analyzing, and disseminating information on the propagation of radio waves at all frequencies along the surface of the earth, through the atmosphere, and in outer space. To carry out this responsibility, it conducts research on the nature of the waves, the media through which they are transmitted, and the interaction of the waves with the media.

In studying the effects of the upper atmosphere on radio propagation, CRPL has been concerned with such phenomena as the aurora borealis or "northern lights" observed in upper and middle latitudes. The aurora takes on a variety of aspects: Sometimes it is a faintly luminous streak or arch; at other times it consists of bright streamers. Recent studies have dealt with subvisible red auroral arcs which are oriented along magnetic parallels of latitude and seem to constitute an equatorial fringe to auroras in general. The satellite Explorer VII crossed over one of these arcs several times during the night of November 27–28, 1959 at heights between 500 and 600 miles. As it passed over the arc there was a marked increase in the rate at which high-energy particles entered the satellite from the outer Van Allen radiation zone. Correlations of this type have produced the most direct evidence so far obtained that auroras are caused by the "dumping" of energetic particles from the outer Van Allen zone into the upper atmosphere.

In work on radio communication systems, a means for synchronizing and setting widely separated clocks to a relative accuracy of a millionth of a second was developed during the year. Long sought as an aid to science, this system offers promise for improving the accuracy of guided missiles and space rockets and the quality of data returned to tracking stations from satellites. The timing system should also be of value in the positioning of high-altitude aircraft from the ground; the location of thunderstorms by precisely locating the lightning discharge; the position-fixing of nuclear detonations; and evaluating the periodicity of the earth's rotation.

Data Processing and Applied Mathematics

Data processing is another field in which the Bureau has been assigned primary responsibility within the Federal Government. Here the Bureau serves both as a central research and development agency and as a readily available source of technical information for other government agencies. The advisory services strengthen the basic program, which ranges from research in components and systems to advanced work in new computer applications.

During the year work continued on the Pilot Data Processor, a multipurpose computer network designed for use as a highly flexible research tool. Engineering design of the system was completed and considerable progress was made in actual construction. PILOT's principal use will be in investigating new and unusual data processing problems that occur in government operations.

Several special-purpose devices were developed to meet the needs of government agencies. For example, a transportable analog computer that predicts radioactive fallout for a selected locality in about 5 seconds was designed and constructed for the Army Signal Corps. This computer can also forecast winds and the distribution of radioactivity within the cloud.

Another development of this kind was AMOS IV, a digital computer designed for the Weather Bureau. AMOS IV is to be used as the central

element of an automatic weather station that will collect and reduce weather data prior to transmission.

In applied mathematics research, special attention was given to the selection and development of numerical methods for solving problems on computing machinery. A wide range of applications in business management and operation, as well as in engineering and the physical sciences, was considered. Significant progress was made in exploring the utility of modern digital computers in the mechanical translation of scientific literature.

Calibration, Testing, and Standard Samples

The demand for improved calibration services based on new or more accurate measurement standards continued to grow during the year. Calibration needs were most evident in electronics, but requests for greater accuracy and wider range of measurement were received in virtually all fields of measurement.

The Bureau has been attempting to meet the present critical situation in three ways: (1) By enlarging and strengthening its own calibration services program, (2) by encouraging industry to undertake improved calibration services within particular areas, and (3) by developing greater cooperation between government and industry in defining and attacking the most important of these problems.

In the military agencies systems of laboratories were organized to help meet their rapidly expanding needs for calibration services. These systems are set up in such a way that the Bureau provides calibration services for a small number of reference standards laboratories which in turn perform calibrations for a great many lower-echelon laboratories. Similarly, some of the large industrial firms have established corporate standards laboratories which serve as intermediaries between the Bureau and the laboratories of various plants within the firm.

Close working relationships were maintained with the military agencies by means of a Joint Army-Navy-Air Force Conference on Standards and several regional conferences dealing with specific problems of the agencies and their contractors.

As an additional means of improving communications with those who use the Bureau's services, the Department of Commerce authorized two new advisory committees—one on Engineering and Related Standards, the other on Calibration and Measurement Services. Unlike the Bureau's other advisory committees, which deal with specific technical areas, these committees will be concerned with the Bureau's entire operations within their respective scopes.

The nature and scope of the activity in calibration, testing, and standard samples are shown for fiscal year 1960 in tables 1, 2, and 3, respectively. A total of 141,930 calibrations and tests were performed for government and industry. In addition, 81,614 individual samples of certified standard materials were issued, representing an increase of 18,179 over the previous year.

TABLE 1. *Summary of calibration services*

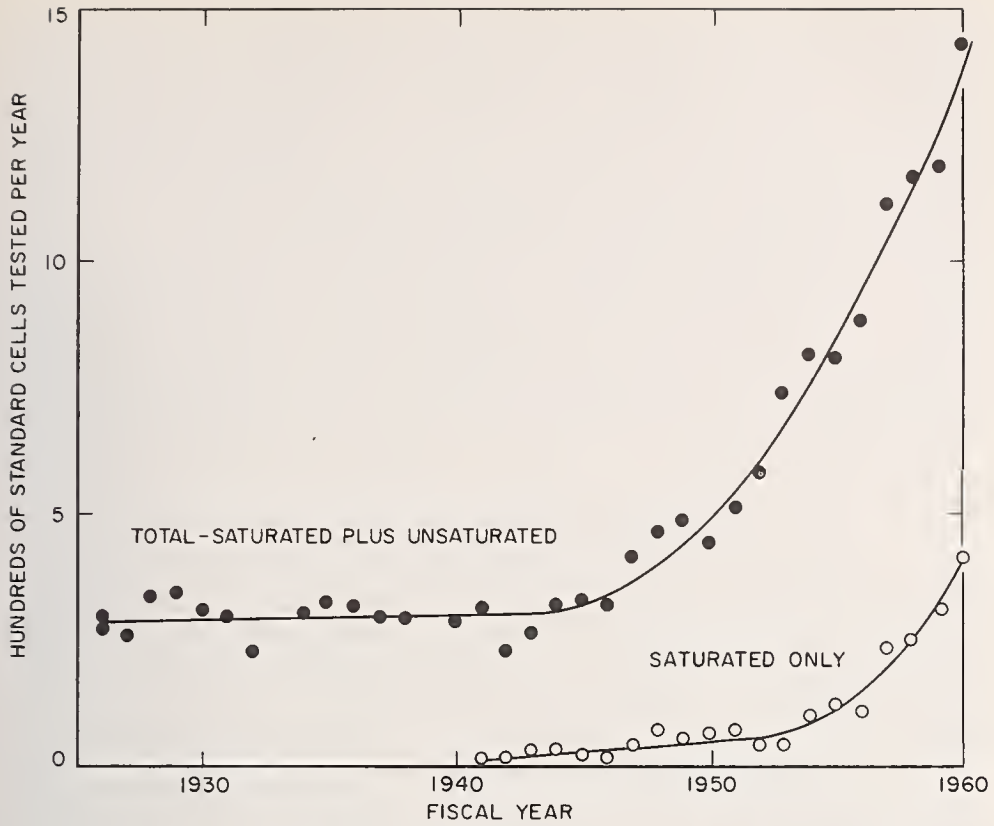
Area of Bureau activities	Representative items	Public		Government		Totals	
		Number of items	Value	Number of items	Value	Number of items	Value
Electricity and Electronics	Electrical instruments, standard cells, resistance, reactance, and capacitance standards, d-c to 30 kc.	8,813	$152,025.25	2,244	$42,807.50	11,057	$194,832.75
Optics and Metrology	Light and color standards, photographic lenses, gage blocks and other length standards, refractive index standards, sieves.	29,585	98,900.80	2,433	32,356.52	32,018	131,257.32
Heat	Resistance and liquid-in-glass thermometers, thermocouples, pyrometers.	6,539	111,624.52	1,160	41,942.50	7,699	153,567.02
Atomic and Radiation Physics.	Neutron sources and instruments, X-ray and gamma-ray protective materials and instruments, gamma-ray sources, alpha-ray sources, radioactive materials.	361	15,634.00	467	22,419.00	828	38,053.00
Mechanics	Acoustic instruments, proving rings, load cells, dynamometers, pressure standards, mass standards, track scales, capacity standards, water current meters.	30,484	225,560.87	3,658	108,073.23	34,142	333,634.10
Building Technology	Thermal conductivity, insulating materials	32	10,469.00	9	2,512.00	41	12,981.00
Radio Standards	Electrical and electronic instruments and standards in radio, ultra-high frequency and microwave ranges.	1,390	100.368.73	1,695	616.851.34	3,085	717,220.26
Totals		77,204	714,583.17	11,666	866,962.09	88,870	1,581,545.26

TABLE 2. *Summary of testing services*

Area of Bureau activities	Representative items	Public		Government		Totals	
		Number of items	Value	Number of items	Value	Number of items	Value
Electricity and Electronics	Dry cells, hearing aid batteries			525	$6,817.00	525	$6,817.00
Optics and Metrology	Lamps			5,101	52,700.00	5,101	52,700.00
Atomic and Radiation Physics.	Radioactive materials, radon analysis			105	8,446.00	105	8,446.00
Chemistry	Paints and other surface coatings, detergents, reagent chemicals	307	$22,341.00	287	15,091.00	594	37,432.00
Mechanics	Mechanical devices, furniture			1,240	20,835.04	1,240	20,835.04
Organic and Fibrous Materials.	Paper, textiles, rubber, leather, and plastic products	57	15,886.50	4,636	108,414.85	4,693	124,301.35
Metallurgy	Metals and alloys			41	15,378.00	41	15,378.00
Mineral Products	Ceramic products, glass			57	8,550.00	57	8,550.00
Building Technology	Building materials, cement, concrete and concreting materials, elevators, air filters, fire extinguishers, heating and air conditioning equipment.	265	15,252.30	40,439	773,087.70	40,704	788,340.00
Totals		629	53,479.80	52,431	1,009,319.59	53,060	1,062,799.39

TABLE 3. *Standard samples issued*

Area of activities	Description of samples	Public		Government		Total	
		No. of samples	Value	No. of samples	Value	No. of samples	Value
Optics and Metrology	Resolution test charts	9,652	$1,930.40	645	$129.30	10,297	$2,059.70
	Calibrated glass spheres	114	1,083.00	24	228.00	138	1,311.00
	Photometric standards	317	11,929.00	30	1,229.00	347	13,158.00
	Spectrophotometric standards	53	4,515.00	5	433.00	58	4,948.00
	Color temperature standards	37	1,534.00	7	388.00	44	1,922.00
	Reflectance standards	157	2,124.00	51	667.00	208	2,791.00
	Opacity standards	84	2,262.00			84	2,262.00
	Signal glass limit standards	107	6,502.00	4	244.00	111	6,746.00
	Gloss standards	140	2,183.00			140	2,183.00
	Haze standards	174	2,200.00			174	2,200.00
Heat	Viscosity oils	852	13,851.00	78	1,263.50	930	15,114.00
Atomic and Radiation Physics	Radiation lamps	44	3,476.00	16	1,264.00	60	4,470.00
	Radioactive standards	330	8,040.00	283	6,289.00	613	14,329.00
Chemistry	Paint pigments	44	132.00	32	96.00	76	228.00
	Sucrose and dextrose	257	963.75	49	184.00	306	1,147.75
	Pure substances, metals, alloys and ores	21,076	92,506.10	1,561	6,596.75	22,637	99,102.85
	Uranium isotopic standards	640	8,578.00	67	708.00	707	9,286.00
	Spectrographic standards	4,026	42,934.00	233	2,539.00	4,259	45,473.00
	Pure hydrocarbons	465	13,625.00	345	10,410.00	810	24,035.00
	Thermometric standard cells	47	2,350.00			47	2,350.00
	Labeled carbohydrates	22,950	18,977.50	6,755	7,635.00	29,705	26,612.50
	Thickness samples for electroplated coatings	1,688	18,420.00			1,688	18,420.00
	Cylinders of certified natural gas	79	5,925.00			79	5,925.00
	Standard benzoic acid thermometric cells	4	880.00	1	220.00	5	1,100.00
Organic and Fibrous Materials	Rubber and compounding ingredients	4,726	26,939.30	57	383.85	4,783	27,323.15
	Standard fading samples	529	4,918.00	35	326.00	564	5,244.00
	Phosphor reference samples	69	207.00	14	42.00	83	249.00
Metallurgy	Gases-in-metals samples	242	2,360.00	22	220.00	264	2,580.00
Mineral Products	Cement	2,182	5,455.00	180	452.00	2,362	5,907.00
Building Technology	Limestone slabs	15	375.00	17	425.00	32	800.00
	Surface flammability standards	3	24.00			3	24.00
Total		71,103	307,199.05	10,511	42,372.40	81,614	349,300.95



The rapid growth in the Bureau's electrical calibration load is reflected in this graph showing the rise in the number of standard cells calibrated yearly. These cells, which serve as standards of electromotive force in other laboratories are tested by comparison with a group of primary reference standards maintained by the Bureau.

Cooperative Activities

The Bureau cooperates extensively with Federal, State, and local governments; with national professional societies and standardizing bodies; and with many international groups. In this way the results of Bureau research are brought to bear on many current problems of science and industry, particularly those relating to measurement standards, building and safety codes, engineering and purchase specifications, and test methods.

Cooperation with other Federal agencies ranges from the supplying of technical information upon request to long-range projects undertaken through various scientific and technical committees. An important example of interagency cooperation is the development of government specifications and test methods. During the year at the request of the General Services Administration, the Bureau accepted responsibility for developing and maintaining 8 additional Federal Specifications, making a total of 158 for which it now has this responsibility. The Bureau also reviewed approximately 385 proposed specifications both for GSA and for other agencies to determine their suitability for use by the Federal Government.

Cooperation with State and municipal governments is principally in the field of weights and measures. Although the Bureau itself does not have

regulatory powers, it offers technical advice and consultation to local regulatory bodies and it calibrates and adjusts State standards of weights and measures. A major medium of cooperation is the National Conference on Weights and Measures. Thirty-six States and the District of Columbia were officially represented at the 45th annual meeting of this Conference, held in Washington, D.C., June 6–10, under NBS sponsorship.

On June 8, in a ceremony at the Department of Commerce auditorium, Secretary of Commerce Federick H. Mueller presented the new State of Hawaii with standards of the fundamental units involved in commercial exchange. Basic studies of materials and design were completed during the year in work directed toward more accurate, constant, and durable standards for the States.

Through the participation of Bureau staff members in the work of professional societies and national standardizing bodies, the Bureau plays an active role in the development of test methods and criteria, in the application of scientific discoveries, and in fundamental research programs of a national nature. During the past year Bureau staff members held 1,133 committee memberships in 137 national groups such as the American Society for Testing Materials, the American Standards Association, American Society of Mechanical Engineers, American Chemical Society, Institute of Radio Engineers, and Instrument Society of America. In many of these groups NBS staff members work with universities, research foundations, other government agencies, and industry to improve engineering standards, purchase specifications, and building and safety codes.

Other means of Bureau-industry cooperation include the Research Associate Plan and the donor program. Under the Research Associate Plan, technical, industrial, and commercial organizations can support work at the Bureau that is of special interest to them, yet of sufficient general interest to justify use of government facilities. The work is done by research associates who are paid by the sponsor but otherwise function as members of the Bureau staff. At the present time 11 groups are supporting research associates at the Bureau (appendix 3.7).

The donor program was authorized in 1950 by Public Law 619 under which the Bureau may accept funds for the purpose of furthering its work. This arrangement permits individuals as well as technical, industrial, and commercial organizations to support work at the Bureau when the results are expected to be of value to the general public. During the past year, 11 projects were supported by gifts from 10 organizations (p. 162).

On an international basis, the Bureau represents the interests of the Government and American science in matters dealing with the establishment and maintenance of standards of measurement and establishment of values for scientific constants. Most of this work is done through participation in a large number of international groups such as the International Union of Pure and Applied Chemistry, the International Union of Pure and Applied Physics, the International Scientific Radio Union, and the International Commission on Illumination. The Bureau participates through the Ameri-

can Standards Association in the work of the International Organization for Standardization on specifications and methods of test of industrial products. Approximately 80 staff members attended meetings of international societies during the fiscal year.

Another aspect of international cooperation involves a program whereby scientists or diplomatic representatives from other countries are accepted at the Bureau as guest workers or visitors. Approximately 1,000 foreign scientists and technicians, representing 51 countries, visited the Bureau during the year. Forty-one of these visitors were specialists who came as guest workers to spend from 1 to 12 months in cooperative research in such fields as radio propagation, free radicals, mathematics, and dental materials. Nineteen were trainees who were being prepared for leadership in the national laboratories of their own countries.

Administrative Activities

Redefinition of mission and adjustments in program emphasis were given more than ordinary attention during the past year. This was part of the Bureau's concentrated effort to meet the burgeoning needs of modern technology, particularly in the vast and diversified field of physical measurement. A statement of the Bureau's mission is given in appendix 3.2.

Program adjustments were reflected in organizational changes which affected all but four of the technical divisions. In the Washington laboratories, most of the organizational changes occurred in connection with the splitting of two divisions into four new divisions. The Atomic and Radiation Physics Division was divided along the lines of its two major program areas into the Radiation Physics Division and the Atomic Physics Division. Similarly, the Electricity and Electronics Division was changed to the Electricity Division, while its electronics sections became the nucleus of a new division, Instrumentation. The Mechanical Instruments Section from the Mechanics Division and the Office of Basic Instrumentation were also transferred to the new Instrumentation Division. At the same time, the Optics and Metrology Division was retitled the Metrology Division and acquired the Mass and Scale Section and the Volume and Densimetry Section from the Mechanics Division.

At the Boulder Laboratories, the major reorganization consisted of a rearrangement of the three divisions of the Central Radio Propagation Laboratory. The four resulting divisions are Ionosphere Research and Propagation, Radio Propagation Engineering, Radio Systems, and Upper Atmosphere and Space Physics. In addition, several programs previously in the Boulder Director's Office were reassigned to the Radio Standards Division.

At the close of the year reorganization action had been completed in all areas of major change except the chemistry programs, which were still under consideration. In connection with the changes and to fill vacancies created by retirements, eight new division chiefs were appointed during the year. The organization as of September 1, 1960, is given in appendix 3.1.

With the diversity of its program increasing, the Bureau's staff increased by about 200. The total complement was about 3,636 at the end of the year. Almost one-third of these were employees of Boulder Laboratories and nearly all of the remainder were in Washington.

Funds obligated during the year totaled $37,087,000, including $748,000 for facilities. Of this total $17,138,000 came from direct appropriations for Research and Technical Services and $19,201,000 from other Federal agencies and private sources.

The National Bureau of Standards, along with other scientific activities of the Department, was given a comprehensive evaluation by the Special Advisory Committee of the National Academy of Sciences appointed in 1958 at the request of the Secretary of Commerce. The Committee's report, released in April 1960, said in part:

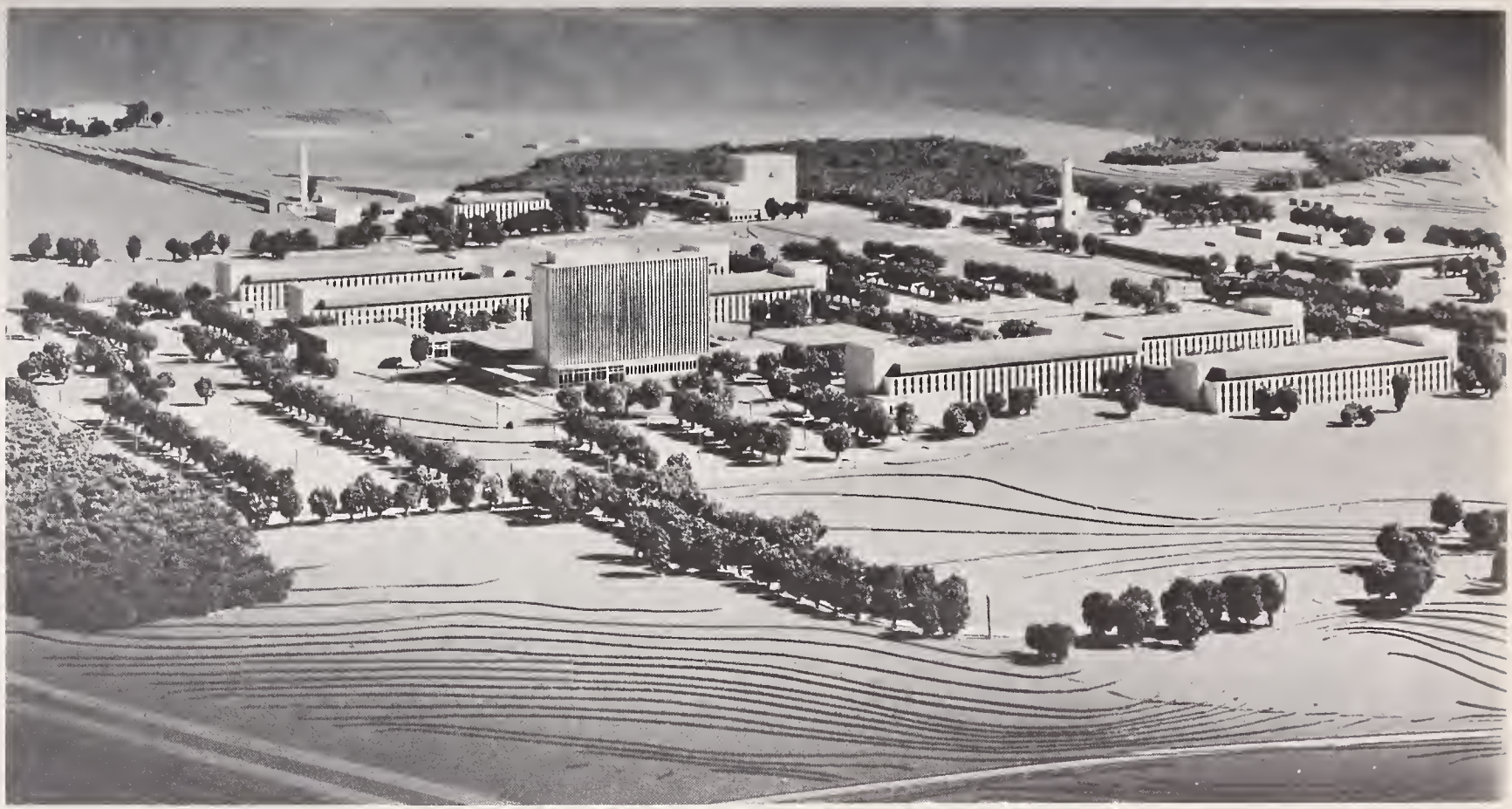
> "The Bureau of Standards is well administered. The Director and his staff have done an outstanding job of managing the limited resources in manpower and facilities to achieve a high level of effectiveness. The staff is of excellent scientific and engineering quality. Within the framework of Government employment and compensation policies and practices, a remarkable job of recruitment and building of staff through educational programs and other means has been done.
>
> "The development of accurate methods of physical measurement and of standards is of large importance to the commerce and industry of our country. Their needs for standards should be fully met * * *. Within its resources, the Bureau's performance of its measurement standards function is excellent."

Near the end of the year Dr. Paul D. Foote was appointed by the National Academy of Sciences as coordinator of the NAS–NRC Technical Advisory Panels for the Bureau. Formerly Assistant Secretary of Defense for Research and Engineering, Dr. Foote will strengthen and extend the role of the Advisory Panels, which are appointed by NAS in cooperation with the scientific and technical societies to advise the Bureau in specific technical areas. A complete list of these panels is given in appendix 3.4.

Progress continued during the year on the complex job of designing new laboratories to be located at Gaithersburg, Md. Plans for the new NBS "campus" provide for 20 buildings to house the Bureau's present programs. The total cost of the new laboratories, new equipment, and moving of present equipment is expected to be about $95 million. For the Fiscal Year 1961 Congress has appropriated $23.5 million to begin construction and site development. The buildings first to receive attention will be the Engineering Mechanics and Radiation Physics Laboratories together with the Power Plant. These involve installation of large equipments in specially designed structures and they are given priority because of urgent needs for expansion of research programs for which they are designed.

Progress continued also on the planning of a research reactor to be located at the Gaithersburg site. Detailed engineering and architectural design will be undertaken under a special appropriation provided for fiscal year 1961.

At the Boulder Laboratories, a major increase in facilities was under way in the design of a sixth wing for the main laboratory building.



Architect's model of the Bureau's new laboratories to be constructed at Gaithersburg, Md. Funds have been appropriated for the first phase of construction, and groundbreaking is expected in the spring of 1961.

Publications

Publications are the main channel through which the results of Bureau research are distributed to the scientific and technological community. Even when the work is developmental in nature—for example, the design of a specific instrument—the activity will culminate in a report, and it is the report which will often prove of most value to Government, science, and industry.

Among the major NBS publications of the past year were two volumes of *Tables of Wavenumber* (Monograph 3)—*Volume I, 2000 A to 7000 A* and *Volume II, 7000 A to 1000 μ.* Wavenumbers are useful in analysis of the light emitted from excited atoms. Such analysis is used to study atomic energy levels and electron configurations for individual atoms and ions. Monograph 13, *Mechanical Properties of Materials at Low Temperatures—a Compilation from the Literature* also appeared. This compilation should help meet the present urgent demands for engineering data in the field of low temperature construction.

Another publication of interest was *Stabilization of Free Radicals at Low Temperatures—Summary of the NBS Program.* This document (Monograph 12) reviews the accomplishments of the Bureau's three-year program in free radicals research which terminated during the year.

In addition to the printed review of the free radicals program, the Bureau produced a 16-mm sound, color motion picture titled, "Trapping of Free Radicals at Low Temperatures." The picture shows in detail the performance of an experiment in the trapping and storing of free radicals at temperatures within a few degrees of absolute zero by a special process developed at the Bureau. Among the interesting features of the film are the brilliant color views of the glows and flashes emanating from free radicals trapped in a solid matrix of frozen gas. Also, there is a sequence showing the handling of liquid helium—the coldest substance known to man. "Trapping of Free Radicals at Low Temperatures" is available for loan or sale from the Bureau's Office of Technical Information.

During the year, the Bureau's reports and publications totaled 1,228, exclusive of calibration and test reports and of general administrative documents. Some 402 classified and unclassified reports were issued to other government agencies, while 926 papers and documents were published formally.

Of the formal publications, 174 were published in the *Journal of Research,* and 554 in the journals of professional, engineering, and trade organizations. There were 121 summary articles published in the Bureau's monthly *Technical News Bulletin.* Seventy-seven papers were published in the nonperiodical series of publications: 16 in the Monograph series, 2 in the Applied Mathematics series, 3 in the Handbook series, 3 in the Circular series, 3 in the Miscellaneous Publications series, and 50 in the Technical Note series.

The other monthly Bureau publication, Basic Radio Propagation Predictions, which is published for a 1-month period 3 months in advance, pre-

sented radio propagation data needed in determining the best frequencies to use in long-range radio communications.

A list of publications for the fiscal year is given in the appendix, section 3.8 (p. 162).

During the year the Bureau participated in 24 scientific and technological exhibitions with exhibits depicting the Bureau's research programs. Typical of these shows were the Instrument-Automation Exhibit of the Instrument Society of America, the Exhibit of Testing and Scientific Apparatus and Laboratory Supplies of the American Society for Testing Materials, and the Southwestern Metals Exposition. The Bureau's motion picture program continued to be active. There were 790 showings of NBS films to a total audience of 256,747, including educational TV.

2. HIGHLIGHTS OF THE RESEARCH PROGRAM

The Bureau's technical program is carried out through organizational units called divisions. These are shown in appendix 3.1. A review of selected research and development programs is presented in this section under headings corresponding generally to these organizational units.

2.1. METROLOGY

To establish, maintain, and disseminate standards of length, mass, volume, light, and color, the Bureau's metrology laboratories carry on a diversified program of research. Studies are made to improve uniformity in the color of fluorescent lamps, and in the brightness of television tubes; instruments are designed to obtain thermodynamic and astronomical data; and new standards are developed for volumetric, density, and fluid capacity measurements. To assure compliance with specifications for optical equipment and optical services purchased by the Federal Government, various tests are conducted; and in other government work, lenses, cameras, and grip plates are calibrated for use in missiles, satellites, and satellite tracking cameras.

During the year, the theory of a new method was developed for measuring the transmittance and optical density of photographic materials; the variability in normal color vision was investigated; a system was designed for lighting the blade tips of helicopters; statistical data on color were programed for high speed electronic computers; new screw thread standards were published; a resolution camera was constructed to measure film resolutions as high as 50,000 lines per inch. In the field of length measurement, greater accuracy was achieved than was ever before possible.

At the request of industry, a new program was initiated on the metrology of gears where national standards are lacking. Equipment was obtained for extending optical measurements in the far ultraviolet part of the spectrum where observations are carried out in a vacuum because of the absorption of air in this region. Such optical data are used in outer space probes. Also, during the year, notable progress was made in the age-old art of weighing.

Calibrating Fluorescent Lamps. Incandescent lamp standards of color temperature have been used for many years as standard light sources for colorimetry. However, to evaluate fluorescent lamp color with these light sources is not easy since fluorescent lamps emit a mercury line spectrum superimposed on a continuous phosphor spectrum. A proposal was therefore recently made by the International Commission on Illumination that fluorescent lamp standards of color be calibrated on an international basis by spectroradiometry. In accordance with this proposal, an instrument was developed, and spectroradiometric measurements were accomplished for comparison with measurements obtained at other industrial laboratories and at the National Physical Laboratory in England. The results were not in close enough accord for standardization purposes, but they did show how interlaboratory precision could be improved. Experimental work is continuing so that the spectroradiometric method can be adopted internationally to assure uniformity in the color of fluorescent lamps.

The Variability of Human Normal Color Vision. Further studies in the theory of color vision dealt with the variations in the responses of human observers when matching pure spectral colors with controllable amounts of 3 primary colors. Generally, the between-observer variabilities, based on the color matching data of 50 British and 18 Russian observers, were found to be about 10 percent of the average values. This result indicates that any one observer picked at random gives a poor approximation to the "standard observer" for color measurements. This result also supports the view that it is desirable and more economical to make color measurements by objective means than it is by using a sufficient number of observers to yield the desired accuracy. The data used for this study were obtained for the International Commission on Illumination in its endeavor to improve the present "standard observer" which was statistically arrived at in 1931.

Color Automatically Computed. In calibrating material standards of color it is common practice to measure the spectral transmittance or reflectance of the standard for each 10 mμ band throughout the visible spectrum and to define the color of the standard by three numbers. These numbers, called tristimulus values, are obtained by adding together the red-producing, the green-producing, and the blue-producing effects of 10 mμ spectral bands.

To determine which if any specimens may require a finer division of the spectrum for their accurate calibration, a program was prepared for the Bureau's electronic computer. The computer automatically converts spectral data for each 1 mμ band to data which would be obtained for 5 mμ, 10 mμ, or 15 mμ bands, and then makes a summation to yield tristimulus values. Thus far this technique has been applied to the master sets of a group of 5 glass standards, developed for checking tristimulus integrators.

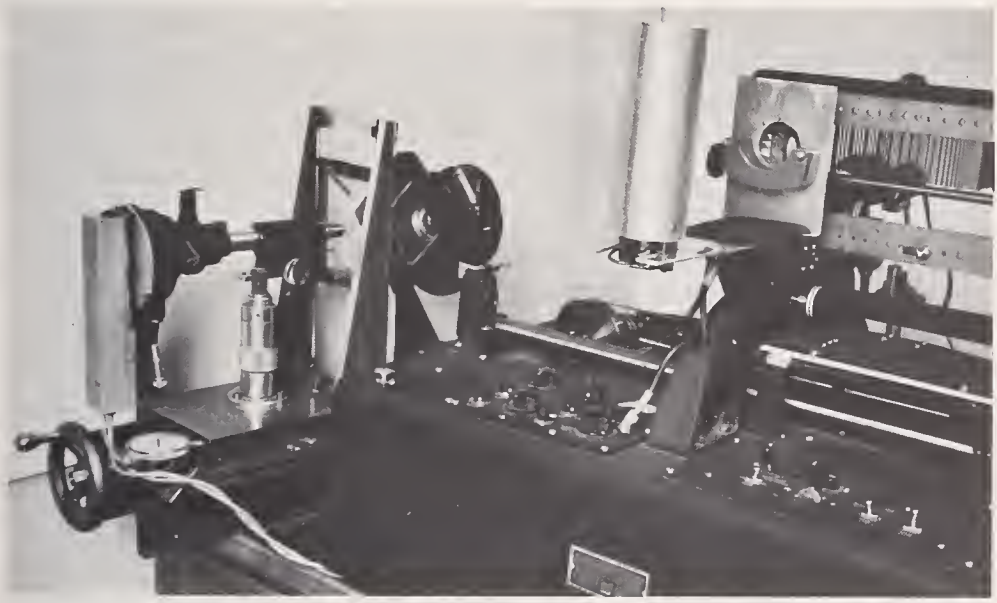
Color Distortions Found with Electronic Computer. Since the invention of the incandescent lamp nearly everyone has experienced the distortion of object colors caused by the substitution of artificial for natural light sources, and with the increasing use of fluorescent lamps greater dis-

tortions have been noted. To obtain a quantitative evaluation of these color distortions for the Illuminating Engineering Research Institute of the Illuminating Engineering Society, the Bureau programed the problem for electronic computation. With the resulting data, rapid evaluations may be made of the color of an object of known spectral transmittance or spectral reflectance when it is illuminated by any light source including fluorescent lamps.

Brightness Standards for TV Tubes. During the past year, six brightness standards approximating in spectral energy output the P4 phosphor of black-and-white television tubes were designed, constructed, and calibrated for the Joint Electron Tube Engineering Council. These standards were made available to the industry, in order to promote uniformity of measurements of television tube brightness.

Helicopter Wing-Tip Lights. To aid the military to fly in close formation at night, a system was developed for lighting the wing tips of helicopters. Powered by a wind-driven generator, each unit of the system consists of four small "grain-of-wheat" type incandescent lamps embedded in a panel of clear plastic, which is installed in each wing. Installation is accomplished merely by substituting blade tips fitted with the lighting units for the original tips. The lights are switched on and off remotely by an infrared source mounted on the tail of the helicopter, and a photoelectric switching circuit built into the blade tip.

Airport Runway Markings Tested. In 1957 a test pattern containing 8 different samples of runway marking materials was installed on a runway at Washington National Airport. Since then periodic measurements have been made of the reflectance of the samples, using both floodlights and simulated landing lights. From the results of this first comprehensive study of



Equipment used to scan electronically the aerial image formed by a photographic lens. This permits the study of contrast in the image independent of photographic emulsions (page 28).

runway marking materials in this country, materials are now being selected for a number of service tests of runway marking materials.

Two-Color Projections. Since 1914, it has been known that colors of all hues might be perceived from the simultaneous projection of two black-and-white lantern slides of the same scene in register, one illuminated by red light and the other by incandescent-lamp light. This two-color phenomenon was first recognized in 1895, and its recent report as a new discovery resulted in many inquires regarding the feasibility of two- instead of three-color pictures. As a consequence of these inquiries, the significance of the original finding was re-evaluated. The study confirmed the earlier reports as well as Bureau results of 1939 in which it was found that the color effects obtained from any pair of projection-light colors can be predicted as a two-dimensional case of the complete three-dimensional theory. By use of red light and incandescent lamp light, good reds and fairly good greens, but only pale yellows and blackish blues, are produced. Such reproduction is not commensurate with present commercial requirements.

Image Analysis. To give a better understanding of the formation of optical images for photography, a method was developed which permits direct electronic scanning of the aerial image of a line object formed by a lens. The resulting measurements, as the width of the lines decreases, show the variations in contrast between light and dark lines. From these measurements information is obtained on the limiting resolution of the lens in various focal planes as well as the effect of lens aberration upon the response at different frequencies.

Glass Lens Free From Residual Chromatic Aberration. Procedures developed for the selection of glasses to construct a lens having a common focal point for three wavelengths were adapted to the selection of glasses for lenses achromatic at four wavelengths. A set of three glasses was selected that combined to make a four-color achromat. The powers of the three elements for a four-color achromat of these glasses were then computed, and an analysis of the resulting system was made. At twelve wavelengths between 0.365 and 1.014 micron, the analysis showed the system to be completely free from residual chromatic aberration.

Lens Distortion Measurements Compared. An investigation of the four principal methods of evaluating lens distortion led to a better understanding of the factors limiting the accuracy of each method. Values of the radial distortion in the image of a single lens were determined by a photographic method using a lens testing camera; by a visual optical bench method using a nodal slide; by a visual inverse nodal slide method using an optical T-bench; and by a visual modified goniometric method. It was found that high precision in photogrammetric lenses is obtained with all four techniques when proper precautions are exercised in taking the measurements. Special caution must be observed to avoid plate curvature, asymmetric use of apertures, prism effect, misalinement of optical equipment, and errors in angle and length measurements.

Instrument used in the calibration of photogrammetric cameras. Measurements made with this device are used to determine focal length and distortion of aerial camera lenses. Lengths on the photographic test patterns are measured to the nearest micron over a range of 14 inches (page 28).

Photographic Research. A new method of photometry was theoretically developed, and plans were made to compare the usefulness of the method with existing methods for measuring the transmittance and optical density of photographic materials. Additional studies of the chemistry of photographic fixation were made during the year, and a study of the effect of storage conditions on the permanence of the bond between a film base and emulsion was initiated.

High-Resolution Camera. A camera to test the resolving power of photographic materials was developed that is capable of projecting line patterns as fine as 50,000 lines per inch on photographic materials. The ability of a photographic material to record the lines distinctly is a measure of its ability to render fine detail in a picture. The tremendous information storage capacity of high-resolution materials was demonstrated by using this camera to copy the first page of Genesis. It was reproduced on an area so small that if the entire Bible were reduced to the same scale it would cover an area less than that of Lincoln's head on a penny. The copy is clearly legible when viewed through a high-powered microscope.

Improved Accuracy in Length Measurements. For the first time in its history, the Bureau certified length measurements, made on two commercial gage blocks, with an accuracy of better than 1 part in 5 million. The blocks, one 16 in. and one 18 in. in length, were measured by two independent methods, one of which gave the lengths directly in terms of wavelengths of light and the other in terms of the present national standard of length, a platinum-iridium meter bar. The results obtained by the two methods agreed to the nearest millionth of an inch or better for both gage blocks, and with

measurements made on the same blocks by the National Physical Laboratory to within 2 millionths of an inch. Another gage block, 4 in. in length, was certified to one part in 4 million and the agreement for this block with the measurements of two foreign national laboratories was to 1 millionth of an inch. Present routine accuracy of gage block measurements is 2 parts in a million.

Reflection Phase Shift Dispersion in Interferometry. An investigation was made of the possibility of using phase shift dispersion by fringes of equal chromatic order (*feco*) with Fabry-Perot interferometry in determining etalon spacing and in measuring unknown wavelengths. It was found that such measurements are useful at three stages in wavelength comparisons. In the first stage, by obtaining the *feco* at several points across the aperture, the degree of uniformity of the phase shift over the aperture is determined for multilayer reflectors; in the second, the phase shift data are combined with the method of exact fractions to yield the integral order numbers. This stage is especially valuable in the case of multilayers where the dispersion of the phase shift is high, and where calculated phase shifts may be in error due to poorly known layer thicknesses. In the third stage, the accuracy of measurements of unknown wavelengths is improved. For example, using high reflection mirrors, wavelengths of *feco* can be measured to about 0.002 fringe, whereas the error in determining fractions in Fabry-Perot patterns is about 0.01 fringe.

Evaporated Multilayer Coatings. A technique for producing cerium dioxide coatings was improved by evaporating this material in a residual atmosphere of oxygen to avoid a decomposition of the oxide. Methods were also developed for evaporating magnesium fluoride, antimony dioxide, zinc sulfide, and cryolite. In other work, a study was made to find the accuracies to which film thicknesses must be controlled to obtain desired tolerances on performance of multilayer coatings.

Polarization of Light at Beam-Dividing Surfaces. A double-image prism interferometer was developed for astronomical applications in which the beam divider is designed as a combiner of wave fronts, so that the light beam is affected only once. In using this instrument, an effect of polarization of light upon reflection-transmission at beam-dividing surfaces was discovered. No fringes were observed, so measurements were made of the phase shift occurring when light is transmitted and reflected by a thin aluminum film. The results showed that a shift of $\pm 90°$ is present for the ordinary beam and $\mp 90°$ for the extraordinary beam. By suitable application of a polarizer, the fringes are seen in good contrast.

Standard Screw Thread Publications. Progress in both national and international standardization of screw threads was marked by publication of several important standards. Part II of NBS Handbook H28 (1957), Screw Thread Standards for Federal Services, covering pipe, dryseal pipe, hose coupling, and gas cylinder threads is now available. Part III covering Acme, Stub Acme, buttress, and miscellaneous threads is in press. ASA B1.1–1960, American Standard Unified Screw Threads, was published, and

the British and Canadian national standardizing bodies are ready to issue standards in substantial agreement. These standards represent a considerable advance in international unification of thread standards over the previous editions published about ten years ago. During the year two publications—ASA B2.1, Pipe Threads (revised), and ASA B2.2, Dryseal Pipe Threads—were approved as American Standards and are ready to go to press.

Improved Techniques for Mass Measurements. Before starting detailed design on the highest attainable precision kilogram balances, an experimental program was inaugurated to resolve certain weighing uncertainties. Preliminary experiments with a one-pan balance indicated that weighing can be performed more rapidly and accurately with that type of balance than could perhaps be accomplished with the older equal-arm type. The latter employs three knife-edges which must be adjusted to be coplanar and parallel. The one-pan balance uses only two knife-edges, greatly simplifying and permitting more precise adjustment. A 50-lb balance of this design commercially constructed in collaboration with the Bureau appears to give better performance than has ever been achieved for that capacity. Modern damped balances giving the last 2 or 3 significant figures by a direct read-out in mass units were also found acceptable, both at State level and for high-precision laboratory weighing.

Standards and Calibrations. In addition to the more than 1,000 standards that were issued for the calibration of light meters and colorimeters, over 100 red filters used to maintain the proper color and brightness of instrument panels were supplied to the aviation industry. Also, over 100 new candlepower standards (inside-frosted, gas-filled, incandescent lamps) that practically eliminate errors introduced by lamp orientation were issued to the illuminating engineering industry. During the year, good progress was made in relating the length of the prototype standard meter bar of the United States to the wavelength of the orange-red line of krypton which has recently been adopted as the new international standard of length.

Operating a new research camera developed for testing the resolving power of photographic materials. Inset: Photomicrographs comparing the size of letters on a microcopy made using the camera with the size of some common bacteria (page 29).

2.2. ELECTRICITY

The Bureau's work in electricity is primarily the development, improvement, and dissemination of the standards of measurement for electrical quantities; and the study of the electrical and magnetic properties of materials. Electrical standards must be established that are constant over long periods of time, uniform throughout the Nation, and compatible with other standards used throughout the world. Measurements of electrical quantities directly in terms of length, mass, and time ("absolute measurements") are extremely difficult and are made only in the realization and confirmation of electrical standards of resistance, capacitance, inductance, and voltage; calibration work is done by comparison with these electrical standards.

An objective related to establishment of standards is development of improved measurement methods and extension of the ranges of voltage, frequency, current, etc., in which precision measurements can be made and referred to the standards. During the past year, several measurement techniques were developed or improved. A new value for the faraday was announced, and the redetermined value of the proton gyromagnetic ratio was substantiated.

Absolute Measurement of Current. Work on two methods for the absolute determination of current was completed. Much of the equipment used for this work was also involved in the 1958 redetermination of the gyromagnetic ratio of the proton at the Fredericksburg Magnetic Observatory of the U.S. Coast and Geodetic Survey. However, additional observations were made at the NBS Washington laboratories during the past year for better determining values of the electrical standards used in monitoring the current through the coils producing the field. Another reason for the Washington observations is that a determination of absolute current had been made at the same magnetic location. At this laboratory, there was practically no uncertainty in assigning a value to a standard cell in terms of the primary group because a direct connection could be made shortly before and after each set of observations. A difference of 3 parts per million persists in the values of the gyromagnetic ratio of the proton as determined at the two locations. In view of the uncertain effect of magnetic materials in the NBS neighborhood and a slight uncertainty in the values applicable to standards cells at Fredericksburg, this difference is to be expected. The results are considered equally reliable.

Absolute Measurement of Resistance. A method of measuring absolute resistance in terms of capacitance and frequency, rather than inductance and frequency, has been developed. The results involve the speed of light, and, when compared with the results obtained with the inductor, may be regarded as a check of the speed of light or, alternately, as a test of electromagnetic theory at low frequency. The preliminary result gave a value for the NBS unit of resistance, as maintained by standard resistors, which differs by only a few parts per million from its assigned value.

Equipment used in obtaining an improved value for the faraday by a new experimental process. The faraday is one of the fundamental constants of physics and chemistry; precise knowledge of its value will show interesting correlation among atomic weights, electrochemical equivalents, energy, and mass (pages 33 and 63).

Redetermination of the Faraday. The Bureau is constantly attempting to determine the constants of nature with increasingly higher accuracy. One such constant which received particular attention during the past three years is the faraday—the quantity of electricity required to dissolve or deposit an equivalent weight of an element (or the quantity of electricity associated with the change of one equivalent weight of a reacting substance) in any electrolytic process. The determination was concluded, giving a value for the faraday constant of 96516.5 ± 2.1 coulombs (ampere-seconds) per gram-equivalent weight on the physical scale. This value differs from previously accepted values by 0.008 percent. The method employed in the new determination involved the electrolytic dissolution of metallic silver of high purity in aqueous solutions of perchloric acid and thereby eliminated occlusion uncertainties encountered in previous methods involving electrolytic deposition of silver. Since the faraday may also be defined as the product of Avogadro's number and the charge on an electron, the new faraday value has a significant bearing on the values of these physical constants.

Electrolytic Purification of Silver. To aid in the redetermination of the faraday, the Bureau perfected an electrolytic process for preparing silver of high purity. Metallic impurities to the extent of 120 parts per million were reduced to less than 0.3 part per million.

The Bureau obtained a new value of the atomic weight of silver from a highly accurate determination of the absolute isotopic abundance ratio. Silver isotopes Ag^{107} and Ag^{109} supplied by the Atomic Energy Commission were each purified by an electrolytic process and blended to give synthetic calibration samples for mass spectrometry measurements (see 2.6, p. 63).

Audiofrequency Current Transformer. Because the use of current transformers for current and power measurements in the audiofrequency range has been expanding, the Bureau has undertaken a study to improve measurement methods in this field. The basic unit of a family of current transformers for operation to 10 kc/s has been constructed and tested. The method used for measuring ratio and phase angle of this 5/5 ampere transformer is very sensitive and can easily detect changes in ratio of less than 1 part in a million and in phase angle of less than 1 microradian throughout the audiofrequency range. The transformer, which shows extremely good performance, will be used in the stepwise calibration of higher range audiofrequency transformers.

Phase Angle Standard. Vehicle guidance systems now in development require very accurate measurement of directional angle by electrical means. Work begun two years ago to provide a standard for calibrating phase-angle measuring devices resulted in a ladder network, with sections which can be connected by decade switches, to set up desired phase shifts. This system has been arranged for internal stepwise calibration, with a 180° reference point provided by a specially wound transformer. Phase-shift values assigned by this experimental procedure agree with those computed from measured component values to within 0.01° for all sections. The first of these ladder networks was designed for 400 c/s operation, and modifications are now being studied which will permit operation at other selected frequencies up to 4,000 c/s.

Transformer-Type Voltage Dividers. Step transformers are now available for subdividing audiofrequency voltages into 10^6 or even 10^7 increments. Such voltage dividers are used in a variety of measurement procedures, and methods have been developed for measuring their accuracy and the phase angles between the input and output voltages. These dividers are now being studied using a method involving comparison with the direct capacitance ratio of shielded three-terminal capacitors.

Guard-Ring Micrometer Holder. A three-terminal holder with guard ring was constructed for use in determining the electrical properties of standard dielectric reference materials having very low losses. A technique was devised for determining the absolute value of the inherent loss of the film on the electrode surface of the holder to 1 or 2 microradians, and of the absolute values of the dissipation factor of the standard capacitor.

Dielectric Properties of Polychlorotrifluoroethylene. The dielectric properties of quenched thin films of polychlorotrifluoroethylene have been measured as a function of temperature and frequency in an effort to obtain more knowledge of the properties of the supercooled liquid phase of

the polymer. The high-temperature holder has been modified by an addition of a guard ring so that dielectric properties of polymers in the pure liquid state may be more accurately determined. The crystallization temperature anod thermal history of the crystalline specimens of polychlorotrifluoroethylene were investigated. It was found that even though two specimens may have the same degree of crystallinity as determined by the density method, their dielectric properties are not identical, indicating a depenence upon the thermal history prior to crystallization.

Dielectric Properties of Nylons. Continuing investigations of dielectric properties of polyamides have shown a clear relation between crystalline-amorphous ratio and a prominent relaxation process at elevated temperatures. This process must occur in the amorphous regions of the polymers. A low-temperature relaxation process has been shown to exist in 610 nylons as well as in the 66 nylons, the latter corresponding to that seen in mechanical relaxation experiments.

Ultra-Low-Frequency Bridge. A bridge of the modified Weingarten type has been designed, built, and tested in the region 0.01 to 200 c/s. Highly acurate measurements of dielectric constant and loss factor can be made with this bridge. Some of the measurements concerning both polychlorotrifluoroethylene and the frequency response of resistors in the range 10^9 through 10^{14} ohms were made with this bridge. This frequency response is largely connected with the distributed capacitance of the resistors.

Dielectric reference materials are placed in constant humidity chambers for measurement of their electrical properties. The three-terminal guard-ring electrode holder recently developed at the Bureau for such work can be seen in the chamber (page 34).

Spherulitic Growth in Polychlorotrifluoroethylene. The rate of radial growth of spherulites in polychlorotrifluoroethylene was accurately measured as a function of temperature in order to determine the growth rate law. The form of the rate law is very important in determining the nature of the crystal growth; and the form found indicates that coherent nucleation is the rate-determining step in the radial growth process. The numerical value of one of the constants is consistent with the concept that the growth nuclei are of the chain-folded rather than the bundlelike type. (Electron micrographs obtained elsewhere suggest folded structures in this polymer.) Crystallization in this polymer strongly affects its dielectric properties.

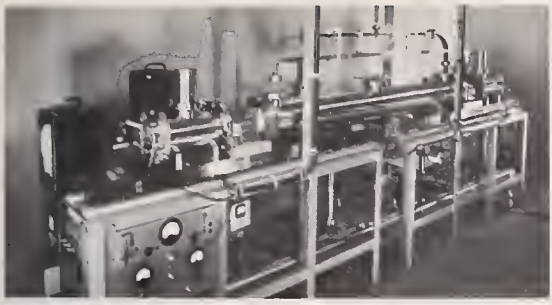
Theory of Chain-Folded Crystallization in Bulk Polymers. The dielectric and mechanical properties of polymers are often strongly dependent on the degree and the form of crystallization. A comprehensive theory of formation of chain-folded crystals, extending earlier work for dilute solution to the bulk phase, was completed. This theory clarifies many of the theretofore unexplained and unpredicted dielectric and mechanical phenomena connected with polymer crystallization, and the conditions under which chain-folded (lamellar) crystalline structures can appear in bulk polymers. These conditions are such that chain-folded polymer nuclei, the preferred type—compared with bundlelike nuclei—in sufficiently dilute solution, are to be expected in bulk.

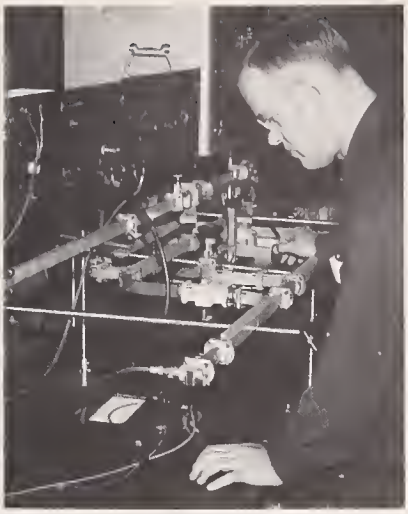
2.3. RADIO STANDARDS

The Bureau's program in radio standards centered at the Boulder Laboratories consists of basic research and development of national standards of fundamental electrical quantities, measurement techniques, and properties of materials. A large calibration service is provided from direct current through microwave frequencies, and radio broadcasts are made of the national primary standards of frequency and time intervals.

During the last few years, demands have increased for radio standards of electrical quantities and for the properties of many radio materials. Extensive calibration programs are being established in military agencies, industries, and private standards organizations. These programs depend upon the Bureau's best reference standards. To meet these needs, the Bureau is continually increasing the kind, range, and accuracy of electrical standards and calibration services.

Improved reflectors for a high-resolution millimeter wave Fabry-Perot interferometer were developed, and the theoretical understanding of diffraction in microwave interferometers was clarified. A number of new and different frequency standards were put into operation. The time signals broadcast by NBS radio stations WWV and WWVH were made more uniform by locking them to the broadcast frequencies. A 20-kc/s standard frequency station was put into operation. Several new instruments were developed to measure certain characteristics of materials of interest to radio physicists and engi-





Above: One of two cesium beam frequency standards that were placed into operation making it possible to refer the national standard of frequency to an atomic resonance. It is accurate to within 1.5 parts in 10^{11}. Right: Intercomparison of Japanese and American microwave power standards by an impedance technique (pages 38 and 41).

neers, and techniques to measure electrical quantities at microwave frequencies were developed.

Numerical Analysis. Much of the computation of the Division involves numerical integration using Gaussian quadrature. The theory of this highly efficient method has been extended and practical Gaussian formulas have been developed for evaluating multiple integrals, multiple sums, the Cauchy principal parts of divergent integrals, transforms which are neither sums nor integrals (e.g., derivatives), transforms which are functions, and transforms which are nonlinear. One explicit general Gaussian formula that was derived facilitates the determination of bounds for indeterminate transforms and, if the input data are experimental, includes a least square treatment of the data.

Millimeter Wave Research. Between wavelengths of 3 mm and the long infrared lies a wide and virtually unused region of the electromagnetic spectrum. Important applications for these wavelengths arise in many fields of endeavor such as nuclear fusion research, high discrimination radar, radio communications, length and time standards, and in precision measurements of physical constants such as the velocity of light. In addition much physical insight on the structure and behavior of matter can be obtained from investigations at these short wavelengths.

The theoretical treatment and understanding of diffraction in mm wave interferometers were further clarified. This work on diffraction deals with the corrections that must be applied to measurements made with mm wave interferometers operating in the near field or Fresnel diffraction region of a radiating antenna. Such corrections are important in all precision work, and in particular for precise metrology applications.

The usefulness of the millimeter wave Fabry-Perot interferometer was increased by adding reflectors with arrays of holes coupling into the resonance region between two parallel metal plates. This assembly gives very sharp fringes with high discrimination and low loss.

Atomic Frequency and Time Interval Standards. The research activities in this field are concerned with four areas: (1) Frequency standards utilizing magnetic transitions between hyperfine levels of cesium and thallium; (2) molecular frequency standards using cavity type masers; (3) fluctuation phenomena in the electronic oscillators and multipliers used to investigate atomic resonances; and (4) gaseous maser techniques at millimeter wavelengths. In this area an investigation was made of the suitability of the hydrogen cyanide molecule as a source of millimeter-wave energy in a maser utilizing a Fabry-Perot type structure rather than the conventional cavity resonator. This device appears to have great potential as a possible frequency standard, length standard, and instrument for measuring the velocity of light.

Two cesium beam atomic standards of frequency and time interval were put into operation. A careful evaluation of them has enabled the United States frequency standard to be referred to in terms of atomic resonance with an accuracy of 1.5 parts in 10^{11}. This evaluation has also added to the weight of arguments in favor of a redefinition of the second in terms of an atomic resonance. Standard frequencies are transmitted by NBS stations WWV, WWVH, WWVL, and WWVB in terms of this standard.

Relatively simple crystal oscillator circuits, stabilized with the ammonia inversion frequency, were used to make spectral analyses of complex helium-cooled crystal oscillators. In addition, the maser-stabilized spectrum analyser was used to investigate the purity of the radiations exciting the cesium resonance. A nonsymmetrical spectrum of the exciting radiation can cause the apparent resonant frequency to differ from the true resonant frequency.

Radio Broadcast Service. On January 1, 1960, the tentative value of 9,192,631,770 cycles per second was adopted by the NBS as the specified cesium line frequency. Also, at this time the broadcast frequencies of WWV and WWVH were offset from the U.S. frequency standard by -150 parts in 10^{10} to establish a scale of time in substantial agreement with the current value of UT–2 but with a uniformity two or more orders better. Thus, the time signals, locked to the broadcast frequency, require less frequent adjustment than heretofore. To preserve these extremely uniform time signals for as long a period as possible, time adjustments are to be made only when UT–2 departs more than 50 milliseconds from the WWV broadcasts. None was made since January 1, 1960.

Many agencies of defense engaged in missile, rocket and satellite research and development work, and related activities, have reached a point where their timing and frequency calibration requirements far exceed the capabilities of the HF signals as received from WWV and WWVH. To meet these critical needs, the NBS has established a standard broadcast at very low frequency. A new method of time signal modulation of VLF carriers has also been developed which, when implemented, will permit frequency and time interval calibrations to be made to a precision and accuracy 1,000 times greater than at HF.

Studies indicated that the propagation effects at VLF may be sufficiently small to make feasible a multiple-frequency technique to identify individual transmitted cycles of the carrier, thereby realizing microsecond timing. Studies were also planned to determine the frequency spacing and number of adjacent carriers required to provide such a service.

Regular operation of a 20 kc/s standard frequency station, WWVL, located near Boulder, Colo., was begun on a six-hour-a-day schedule on April 5, 1960. Reception reports were soon received from coast to coast in the United States. The signals were also received regularly in New Zealand. In June the schedule was made continuous except for periods during the "dark" phase of the moon when another project used the antenna from 6 a.m. to 6 p.m.

Three ultrastable crystal oscillators with the crystal at liquid helium temperature (4 °K) were maintained continuously throughout this year. The best of these oscillators has an aging rate of about 1 part in 10^{11} per day.

An investigation of the relative intensities of X-rays reflected from a number of the atomic planes in quartz was made several years ago, but not published at that time because of certain apparent violations of Friedel's law. Mathematical calculations were recently made verifying the experimental data. Further verification was obtained through the preparation of etched specimens oriented with respect to selected planes.

Work continued on the solid-state properties of quartz with emphasis on the electrical conductivity-temperature relationships with various impurities and impurity bonding to the lattice structure. In connection with this study, precise oven controls were developed as well as a circuit that accurately measures differential conductivity of two quartz samples as a function of temperature.

A new 20 kc/s standard frequency station was put into operation this year near Boulder, Colo. The antenna, a copper coated steel cable, weighs more than a ton, stretches 3,400 ft from anchor to anchor, and is 900 ft above the canyon floor (page 39).

Radio and Microwave Materials. The introduction of new semiconductor, metallic, magnetic, and dielectric materials during the past decade has stimulated many developments and investigations in electromagnetic technology. In addition to its regular program in this area, the Bureau is establishing a laboratory under the sponsorship of the Department of Defense for the accurate characterization, analysis, and evaluation of magnetic materials at radio and microwave frequencies.

The evaluation of electromagnetic parameters at radio and microwave frequencies of ferro- or ferrimagnetic materials was extended by developing specialized highly reliable measuring methods and equipment, which include apparatus for determining complex tensor permeability as a function of frequency, a magnetometer for measuring spontaneous or saturation magnetization and curie temperatures. measuring services for extremely high dielectric constants based on an improved RF permittimeter, and a new Maxwell bridge technique which permits low loss magnetic measurements.

A technique was developed for making complex permittivity or complex conductivity measurements at radiofrequencies without applying electrodes to the material. This technique uses a coaxial RF impedence transformer in which the secondary is a single turn (toroid) of the material to be measured. The device, called a radiofrequency permittimeter, is connected to an impedance bridge. Many conductors, semiconductors, electrolytes, and high permittivity materials can be evaluated to about 1 percent. Complex conductivities differing considerably from those observed by other methods have been measured.

Using the newly developed permittimeter, measurements were started on the complex conductivity of a series of strong electrolytes. Such measurements at radiofrequencies have not previously been reported and the first measurements show two interesting trends: (1) The out-of-phase portion of the conductivity at certain frequencies and concentrations appears as a negative dielectric constant for the material, and (2) when this apparent negative dielectric constant appears, the solution is near saturation indicating that there may be a connection between the thermal frequencies of the ions, the relaxation time of the ions in concentrated solutions, and the solubility of the solute. The negative dielectric constant apparently comes from the inertial properties of the carriers in contrast to the restoring force usually associated with dielectric polarization phenomena. The new permittimeter makes possible measurements of the reactive component in the presence of a large loss term, thus opening a new region of heretofore unavailable data.

Partially successful attempts were made to measure the complex tensor conductivity (or tensor dielectric constant) of some semiconductors as a function of radiofrequency, static magnetic field, and temperature. Future measurements using more sensitive measuring instruments and lower temperatures (<10 °K) are planned.

Various extensions and improvements in microwave dielectric measurements were made. By using a centered dielectric post in a TE_{011} mode cavity resonator, and a theoretically calculated "port-Q," a dielectric test set

was developed to obtain accurate loss measurements from the change in transmission of a cavity. Also, surface impedance and surface Q cavity methods were standardized.

High Frequency Electrical Standards. The development and construction of a 30 Mc/s facility to measure attenuation was completed for use in the Electronic Calibration Center. It has the widest range (0 to 150 db) and highest accuracy known to be available for this frequency; it also has exceptionally high operational efficiency (about a minute per measurement) for such performance and incorporates a number of unusual electronic and structural features. The overall accuracy of this facility will be checked in terms of an entirely new national primary standard system at present under development.

Among other activities in the high-frequency area were continued research on techniques and equipment to appraise the quality of basic standards of thermal noise and to intercompare noise sources with high accuracy. A new thermistor mount for power measurements was developed for 0.1 percent accuracy instead of the previous 1 percent. A useful method was developed to measure undesirable transmitter outputs of levels 80 to 100 db below and at certain frequency-separations from the carrier.

Visiting French scientists are shown microwave apparatus in a new laboratory established for the evaluation of magnetic materials (page 40).

Microwave Circuit Standards. The Bureau's program includes research and development at microwave frequencies (about 300 Mc/s) on power, impedance, attenuation, phase shift, noise, and field strength. Standards and measurement techniques were improved in a number of these quantities.

A number of barretter mounts serving as national power standards in the Electronic Calibration Center were calibrated with a microcalorimeter. A new method for transferring the calibration from one power standard to

another, which is substantially independent of the impedance discontinuities of waveguide joints or connectors, was developed. This technique should prove to be especially valuable when used in coaxial systems.

The error analysis for a recently developed method of using the impedance technique of measuring barretter mount efficiency was completed. In connection with an International Scientific Radio Union resolution, international intercomparisons of microwave power standards were carried out. The most recent ones with Japan yielded agreement within one quarter of 1 percent.

Impedance standards having a known reflection coefficient accurate to 0.005 percent were produced and evaluated by several independent techniques. These provide a sound basis for the new microwave impedance calibration service offered by the Electronic Calibration Center.

A technique was developed to measure accurately both phase and magnitude of microwave impedances by a two-channel reflectometer circuit.

New and sensitive techniques were devised to measure reflections and losses of waveguide joints and connectors. Reflection coefficients as low as 0.00015 and efficiencies in the range 99.90 to 100 percent were measured for rectangular waveguide joints.

Two entirely different attenuation measurement techniques, each capable of accuracies from 0.0001 to 0.06 decibel over a range from 0.01 to 60 decibels, were developed. One method employs differential power measurements by refined bolometric techniques, and the other is a modulated subcarrier system which lends itself to audiofrequency techniques. Calibration accuracies of these techniques exceed the precision to which presently available attenuators can be set and read. The feasibility of coaxial attenuator calibrations at frequencies up to 12 Gc/s was demonstrated so that the Electronic Calibration Center could extend the range of the attenuator calibration service.

Analysis of errors in a standard phase shifter was completed, providing the basis for a future calibration service. The analysis of mismatch errors in microwave phase shift measurements was completed. A new technique permitting 0.1 degree accuracy in microwave phase shift measurements was developed.

A microwave noise standard and radiometer having an accuracy of 0.01 decibel were developed for a new calibration service offered by the Electronic Calibration Center.

Electronic Calibration Center. The work of the Electronic Calibration Center was divided among meeting the increasing demands for calibration services, using measurement instrumentation already available, and improving and extending the measurement instrumentation to provide additional services. Calibration services provided for about 30 standards laboratories of Department of Defense agencies and for about 100 standards laboratories in industry, increased about 45 percent over the preceding fiscal year.

An oil bath for standard cells was completed and put into service, and additional data on the stability of the Center's saturated standard cells were

obtained. The stability of the Center's Thomas-type standard resistors already has been found to be excellent. It is expected that in the near future the Center's resistors and saturated cells can be incorporated into the national "primary group" used to maintain the units of emf and resistance in the intervals between the basic determination of these units.

A "microvolt" console was completed for the high frequency calibrations of meters or voltage generators in the microvolt and millivolt regions. Progress was made in calibrating the Center's working standards of high-frequency impedance.

The range of the X-band power calibration system was extended slightly, and a duplicate system was built to handle the increasing workload with greater efficiency. Calibration systems in four additional waveguide sizes were made ready for calibration services when power standards for these frequency ranges become available. Instrumentation for impedance measurement (reflection coefficient magnitude) in the X-band was completed, and a calibration service was announced. This system, and the standards on which it is based, can be extended readily to other waveguide sizes. Further improvements in the microwave radiometer were made during the year, so that it can measure the noise temperature of a gas discharge noise source to better than 0.1 db. These measurements will be referred to a "blackbody" noise standard.

Accuracy of a Hierarchy of Standards. The optimization, i.e., minimization of cost, of an entire hierarchy of standards fanning out from the National Bureau of Standards was considered by setting up and analyzing a reasonable theoretical model. This study was motivated in part by the frequent statement that the accuracy of each echelon of the hierarchy should be 10 times better than the accuracy of the immediately following echelon. It was found instead that the optimum accuracy ratio between two successive echelons is equal to a certain root of the number of laboratories in the lower echelon reporting to each laboratory of the upper echelon, the root depending on the rate of rise of cost with accuracy. This optimum ratio frequently turns out to be between 2 and 4.

2.4. MECHANICS

The Bureau's work in mechanics is primarily in the development, improvement, and dissemination of the standards of measurement for mechanical quantities. These include sound pressure and intensity, shock, vibration, force, strain, pressure, and rate of gas and liquid flow. The work requires the development of measurement techniques and transfer standards for all of these quantities. It also involves important studies of the properties of materials and structures.

Current applications of the results of the Bureau's work in mechanics are found in the design, construction, and operation of high-performance aircraft, space vehicles, and modern weapon systems requiring mechanical measurements of greatly improved accuracy over greatly extended ranges.

The urgent need for this work is illustrated by the estimate of a leading manufacturer of rocket engines that savings of 150 to 200 million dollars would result from improvement in accuracy of pressure and thrust measurements by a factor of three. Similar improvement and extension of the standards for other mechanical quantities and the development of improved transfer standards are required so that the Bureau's laboratories and the chains of primary and secondary laboratories operated by other governmental agencies and their contractors can meet the requirements of today and the near future.

Infrasonic Waves in the Atmosphere. Detection and recording of very-low-frequency infrasonic waves have disclosed a completely new means of detecting tornadoes, earthquakes, and other natural phenomena at great distances. Four microphones were set up near Washington, and recordings from them revealed that the atmosphere is full of sound at these very-low frequencies. The periods of the sound waves range from about 1 second to well over 200 seconds. The sounds have about the same physical intensity as speech, but are far too low in frequency to be heard and are therefore called infrasonic waves. The corresponding wavelengths are very great, between about 340 meters and 80 kilometers.

The great earthquake in Montana on 18 August 1959 produced infrasonic waves in the atmosphere when the earthquake wave passed through Washington, and the sounds were readily measured with the microphone system. Severe tornadoes produce infrasonic waves at Washington even though the

Compact wedge-type apparatus (right) for producing extremely high pressures is placed in a hydraulic press. Such devices are used to extend and improve the range and accuracy of the Bureau's pressure measurements (page 45).

tornadoes are more than a thousand miles away on the western plains. A source of unknown origin produces the ubiquitous and mysterious "microbaroms," whose periods lie in the range between 5 and 7 seconds. Interesting infrasonic waves are generated during the abrupt disturbances of the earth's magnetic field known as geomagnetic storms. They arrive usually from northerly directions, and are of very long wavelength—well over 15 kilometers in many instances. In all it is conjectured that there may be more than a dozen sources of infrasonic waves, of which only a few are identified so far.

Cavitation with Ultrasonics. In a project partly supported by the Office of Naval Research, an ultrasonic source was developed to create cavitation bubbles, that is, holes in the form of bubbles, in the interior of a mass of water. The source was a cylinder of barium titanate containing the water. Matching of the resonant frequencies of the cylinder and of the water created tensile stresses great enough to open up cavitation bubbles away from the walls. This makes it possible to measure conveniently the tensile strength of water and other liquids.

Pressure Measurement. This year was marked by an improvement in accuracy and an extension of the range of pressures covered by the pressure calibration services. With new equipment for developing ultra-high pressures, it is now possible to reach well over 1,000,000 psi. These pressures will be used in exploratory studies of reactions, and may also provide calibration points. One possible calibration point was provided by the conversion of graphite to diamond, demonstrating that it was possible to heat a sample to 1,500 °C while maintaining a pressure of about 1,000,000 psi.

Multiple-Anvil Apparatus Used. A multiple-anvil apparatus is used now to generate high pressures through application of force by an anvil against each face of a solid polyhedron. It employs an assembly in which external force is applied to only one of the four anvils, and wedge reaction forces act on the remaining three anvils. This results in compact equipment that can be used in a press of conventional design and may permit use of existing presses of very large capacity to obtain high pressures in relatively large volumes. A number of other laboratories in the United States and in Europe developed apparatus based on the NBS design.

High-Vacuum Pressure Measurements. A program on the development of standards in vacuum measurements was started. A laboratory was set up for this purpose. Equipment of new design is being built with the hope of measuring directly the pressures in the high-vacuum range. High-vacuum pressures correspond to the pressures encountered by missiles and space vehicles in flights to altitudes many miles above the earth's surface, and a growing need exists for precise measurement of such pressures.

Acceleration Due to Gravity. Many measurements made at the Bureau require application of accurately known forces. These measurements include standardization of the unit of electrical current and precise determination of fluid pressure. They include also calibration of instruments for measuring the thrust of rockets and missile propellants. The most reliable standard

for such forces is the gravitational attraction of the earth on known masses. However, the value of a gravitational force can be determined accurately only if the intensity of gravity is known at the point where the force is generated. This intensity is measured by determining the acceleration due to gravity—that is, the acceleration which gravity would impart to a mass falling freely in a vacuum. Once such an absolute measurement is made at one point, values of the intensity of gravity at any other point on the earth may be determined by a survey with precise comparison instruments.

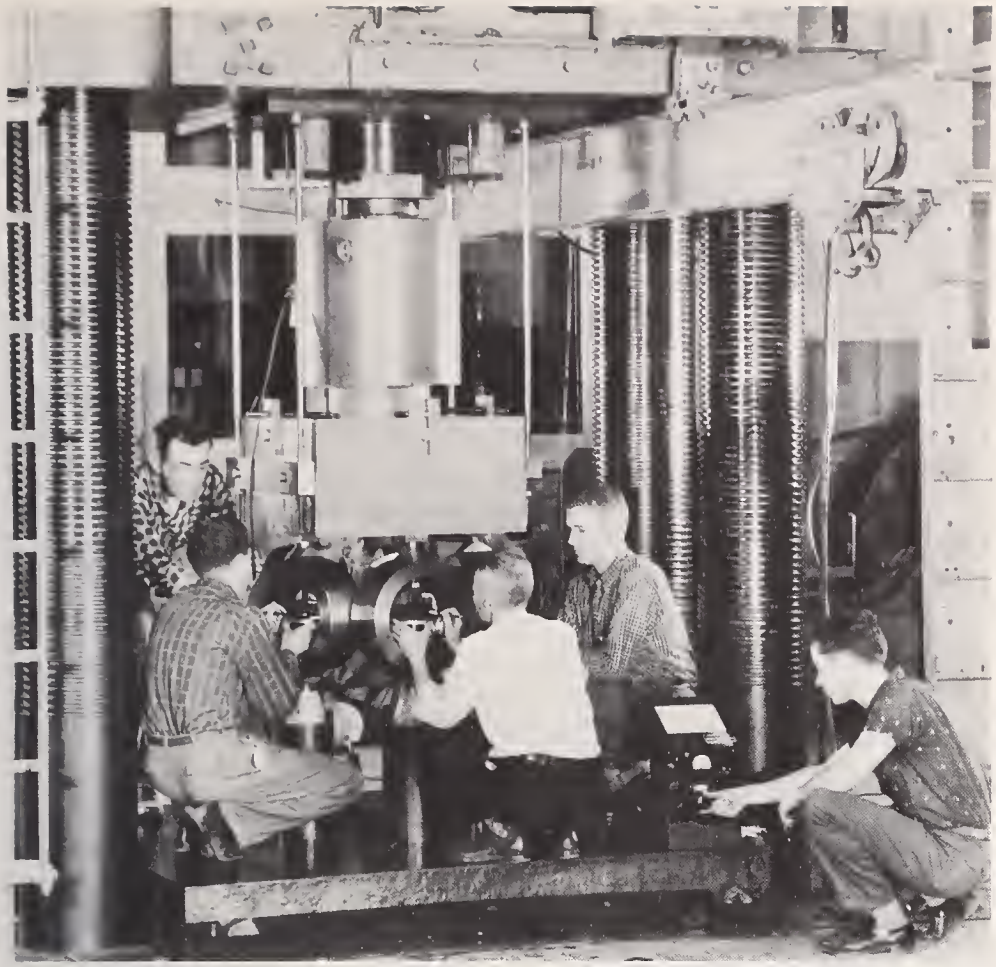
Cooperating with other nations, the Bureau is making an absolute determination of the acceleration of gravity in its laboratories in Washington. A quartz rod, falling in a vacuum, is timed to one ten-millionth of a second as it falls for a distance of 1 meter. An unusual feature of the experiment is that the vacuum chamber is allowed to fall with the rod, facilitating the task of picking the rod up for successive drops and greatly simplifying the process of measuring the length of the rod. During the fall the rod does not touch any part of the vacuum chamber which is artificially accelerated to overcome air resistance and thus keep pace with the rod inside. The rod is timed by a photoelectric cell which "sees" it through windows in the vacuum chamber wall. Preliminary results of this experiment are expected within a year.

Advances in Force Measurements. The demand for the Bureau's calibration service by manufacturers and users of elastic force measuring devices such as proving rings, dynamometers and load cells has grown more than four-fold in the past 10 years. Requirements for improved accuracy and for measurements of larger loads have accompanied the increase in the number of calibrations. These new requirements result primarily from the needs of the military rocket and missile research and the space exploration programs.

Because of the need for the best possible accuracy in the calibration of large load cells of 1,500,000- and 2,000,000-lb capacity, the cells were calibrated using proving rings up to 1,500,000 lb. Previously, cells of this capacity were calibrated only to 1,000,000 lb by proving rings and above this load, with NBS elastic load measuring devices. With the proving rings, the loads applied are believed to be accurate to one-tenth of one percent and with the NBS elastic load measuring devices, three-tenths of one percent.

For higher loads, the Bureau has its four one-million-pound capacity and its four three-million-pound capacity elastic load measuring devices whose accuracies meet the requirements of ASTM Specification E74–57. This specification provides tolerances of 0.3 percent for 1,000,000-lb capacity devices and 0.4 percent for 3,000,000-lb capacity devices, to be used in the calibration of elastic load measuring devices up to 10,000,000 lb. Study of the behavior of these devices continued this year.

To calibrate force-measuring devices whose capacities are 111,000 lb or less, the Bureau utilizes its dead weight machines which are accurate to 0.02 percent. To extend the range over which accurate test loads may be applied



Calibration of a 1,500,000 lb capacity load cell for use in tests of a 1,500,000 lb thrust rocket engine that is being developed for space exploration. Each of the five 300,000 lb capacity proving rings (below large block) has been calibrated by dead weights to 110,000 lb and by other calibrated proving rings for loads greater than 110,000 lb (page 46).

by dead weights, machines of 30,000- and 1,000,000-lb capacity have been planned for installation at the Bureau's new facility at Gaithersburg, Md. These machines are designed to provide accuracies of better than 0.01 percent in both tension and compression. These new facilities will make possible the direct calibration by dead weights of most of the existing devices. They also will make possible the development of improved portable secondary standards, which are needed as working standards in other laboratories.

High-Temperature Thermocouples. The iridium versus iridium-rhodium thermocouples designed for use at temperatures to 3,500 °F and above continued to gain favor during the year. A temperature-emf reference table for the combination containing the 40 percent iridium—60 percent rhodium alloy neared completion. In the meantime, summaries of calibrations comprising the most recent information were supplied to those with an immediate need for such a table. Some data were also obtained on an iridium versus iridium 60 percent—rhodium 40 percent thermocouple.

The search continued, with limited success, for electrically insulating materials satisfactory at the high temperatures. Meanwhile, techniques were devised, which, although laborious, reduced to a tolerable magnitude the inaccuracies resulting from deficiencies of insulation and other causes.

Thermocouple Reference Table. Complete data were obtained for a temperature reference table for a new type thermocouple designed for long-time use in gas turbines where the gas temperature may be as high as 2,300 °F, and for short periods up to 2,600 °F. This thermocouple, developed by an industrial contractor for the sponsor of this project, the Wright Air Development Division of the Air Force, has palladium for one element and platinum with 15-percent iridium for the other. The reference table is expected to become available in a short time.

Heating Tests of a New Thermocouple. Another new thermocouple, currently being developed by a manufacturer, was examined to determine the effects of prolonged heating in a project sponsored by Wright Air Development Division of the Air Force. Two samples, each subjected to up to 1,500 hours of heating, one at 1,600 °F and the other at 2,000 °F, showed changes comparable with the tolerances normally prescribed for the commonly used jet-engine thermocouples. The purpose of this thermocouple is to extend the temperature range for long-time use beyond that of the currently used base-metal thermocouples.

Catalytic Reactions on a Rare-Metal Thermocouple. It is often necessary to determine the temperature of gases containing appreciable amounts of combustible material and oxygen. This is particularly so in the cases of jet and gas-turbine engines when evaluations of performance of the combustor and turbine are required. Values of combustion efficiency are obtained from measurements of the temperature of the air entering the burner and of the exhaust products leaving it. Similarly, evaluation of turbine performance requires a knowledge of the temperatures of the gas entering and leaving the turbine.

In connection with the above temperature measurement problem, it was noted that platinum is a catalyst under some conditions in products of incomplete combustion; and the question arose about the magnitude of errors in measured temperature that might arise from the use of the palladium vs platinum—15 percent iridium thermocouple. Preliminary measurements were made of the catalytic effect in terms of rise of temperature of this thermocouple in mixtures of air and small quantities of methane, propane, hydrogen, and carbon monoxide, in a project sponsored by Wright Air Development Division of the Air Force. The temperature range over which effects appear was found to be 400 to 1,300 °F, and the magnitude was from 0 for methane to about 240 °F for hydrogen. Both sets of values depend upon the gas mixture used and the velocity of the mixture over the thermocouple. Further work on this and other rare-metal thermocouples is planned.

Fuel Flowrate Studies. Under sponsorship of the Bureau of Naval Weapons, progress continued on the fuel flowrate standardization program

for the aircraft industry. The program includes flowrate calibrator correlations with many different facilities in both industry and the services. The agreement obtained upon completion of a successful correlation program is usually within plus or minus 0.15 percent of rate throughout the range of interest. Part of this program is devoted to construction of a reference calibrator at the Bureau for use with hydraulic and lubricating oils (range 1 to 30 gpm, accuracy about plus or minus 0.1 percent).

Other work included: Continued investigation of characteristics of both new and conventional flowmeters used in the aircraft industry; the writing of purchase specifications for the sponsor for transfer reference flowmeter assemblies; and the evaluation and calibration of specific reference units for use in Naval Primary Standards Laboratories.

Through such work more accurate flowrate calibration facilities are being maintained in the aircraft industry, and more suitable flowrate transfer references are being developed and manufactured.

Calibration of Aircraft Fuel Metering Accessories. Reference test and calibration equipment for aircraft fuel metering accessories is maintained and operated at NBS for the Bureau of Naval Weapons. The primary purpose is to develop uniform test and calibration procedures for gas turbine fuel controls and aircraft carburetors for use by Naval overhaul facilities. Another purpose is to maintain reference standards whereby the performance of similar test units installed in the field may be evaluated, and to develop and evaluate new instrumentation and procedures for use in tests of these fuel metering components.

Hypervelocity Missile in a Combustible Gas. A hypervelocity missile in a combustible gas provided a new technique which may be employed to secure information over a wide range of conditions on combustion at supersonic speeds. Such parameters as pressure, temperature, fuel, and speed may be changed at relatively little cost to learn of their effects on combustion. The stagnation temperatures realized by this method are realistic, and the method of mixing of air and fuel and the degree of turbulence cannot affect the results.

Effects of interaction of a shock wave and the combustible gas, and of interaction of the combustion and the solid body were analyzed in a project sponsored by the Office of Scientific Research of the Air Force. In this way, problems associated with stabilization of a detonation wave on a stationary object in a moving combustible mixture can be examined in advance of the application of this kind of combustion.

Several kinds of combustion were observed. Delayed ignition was observed in some cases; and the conditions of temperature and pressure and delay time observed may be used in attempts to make theoretical descriptions of combustion processes. Laminar combustion in a supersonic stream also was observed. If the flow field can be described, the laminar flame speed can be derived and compared to that measured under ordinary conditions. Strong detonation waves were observed. The minimum Mach number for

the detonation wave can be derived and compared to that observed in tube experiments. Effects due to boundary layers, which influence results in tube experiments, were absent in these experiments, except at the front of the sphere. It was noted that interaction of the combustion and the front of the solid body produced oscillations of large amplitude in the megacycle frequency range.

Fatigue Strength of Aircraft Structures. It is now increasingly apparent that fatigue properties determined with fixed amplitude tests do not accurately describe the resistance of a member to randomly varying loads. Airplane wings, for example, are exposed to a variety of random loads resulting from maneuvers, gusts, landing impacts, and other factors.

In order to provide essential design information on the strength of built-up structures under random loads, specimens must be subjected to spectrums of loads which are derived from force history measurements made in service on similar structures. A pneumatic fatigue testing machine was designed and constructed for this purpose with an electronic programer which is capable of automatically applying predetermined load sequences to structures.

At the request of the Bureau of Naval Weapons, random load fatigue tests are being carried out on a series of riveted and bolted box-type wing beams in bending. Through these tests, a better understanding of fatigue behavior under random loads is being sought. Another objective is the establishment of methods by which the fatigue properties of structures under random loading can be estimated from fatigue properties under fixed amplitude loading.

Aircraft wing beam specimen being prepared for pneumatic fatigue tests. This study will provide essential design information on the strength of built-up structures under random loads resulting from maneuvers, gusts, landing impacts, and other factors (page 50).

Culvert Hydraulics. Seeking to lower costs of modern culvert construction through increasing the carrying capacity, the Bureau of Public Roads sponsors an experimental investigation of pipe culvert hydraulics at NBS. The principal problem is that conventional culverts do not flow full even when the entrance is completely submerged. Hence a large portion of the culvert barrel is not utilized in transporting water through the highway fill.

The study resulted in a definition of the complex interrelationship between the hydraulic and pneumatic processes involved in the onset of full conduit flow in a culvert. In addition, the substantial adverse effects of air-carrying vortices over the inlet were indicated.

The investigation is directed largely toward increasing the efficiency of the culvert by geometric modifications of the inlet structure. Design standards for improved inlets were developed.

2.5. HEAT

The advances of sciences and technology demand constant improvement and extension of standards and methods of measurement in the field of heat. In response to these demands, the Bureau maintains the temperature scale from the lowest to the highest accessible temperatures and continually extends this scale. In addition, standards are developed for viscosity and for such measurements as thermal diffusivity, heat capacity, and heat of combustion.

In an intensive research program to improve and extend these standards, special emphasis is given to statistical thermodynamics, molecular structure, high-pressure thermodynamics, low-temperature physics, rheology, high-temperature processes, and various aspects of plasma physics.

During the past year, these activities were characterized by efforts to obtain new extremes of temperature and pressure, to increase the degree of automation of precision measurements, to extend knowledge of the statistical thermodynamics of dense systems and of highly ionized gases (plasmas), to investigate the rheological behavior of a variety of systems, and to study the mechanisms of high-temperature processes with greatly improved instrumentation. The three-year program to investigate the behavior of solids containing trapped free radicals was brought to completion. A long-range experimental and theoretical program devoted to characterizing and predicting the properties of hot gases is under way.

Plasma Thermometry. To meet the rapidly growing needs of the space sciences and the military for basic data on the behavior of hot gases and plasmas (hot-ionized gases), a special research program was initiated to unify and strengthen the Bureau's activities in these areas. As part of this program, a plasma thermometry laboratory was established to develop stable plasma sources, to investigate the precision and accuracy of measuring plasma temperatures, and to study the characteristics of plasmas which are not far from local thermodynamic equilibrium.

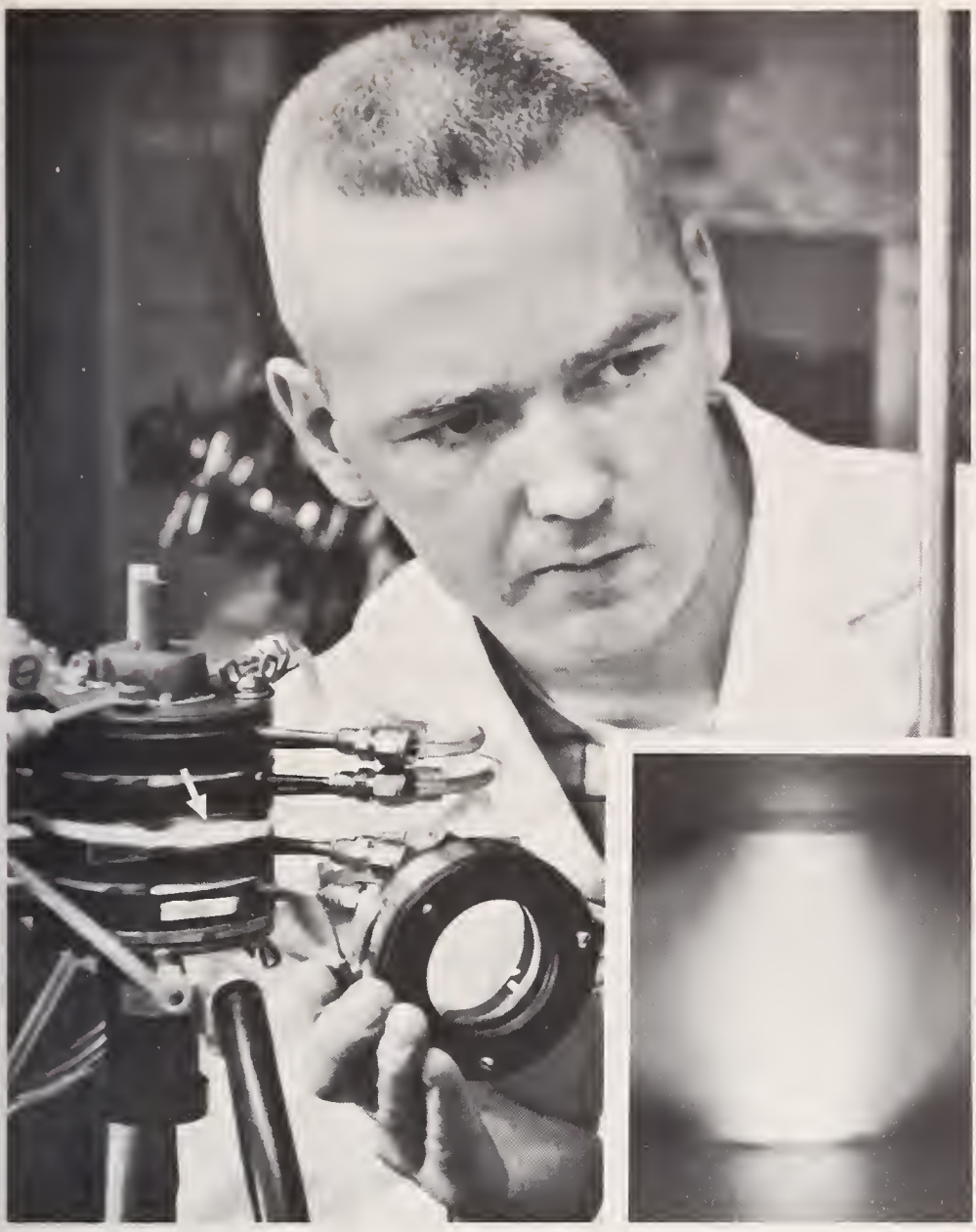
High-Temperature Arc Developed. During the first year of its existence, the plasma thermometry laboratory developed an improved version of the wall-stabilized, high current-density arc. A special feature of this arc, which operates in the 10,000 to 20,000 °K region, is that the electrodes are surrounded by an inert gas such as argon. The gas to be studied is introduced in the central region, the argon serving to isolate it from the electrodes. As a result, a large number of gases—including oxygen and nitrogen—can be maintained at temperatures of the order of 15,000 °K without electrode contamination. Moreover, the gases are introduced and exhausted in such a manner that it is possible to keep the center of the arc free from the buffer gas, argon. When operating in nitrogen at 14,000 °K, the intensity of a spectral line can be kept constant to within 1 percent for the order of an hour. Because of its purity and stability, this arc serves as the basic source of high-temperature radiation in many of the Bureau investigations.

Hydrogen and Helium Studied. For systems in local thermodynamic equilibrium the absolute and relative intensities of spectral lines, the shapes of spectral lines, and the intensity of the continuum radiation are functions of the temperature. However, only in the case of atomic hydrogen and helium are the details of the relationship accurately known. For this reason, initial investigations are being conducted on hydrogen, helium, and mixtures of these gases with other gases. Because arcs in pure hydrogen and helium are not as easily stabilized as in argon or nitrogen, more stable and pure H and He arcs are required before theoretical and experimental results can be considered conclusive.

Another serious problem arises when hydrogen or helium, acting as thermometric indicators, are mixed with other gases. It is usually difficult to find the relative concentrations of the gases in mixtures, because the concentration of some gases at high temperatures is not uniform throughout the volume. For example, if 98-percent oxygen and 2-percent hydrogen were initially fed to an arc, the actual concentrations might vary as a function of the radius from 4-percent hydrogen on axis to 1-percent hydrogen at the edge. This phenomenon of nonuniformity is now being investigated with mixtures of hydrogen and oxygen and is to be extended to mixtures of helium, nitrogen, and argon.

Nonequilibrium Systems Investigated. High-temperature systems not in local thermodynamic equilibrium are becoming increasingly important. One such system is a hyperthermal wind tunnel where a plasma is injected at sonic velocity into a high-vacuum environment. To study the magnitude of the departures from equilibrium, low- and high-pressure arcs were developed to operate at pressures from about 0.01 to 100 atmospheres. Preliminary tests are now being performed on these arcs.

Detailed investigations on the existence of equilibrium and on the determination of plasma temperatures may lead to accurate measurements of the transition probabilities of atomic and ionic spectral lines. These data are of great importance to aeronomists, plasma physicists, and astrophysicists (see p. 60).



Scientist images a 15,000 °K plasma arc on a spectrograph. This is one of several high-temperature arcs developed as a tool in the Bureau's high temperature measurement program. Right: Image of the arc as it appears through the window (arrow) (page 52).

Thermodynamic Properties of Light-Element Compounds. One of the most effective means of developing more efficient chemically propelled rockets is to select particular fuel materials which generate more power per unit mass and lose less power in the exhaust products. Although it is clear that such fuel materials should be composed of light elements or their compounds, selection for top performance cannot be reliably predicted until more thermodynamic data are acquired for these compounds.

To meet this need, the Bureau—under the sponsorship of the Defense

Department—is continuing its comprehensive interdivisional program of research on aluminum, beryllium, lithium, and magnesium compounds. Although this program has one goal—determination and dissemination of thermodynamic data of light element compounds—the means of reaching this goal are widely diversified. For example, the entropy of lithium aluminum hydride is being determined by low-temperature thermal measurements, and should help in predicting under what conditions this new compound can be formed or will decompose. Gas-density measurements on boron trifluoride indicate its deviations from gas ideality up to 250 atm and 500 °K. The important aluminum-oxygen gaseous system, on the other hand, can exist only at much higher temperatures, but an exploding-wire apparatus designed to measure its energy, density, and composition up to 100 atm and 6,000 °K is showing some promise. A new, more accurate value was obtained for the heat of formation of beryllium chloride, using a calorimeter operating at elevated temperatures. New results, whose further refinement is planned, were obtained for both the heat of formation and the molecular structure of N_2F_4, the newly available fluorine analog of hydrazine.

Such basic data, combined when necessary with results from other laboratories, are most useful when tabulated as the fundamental thermodynamic properties for a wide temperature range. In the current program the properties of over 100 substances were tabulated by high-speed machine computers. Where the needed data are still lacking, they are estimated by theoretical and semiempirical methods which, in practice, are usually adequate for minor constituents of rocket fuels. Because major constituents are also tabulated, it is possible to calculate the chemical composition and energy content of fuel systems under equilibrium conditions.

Omniform. Considerable progress was made in techniques for high-speed computation of thermodynamic data—both in large-scale table generation and in the application of high-speed machines to a variety of time-consuming ad hoc calculations, which are part of the daily research routine. To eliminate some of the delay caused by a wide variety of tedious computations which, because of their ad hoc character, are not usually programed, a general-purpose machine program called "Omniform I" was developed. This program enables a scientist to have direct access to a high-speed machine without learning the specialized programing ordinarily required. Thus he is able to use the high-speed computer in a manner highly analogous to his use of a desk calculator. "Omniform I" can perform any algebraic calculation which is given explicitly in terms of one variable and a series of constants or parameters. Among its built-in provisions are two dozen elementary and special mathematical functions, a means for taking functions of functions, numerical differentiation, and a wide variety of numerical integration methods. Although this program was created primarily to meet the needs of workers in thermodynamics and molecular physics, the mathematical operations involved are applicable to calculations in many other research areas.

Theoretical Rheology. Advances in both linear and nonlinear rheological theories led to improved definition and measurement of material properties and increased understanding of relations between properties and structure. From the point of view of continuum mechanics, the flow of an incompressible fluid is governed by a set of equations made up of (1) a statement of Newton's laws, (2) the condition of incompressibility, and (3) a constitutive relation connecting deformation and stress. This constitutive relationship—which characterizes the material—is the concern of the rheologist. Although it is well known that most materials respond to stress in a nonlinear manner, the great majority of presently accepted results in rheology apply only to situations where a linear approximation of the constitutive relation is justified. On the other hand, even Newtonian fluids which conform to a linear constitutive relation are governed by a nonlinear expression of Newton's law. Therefore to study nonlinear rheology of fluid flow it is important to be able to distinguish the nonlinear effects which are independent of the rheology of the fluid. A theoretical attack on this problem has resulted in criteria for estimating the maximum effect of these extraneous nonlinearities for typical viscometer flows. These bounds promise to be a valuable tool in designing experiments for the growing study of nonlinear rheology. They are also being used in the evaluation of the effect of secondary flow on the performance of an absolute viscometer in which the liquid is contained in an oscillating hollow sphere.

In the linear region, the most complete expression of the current molecular theories for the viscoelastic behavior of rubberlike materials was formulated in terms of the response to a steady stress or strain. Previously this particular formulation had been expressed only in terms of steady-state response to sinusoidal stress or strain. This solution, carried out in collaboration with the Bureau's computation laboratory and with the support of the Office of Naval Research, will permit the comparison of the theory with various experimental measurements of stress relaxation and creep, and should help in assessing the effect of molecular weight distribution on the linear viscoelastic properties of such materials.

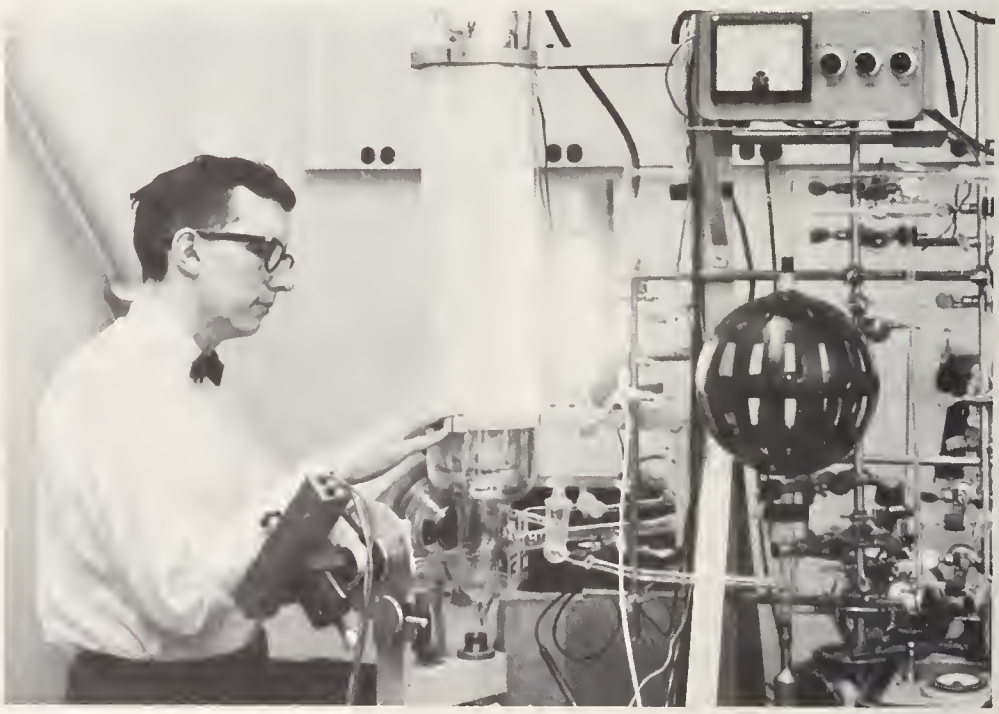
A New Simplified Approach to the Many-Body Problem. In recent years much attention has been given to the use of perturbation theory in many-body systems. In typical applications, some property of a system is expanded in powers of a perturbation; the expansion is observed to be divergent; certain parts of the expansion are collected and resummed; and a convergent result is obtained. Graphical methods are generally used to represent terms in the expansion. Difficult analytic, combinatorial, and topological problems arise in using such graphical methods.

A program of study was initiated to simplify the use of perturbation theory in such problems so that useful results can be obtained with a minimum of time and effort. General equations for the average time dependence of molecular quantities were derived without the use of graphical techniques. Applied to a few well-known situations, they give the same results as earlier,

more complicated methods. As a result, they were used in a new calculation of the coefficient of self-diffusion in a moderately dense gas (where triple collisions are important).

Paramagnetic Resonance in the Free Hydroxyl Radical. The neutral hydroxyl radical, OH, has a transitory existence in certain gaseous electrical discharges and flames, and is thought to act as an intermediate product in many chemical reactions. In a program for the Defense Department the optical spectrum of this radical, which was intensively studied for many years, was recently extended to the microwave range of wavelengths. These microwave spectra were investigated because they yield information on the physical properties of the OH radical itself, and aid in detecting the presence of the radical and studying reactions in which it is involved.

Because of the strong magnetic moment associated with its unpaired electron, the OH radical can also be studied by the well-developed technique of paramagnetic resonance absorption. This process involves measuring the microwave absorption of a vapor containing OH radicals, while subjecting the vapor to a moderately strong magnetic field. The radiation incident on the vapor has a single fixed wavelength, and the magnetic resonance spectrum is displayed by varying the strength of the magnetic field. In the Bureau experiment, OH radicals were generated by an electric discharge in low-pressure water vapor. The radical vapor was pumped continuously out of the discharge region and through a quartz absorption cell located within the



Measuring the refractive index of a thin film of gas condensed on a liquid helium-cooled surface. The measurements, believed to be the first of their kind, were made in connection with the Bureau's free radicals research program (page 58).

microwave cavity of the paramagnetic resonance spectrometer. Several discrete line spectra were observed. On theoretical grounds, these spectra were assigned to OH radicals by matching the spectra against those predicted from the theory of Zeeman effects and hyperfine structure of diatomic molecules. This identification was verified by substituting deuterium oxide (D_2O) vapor for water (H_2O) vapor in the electric discharge.

From precise measurements on the paramagnetic resonance spectra, several molecular constants of OH and OD were deduced. These include values of the molecular magnetic moments, lambda-type doubling energies, and hyperfine structure interaction constants. The latter are of special interest as a test of theoretical molecular wave functions; the hydroxyl radical is one of the most complex physical systems for which accurate wave functions have been calculated.

Transfer of Rotational Energy in Collision Between Molecules. The development of jet engines and gas turbines has led to the need for fundamental research on the physical and chemical processes occurring in the gases and on methods of temperature measurements where usual procedures fail. Continuing detailed spectroscopic studies on well-controlled systems is providing basic information required in this field, as well as in chemical kinetics and in upper-atmosphere chemistry and physics.

Any chemical reaction is a complex combination—or the average of the effects produced by many different kinds of collisions between molecules—occurring both simultaneously and in sequence. The exact course of the reaction can, in principle, be predicted if the result of each type of molecular collision involved in the reaction is known. These results can be expressed as a set of transition probabilities. However, such probabilities, because they are derived from each specific state of a molecule to every other state, are difficult to calculate.

Transition probabilities are now being studied in a program sponsored by Wright Air Development Center. Electronically excited hydroxyl radicals (OH) are produced in a single rotational energy level, and transitions from this level to neighboring levels are directly observed. For the experiment, a flame is illuminated with a narrow spectral line which coincides with a single OH absorption line, producing excited molecules in the single energy level. Relative intensities of fluorescence from this and other levels populated by collisions give the data from which transition probabilities can be calculated. The data obtained so far show that rotational energy is transferred at every kinetic theory collision, and that the jumps are not restricted to the immediately adjacent levels.

Precise Molecular Structures from Microwave Spectra. The interpretation of certain molecular properties requires a very precise knowledge of the molecular structure constants. Microwave spectroscopy—in cases where it can be applied—provided a means of establishing molecular structures with a precision probably surpassing that available by other procedures. To minimize the effects of zero-point vibration on the structure, the method of "substitution" parameters is used. In this method, isotopes are

substituted for every atom in the molecule so that isotope shifts rather than the absolute values of the moments of inertia can be determined. The basic procedure, which was applied to propylene, propane, and isobutane, resulted in very precise measurements for bond distances and angles. The heights of the barriers to internal rotation of the methyl groups in these molecules were also accurately determined from their microwave spectra. For example, where tunneling effects can be directly observed—as in propylene—the barrier height can be determined with an accuracy better than one percent. Because these techniques are fairly general, they are being applied to other prototypical molecules.

Free Radicals Research Program. The three-year program of experimental and theoretical research on the properties of reactive atomic and molecular species trapped in solids was recently completed. Although the Bureau served as the central laboratory facility for the study, the program was established as a cooperative venture among government, industrial, and university laboratories with financial support from the Department of Defense. The research of the past year developed along three main lines: production and determination of concentrations of trapped species, nature of the solid containing the trapped species, and reactions of the trapped species in the solid.

Production of Trapped Radicals. Radical formation was explored by electrical discharge, thermal dissociation, ultraviolet photolysis, chemical reactions, electron and proton bombardment, gamma and X-irradiation, and thermochemical explosions. Free radicals were either formed in the gas phase and subsequently condensed on a cold surface, or formed directly in the condensed solid phase. From both the experimental and theoretical research, it was observed that mixtures of atoms and molecules may condense until certain critical conditions in the condensate are reached. Then a small explosion or ignition takes place. This ignition appears to correspond to an abrupt atom recombination in the solid, such that the atom or radical concentration in the solid always remains below a few tenths of a percent. Although this concentration is far below the value required for practical power applications, it is significant enough to make the properties of the solids unusual and interesting.

Behavior of Trapped Radicals. To study the nature of condensed gases, X-ray and electron diffraction methods were applied for the first time. X-ray studies showed that the degree of crystallinity of the condensates is very sensitive to the method and rate of deposition. In general, less crystalline order was observed if the deposit was accumulated slowly, while more order was revealed if deposition was obtained by fast condensation, or condensation after passage through an electrical discharge. These diffraction studies contributed considerable data on the mechanism of the deposition process, and on the possibilities for trapping radicals within the deposit.

The index of refraction and the dielectric constant of the condensed gases were measured for the first time. These properties were obtained by ellipsometric and capacitance techniques, respectively. Considerable em-

phasis was also placed on the spectroscopic studies of the low-temperature condensates. In general, the spectroscopic studies aided in identifying the trapped species and also in studying the nature of the interactions between the trapped radicals and the lattice.

Reactions Involving Trapped Radicals. Some of the most promising work involving the potential utilization of trapped radicals was done in low-temperature chemistry. One such investigation concerns the interactions of hydrogen atoms—formed on an incandescent tungsten ribbon—with thin films of solid olefins. Hydrogen atoms were observed to diffuse readily through the solid layers and to react with the solids. By using this approach, an excellent tool is provided for studying the details of reactions and determining activation energies of reactions that could not be obtained any other way. The stability of trapped radicals was examined by observing the electron spin resonance spectrum as a function of time. At sufficiently low temperatures, the radicals appeared to be stable in the solids for very long periods.

Primary Diesel Reference Fuel Studies. The ignition quality scale (cetane number) of diesel fuels was defined for many years in terms of hydrocarbons *n*-hexadecane and 1-methylnaphthalene. Because it was not possible, until recently, to obtain these materials in a highly pure form, impurities in the standards caused slight errors in the scale. In addition, there are serious doubts regarding the storage stability of 1-methylnaphthalene.

As part of a program to find a low-cetane primary standard to replace 1-methylnaphthalene, the compound 2,2,4,4,6,8,8-heptamethylnonane (tetraisobutane) was prepared and tested. This material has the same molecular weight as the high-cetane standard, *n*-hexadecane, and very nearly the same density. While the cetane number of tetraisobutane is higher than 1-methylnaphthalene, the two cetane-number scales may be linearly related in the useful range. Tetraisobutane, easily prepared and purified from the readily available diisobutylene, is stable in storage. Its performance in the diesel test engine at low-cetane levels is much superior to 1-methylnaphthalene. For these reasons, tetraisobutane was proposed to the American Society for Testing Materials as a possible replacement for the present, low primary-reference fuel, 1-methylnaphthalene.

2.6. ATOMIC PHYSICS

As a result of the rapid increase of effort in the fields of space exploration, missile technology, and astrophysics by government agencies and industrial laboratories, there is a greatly expanded demand on the Bureau for precise data on atomic constants, energy levels, and transition probabilities. The Bureau has established a broad research program to unify and strengthen its activities in these areas through the use of spectroscopic and ultra-high-temperature studies, crossed-beam experiments, and observations in plasma, atomic, and solid-state physics. In the solid-state work, emphasis is placed on basic research in the field of semiconductors. Increased knowledge and understanding of the microscopic and macroscopic behavior of such sub-

Strong lines in the thorium spectrum from this thorium halide lamp are used as secondary standards with which to compare wavelengths of unknown spectra. About 15,000 distinct lines have been observed and their wavelengths measured (page 61).

stances must be gained if their potentialities for technological applications are to be evaluated.

Laboratory Astrophysics. Properties of electromagnetic radiation and of particles and their interactions are studied in relation to thermodynamic equilibrium, energy levels, and collision processes.

Transition Probabilities. Knowledge of the abundance of the various elements in the sun and other stars is entirely dependent upon knowledge of the transition probabilities associated with the various lines observed in solar and stellar spectra. Data on these transition probabilities are necessary also for determinations of temperature and for evaluating departures from thermodynamic equilibrium in both stellar atmospheres and high- temperature plasmas generated in thermonuclear fusion devices.

In order to obtain the necessary data, the Bureau has established a center to gather and index all published information in the field of atomic transition probabilities. The accumulation of the necessary material has been started. Since the experimental data can be presented in several equivalent forms (transition probabilities, oscillator strengths, Einstein coefficients, lifetimes), one of the first tasks will be the reduction of all published data to a common form. It is hoped that this work will lead to publication of critically assembled tables of transition probability data.

A research program to measure transition probabilities has been started in the laboratory. The first phase of this work will utilize high-current wall-stabilized arcs. Data obtained in this way will be checked by parallel experiments utilizing direct measurements of atomic lifetimes and high-temperature plasmas generated by shock tubes.

Atomic Energy Levels. A program on atomic energy levels has already resulted in the publication of three volumes covering data on energy levels of all atoms except those in the rare earth series. Research is being concentrated presently on the collection of data on these rare earth spectra. Such analysis is extremely difficult, but considerable progress has been made through the applications of new techniques of exciting spectra and more extensive use of automatic equipment for handling the large quantity of data.

Considerable progress has already been made on the very complex spectrum of thorium; 15,000 lines have been observed and their wavelengths measured with a precision of about one part in 500,000. Other rare earth elments on which work has been started at NBS are ytterbium, cerium, praseodymium, and thulium.

Collision Cross Sections. The Bureau has undertaken a program of measurement of low-energy collision cross sections, with the objective of obtaining accurate absolute total and differential cross sections for selected processes of critical importance to astrophysics and plasma physics. Such accurate data also would be valuable in facilitating the development of theoretical methods for calculating cross sections for a wide range of collision processes.

Effort was concentrated on instrumentation for studies of electron collisions with neutral atoms and with negative ions. The cross section for inelastic collision of electrons with negative hydrogen ions is believed to be very large and to play a leading role in determining properties of the solar atmosphere. Recent high-vacuum techniques and novel detection methods were employed in these investigations. Also in progress is the development of an apparatus for measurement of elastic and inelastic collisions of electrons with atoms. Hydrogen atoms will be considered initially because of the importance of hydrogen in astrophysics and fusion physics problems and because of its critical role in the development of theory.

An elaborate calculation of the cross section for elastic scattering of electrons from hydrogen atoms has been completed. Terms describing the dis-

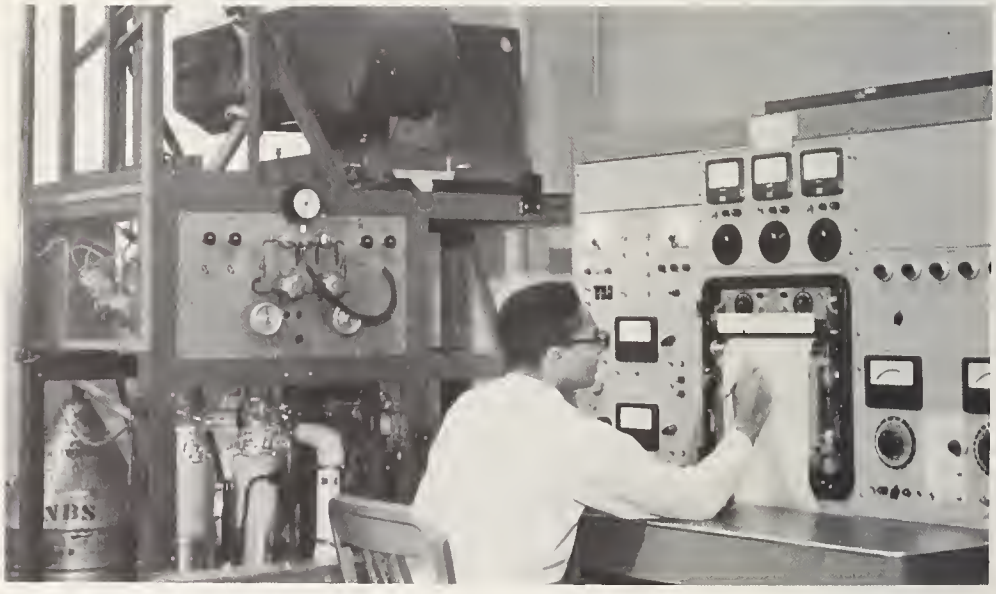
tortion of the atom by the field of the incident electron and correctly incorporating electron exchange effects have been included in the mathematics. This calculated result will be compared in detail with experimental results.

Wavelengths as Length Standards. Work is continuing on the development of better optical length standards for metrology. Three devices have been developed at the Bureau, each capable of producing relative line widths 0.06 to 0.12 as wide as that of the proposed international standard of length, Kr^{86}. Very sharp lines are absorbed or emitted in collimated beams of mercury atoms. Another device utilizes a very narrow band pass filter for radiation obtained by application of magnetic fields to mercury vapor at the resonance wavelength (2537 A) for the isotope Hg^{198} (see also 2.1, p. 29).

The wavelength of the emission line at 2537 A from a beam of Hg^{198} atoms has been measured relative to the radiation provided by a Kr^{86} lamp operated at the triple point of nitrogen. Very precise measurements have been made of the hyperfine structure of the 2537 A radiation produced by the naturally occurring mixture of mercury isotopes.

Radiometry. The emissivity of platinum from 1.5 to 15 microns has been very accurately measured. The experimental data agree closely with the calculated emissivities determined from Planck's theory on the relation between resistivity and emissivity. The emissivity of platinum is of considerable importance since the emissivities in the infrared region of other materials can be determined by intercomparison with the values for platinum. This investigation was sponsored by the Army Office of Ordnance Research.

Infrared Spectroscopy. The infrared spectra of several polyatomic molecules have been observed. In the analysis of the spectra of ethane and completely deuterated ethane, it was possible to obtain accurate molecular



Surface emission mass spectrometer used in the redetermination of the atomic weight of silver, an important physical and chemical constant which plays a key role in determining other atomic weights and fundamental constants. The chemical atomic weight derived is 107.8731±0.0020, significantly different from the accepted value of 107.880 (pages 9 and 63).

constants. The C-C distance in the ethane molecule was found to be 1.534 A. which is larger than previous values. Further work has been completed on the ammonia spectrum in the region from 3 to 4 microns. With the high resolution available, it was possible to identify several new energy levels. A number of interactions have been found between the bands in the 3- to 4-micron region.

Atomic Weight of Silver. Natural silver consists of two isotopes of mass numbers 107 and 109 in nearly equal abundance. Although the atomic weights of the two isotopes have been accurately measured by Nier, existing data on the isotopic ratio are discordant. In conjunction with a redetermination of the faraday, a new value was obtained for the atomic weight of silver. The isotopic abundance ratio was determined by the Bureau with the cooperation of the Atomic Energy Commission using a 60° surface emission mass spectrometer with a triple rhenium filament source and a 12-in. radius of curvature. A value of $Ag^{107}/Ag^{109}=1.07547\pm0.0013$ was found. When this ratio is combined with Nier's values of the mass of the isotopes, the chemical atomic weight of silver is 107.8731 ± 0.0020, significantly different from the accepted chemical value of 107.880 (see also 2.2, p. 33).

Solid-State Physics. An important contribution was made to the theory of electronic transport in high-magnetic fields. During studies of these phenomena, it was shown that divergencies can be avoided and bona fide expressions for the magneto resistance obtained by using the exact scattering solution rather than perturbation theory.

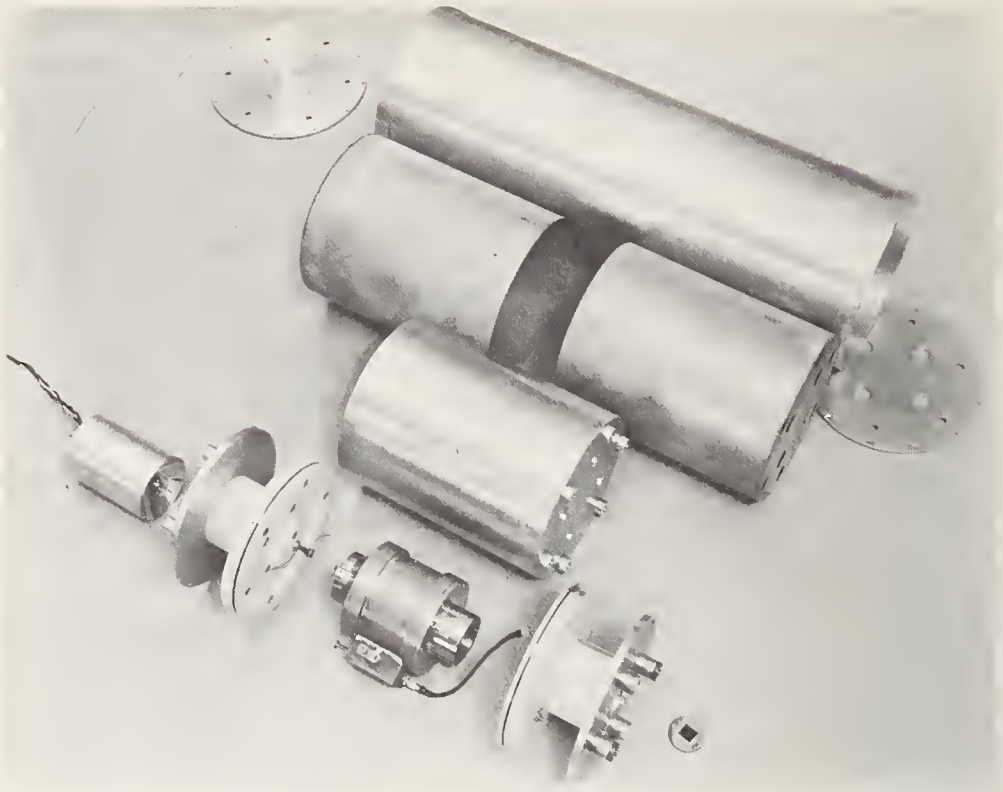
Studies of Rutile. Considerable progress has been made in the investigation of the physical properties of rutile (TiO_2). A working model of electronic behavior in this material was formulated. It can be used to explain most results on conductivity, Hall coefficient, and thermoelectric power. Conduction in this material involves the occurrence of polarons with very small binding energy. (A polaron is an electron surrounded by a cloud of induced lattice polarization.) During the last 12 years, a considerable amount of theoretical work about the polaron has appeared, but experimental verification of these theories is meager.

A start was made toward the study of magnetic susceptibility of pure and reduced rutile. A very sensitive apparatus was built which has a limit of measurement of about 10^{-9} cgs units.

Other work on rutile was concerned with investigations of the dielectric constant and losses. Investigations of these parameters as a function of frequency, temperature, and d-c bias voltage indicate that barrier layers play a dominant role in low frequency a-c measurement. The "static" dielectric constant of "pure" rutile was measured over a wide range of temperature down to 1.6 °K.

The facilities for crystal growth were extended by the construction of a flame fusion furnace to prepare simple crystals of oxides, spinels, etc.

Electron Scattering. A technique has been devised to study plural inelastic scattering. This method utilizes the discrete nature of characteris-



Expanded view of light source and gas cell package from a prototype rubidium vapor frequency standard. It will ultimately be miniaturized for a satellite flight check of the gravity-dependent frequency shift predicted by Einstein's theories. Tests indicate a stability of 1 part in 10^{11} per month, or better (pages 65 and 102).

tic energy loss events. Since at each event a known amount of energy is lost, the number of individual inelastic events experienced by a particle is uniquely determined by the total energy loss. The relative probability of one, two, or more events may therefore be determined experimentally; and the mean free path may be obtained by a multipoint fit to the Poisson distribution function. A well-known stumbling block in this procedure has always been the presence of a continuous background which distorts the relative probabilities of the multiple events. A new method of correction for this background permits consistent fits to the calculated curve and thus determination of the mean free path within a few percent.

Vacuum Ultraviolet Spectrometer. The design has been completed and the construction almost completed of a unique vacuum ultraviolet spectrometer. An instrument having a focal length of one meter and compact enough that a bakable ultra-high vacuum housing became practical, was designed using a Rowland circle mounting based on a pantograph. This arrangement maintains perfect focusing properties for all wavelengths, while permitting the entrance and exit beams to remain fixed in position. Such an instrument will be suitable to measure the optical constants of metals prepared, mounted, and studied under such conditions that no changes would occur in the surface of the specimen.

Atomic Standards of Frequency. The examination of the hyperfine and Zeeman resonances in rubidium vapor continued in order that the limits of applicability of these transitions to frequency standards development could be defined. Optical pumping techniques were applied to the study of line shapes and to the clarification of relaxation mechanisms.

The first of three prototype rubidium vapor frequency standards was operated. Ultimately to be miniaturized for a satellite flight check of the gravity-dependent frequency shift predicted by Einstein's general theory of relativity, the standard will have a volume of about one cubic foot and will weigh about fifteen pounds exclusive of power supply. Tests indicate a stability of one part in 10^{11} per month or better. Exposure to radiation at 100 roentgens per hour from a cobalt-60 source, simulating three months of exposure in the Van Allen radiation belts, produced no observable change within the measurement accuracy of $1:10^{11}$.

Sensitive apparatus was constructed for measuring stimulated emission of microwave energy from rubidium vapor. A low level of stimulated emission was detected.

2.7. RADIATION PHYSICS

The continuing increase in applications of atomic and nuclear technology to medical, industrial, and defense problems requires that research in these fields move forward at an accelerating pace. Fundamental to this advance is an increase in the knowledge of the properties of radiation. The Bureau is contributing to this knowledge through investigations of the basic character of radiation and examination of the interaction of radiation with matter.

The scope of the program and accomplishments in these areas during the past year is illustrated by the diversity of activities, which ranged from participation in the work of organizations directly concerned with human radiation protection to the development of techniques for controlling intense, high-energy electron beams. These two examples indicate the significance of the work in that radiation protection is vital to safe expansion of atomic and nuclear technology, while control of electron beams is of considerable importance for industrial and research purposes.

Standards. In the radioactivity standards program, solution standards of strontium 85 and niobium 95 have been developed; zinc 65 has been reissued as a solution standard with higher accuracy (2% as compared with 5% for the 1957 issue); cobalt 60 has been recalibrated, so that new working standards are now in use; and a method for the preparation of americium 241 alpha standards has been developed. Half-life measurements have been continued on carbon 14, sodium 22, cobalt 60, zinc 65, krypton 85, cesium-barium 137, and promethium 147. Half-life measurements were concluded on iron 59, bromine 82, strontium 85, niobium 95, and mercury 203. Work was begun on a laboratory capable of preparing low-activity standards of such nuclides as cobalt 60, thorium 92 in equilibrium, cesium-barium 137, radium 226 in equilibrium, uranium 235 and uranium 238 in equilibrium, and plutonium 239. This laboratory will be concerned

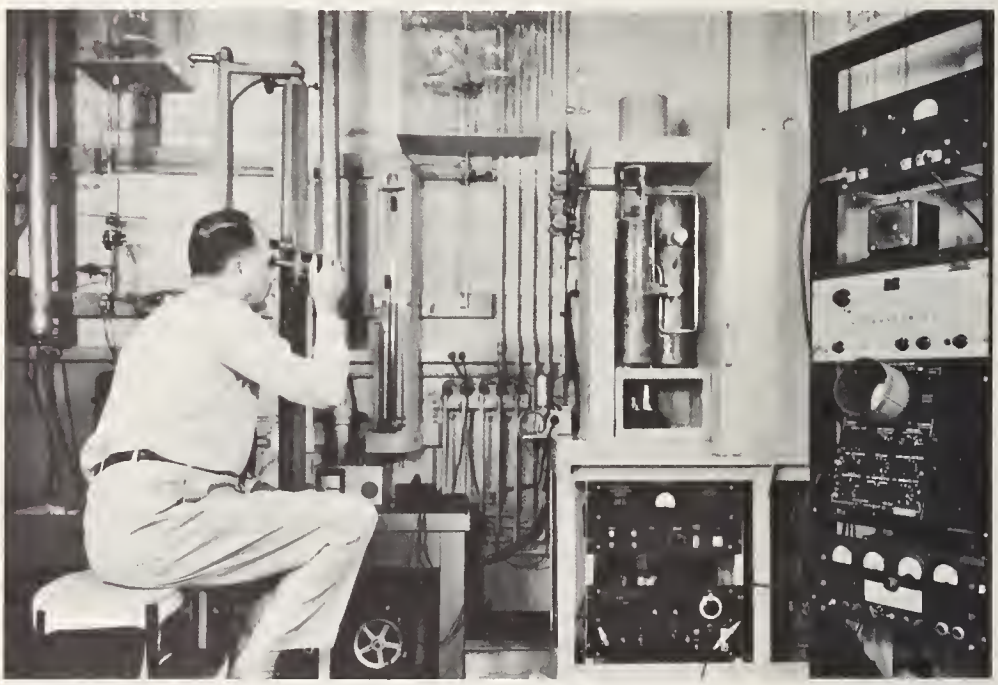
with the development of methods of radiochemical separation, assay methods, and counting equipment for the measurement of low levels of radioactivity.

Radiation Theory. The complex of research, development, and production activities in the field of atomic energy depends to a major extent on knowledge regarding the production, propagation, and effects of radiations. The Bureau is contributing to the increase of this knowledge with a program in radiation theory which provides new methods of calculation, results of specific calculations, and dissemination of data.

Cross Sections. The theoretical analysis of bremsstrahlung and pair production continued. The differential cross sections for these processes were calculated to a better approximation, and the integration of these cross sections over all angles of the final particles is now in progress. A revised table of X-ray attenuation coefficients from 10 kev to 100 Mev was published as a supplement to NBS Circular 583.

Multiple Scattering. A program was established to calculate automatically by a combination of analytical and Monte Carlo methods the multiple scattering of electrons in bounded media. Preliminary results were obtained for the back scattering from semi-infinite media.

With the support of the Defense Atomic Support Agency and the Office of Civil and Defense Mobilization, work continued on the problems of shielding from the radiation effects of nuclear weapons. Further work on the analysis of shielding by foxholes resulted in estimates of the "lip" contribution in reasonably good agreement with experimental results. Further work on blockhouses yielded estimates in good agreement with experiments.



Equipment used in redetermining the half-life of carbon 14. The improved value is important for the calibration of radiation-measuring devices in chemistry, biochemistry, and industry (page 65).

Digital computer programs prepared in previous years were used to extend basic moment data to include protective shields of iron and to extend basic shielding graphs to include penetration in concrete and air barriers by Co^{60}, Cs^{137}, and average fission spectrum sources. There has been further progress toward devising engineering rules for estimating structure shielding, particularly in regard to maze-type geometries and heavy, multistory buildings.

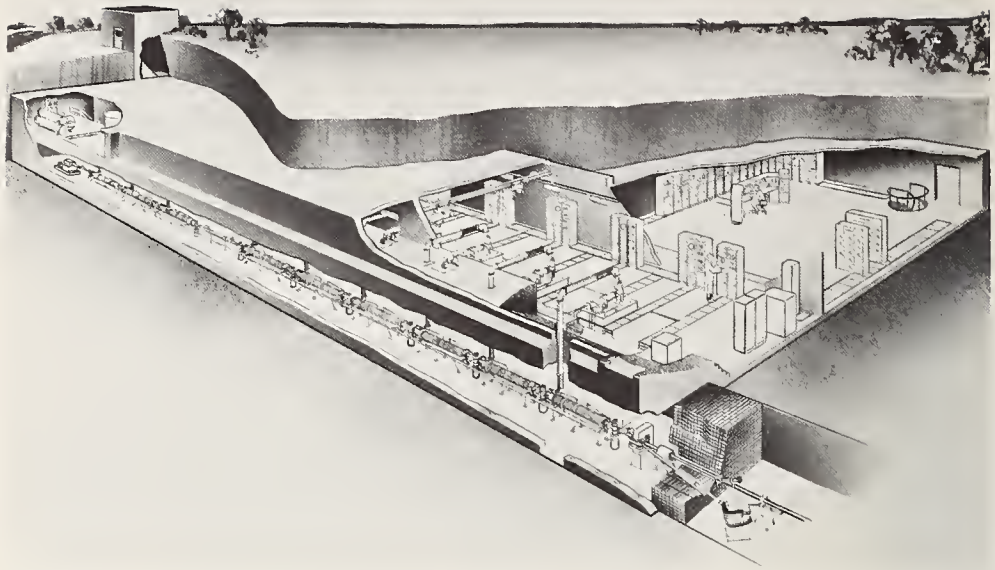
Radiation Protection. Research on the fundamental properties of radiation and on radiation standards has placed the Bureau in a unique position to translate the latest information in this field into practical working codes for radiation protection. The Bureau has assisted in the dissemination of this information by publishing as NBS handbooks the recommendations of the National Committee on Radiation Protection and Measurements. Staff members have been very active in the work of the National Committee on Radiation Protection and Measurements, the International Commission on Radiological Units and Measurements, and the International Commission on Radiological Protection. These groups have formulated recommendations which represent the best scientific thinking in the broad area of radiation protection and units. A number of new or revised handbooks are nearing completion.

X-Ray Studies. As the country's primary radiation standardization laboratory, the Bureau provides basic information for the calibration of X- and gamma-ray measuring instruments.

Ion-Pair Production. Four experiments were completed on measurement of the energy required to produce an ion pair. This energy measurement is a conversion factor for the determination from ionization measurements of energy absorbed. Techniques used in one of these experiments led to a new method for determining electron attachment time. An experimental arrangement is being constructed which will make possible a comparison of the slow and fast methods of ionization collection so that differences in results obtained by the two methods can be resolved. This arrangement will also make possible a determination of the dependence of ion-pair production on alpha particle energy.

Intercomparison of Standards. International intercomparisons of X-ray standards have been made with a number of countries. Direct intercomparisons with the standards of Canada have been completed, and indirect intercomparisons by means of transfer instruments have either been completed or are underway with the standards of France, the United Kingdom, Germany, New Zealand, and Australia.

Linear Polarization. A comprehensive study was completed of X-ray linear polarization using the Bureau's low-energy electron accelerators operating in the 0.05 to 1.0 Mev region. The quantitive behavior of the linear polarization is given as a function of the incident electron energy from 0.05 to 1,000 Mev for various photon energies and emission angles and for thin targets of both low- and high-atomic numbers. A comprehensive survey of bremsstrahlung cross sections over this same energy region was also published.



High intensity accelerator now being designed for the Bureau's new laboratories in Gaithersburg, Maryland. The accelerator will produce one of the world's most intense electron beams, with energies continuously variable from 10 to 100 million electron volts (page 68). (Drawing supplied by High Voltage Engineering Corp.)

Radioactivity. The increasing demands for precision radioactivity standards and for techniques of radioactive metrology require that the details of the dynamics of the disintegration process be known. Such quantities as energies, intensities, angular momenta, and polarization properties of the radiations are being studied and correlated with the properties of the nuclear energy levels involved

Beta Decay. The Bureau is presently using the results of investigations which led to the experimental discovery of the nonconservation of parity to investigate polarization effects in nuclear beta decay. These investigations led, in turn, to the determination of nuclear matrix elements for beta decay. Extensive measurements of certain rare earth radioactivities were begun, with those on cesium 141 and neodymium 147 being essentially completed.

Linear Electron Accelerator. Economical and efficient use of nuclear radiations in many industrial and medical applications requires understanding of the fundamental interactions of these radiations with matter and development of the most precise standardized measurement techniques. To extend the Bureau's research programs in nuclear and radiation physics, Congress has provided funds for a high-intensity linear electron accelerator, for the design of a high-power neutron reactor, and for the housing of a high-current, variable-energy cyclotron for protons and deuterons.

The laboratory for the linear accelerator was designed to provide shielding against the radiation from an electron beam that will be among the most intense in the world and about 100,000 times more intense than those available in present Bureau accelerators. The design provides for directing this

intense electron beam into any one of three experiment rooms located, as the accelerator itself will be, 40 ft below ground level and separated by concrete walls 12 ft thick. This beam switching arrangement will provide considerable flexibility for conducting a wide variety of experiments.

In connection with this design effort, two staff members participated in experiments at other laboratories having linear accelerators. In these investigations, studies were made of the resonance fluorescence of nuclear levels, the annihilation of 10–Mev positrons in flight, and the inelastic scattering of 80–140–Mev electrons by the carbon nucleus.

High-Energy Radiation. Some of the significant results obtained in the study of the basic interactions of radiation with matter (particularly the measurement techniques developed) will be directly applicable to the medical and industrial uses of high-energy X-rays. Other results have increased considerably the understanding of some of the basic interactions of high-energy X-rays with matter.

In research employing the Bureau's 50–Mev betatron and 180–Mev synchrotron and supported by the Atomic Energy Commission, measurement techniques were developed which provide more accurate information on the standardization of high-energy X-ray intensities, the measurement of absorbed doses, and the measurement of accelerator magnetic fields.

Measurement and Standardization. A portable instrument for measuring the absolute intensities of X-rays up to 180–Mev was calibrated by the NBS standard intensity calorimeter. This portable instrument was then used to calibrate portable instruments in four European laboratories in a program supported by the World Health Organization.

An improvement in the technology of absorbed dose measurements was brought about by the development of a dose calorimeter with increased stability and sensitivity. This instrument has been used to measure to an accuracy of 5 percent a dose as low as 500 rads supplied at a rate of 1 rad per second.

An electron spin resonance detector was developed for the measurement of magnetic fields which vary with space and time. This detector can measure a 3,000-gauss magnetic field to an accuracy of 3 gauss.

Nuclear Studies. In work supported by the Atomic Energy Commission, an accurate method for measuring nuclear radii and the shape of nuclear matter distributions was developed from the detailed computer analyses of experimental data on the angular distributions of neutral photomesons. The cross sections for neutron production and for nuclear elastic scattering of X-rays at 90° were determined for holmium and erbium. The neutron cross sections are essentially identical and show clearly the splitting of the giant resonance resulting from the large intrinsic deformations of these nuclei. Considerable progress was made toward understanding the theoretical relation of these two cross sections. Information gained from analyses of these data is valuable in determining the shape and structure of these nuclei.

Gamma- and X-ray Calibration. Radiation sources for industrial, medical, and military purposes and for instruments for measuring the radiation from these sources must be properly calibrated. Investigations of radiation effects on materials greatly increased the range of dose rates required and thus the need for extended or new dosimetry procedures.

Increasing interest in higher gamma-ray dose rates led to the procurement of a 1,000-curie Co^{60} gamma-ray beam device and a similar facility with 2,000 curies of Cs^{137}. The Co^{60} source has been installed and calibrated during the past year.

Medical applications of radioactive nuclide gamma-ray sources continue to employ the activity of the nuclide as an indication of the effectiveness of the source. However, the fact that such sources must be encapsulated means that this measurement will be erroneous unless the effects of the capsule walls on the source output are known. This requirement led to an investigation of the parameters needed to determine wall corrections for radium standards. Experimental and theoretical studies of the corrections for different wall thickness, capsule diameter, and material were made and the effects of these parameters were evaluated.

Surveying the radiation field around a calibrated cobalt-60 source (encapsulated in the lucite cylinder at the center) which is used to expose dental-size film packets. The film packets are ordinarily used to measure total radiation exposure of workers in hazardous areas (page 71).

Dosimetry. Photographic dosimeters for total exposure measurements, although simple and rugged, lack certain desirable characteristics. An investigation with the support of the Atomic Energy Commission was therefore made of the basic phenomena governing the response of photographic emulsions to high-energy electromagnetic and corpuscular radiation.

In an effort to learn more about photographic reversal effects with X-radiation, reversal effects of visible light were studied with particular attention given to the Herschel effect (red-light exposure following white-light exposure and erasing some of the effect of the white light). These studies led to a greater understanding of reversal effects in general.

Studies of neutron sensitivity of photographic emulsions were continued. Order-of-magnitude agreement was obtained between theoretical and experimental determinations of thermal neutron sensitivity of one film type. Studies of fast neutron sensitivity were completed and indicate that the relative fast-neutron-to-gamma-ray sensitivities were in the ratio of the reciprocal of the grain diameters of the particular film types.

A study was conducted of the influence of relative humidity and temperature on the optical density of a film type exposed to gamma rays over periods of 1 to 3 months. Film samples were exposed to cobalt-60 gamma radiation while subject to the Washington, D.C., climatic changes from August through November. Much of the data were too erratic for interpretation, probably because of the influence on the film of both extreme heat and very high relative humidity. A laboratory experiment with more precise control of humidity and temperature is now under way.

Work on solid-state dosimetry continued with the completion of the investigation of the photovoltaic effect produced by X- and gamma rays in silicon solar cells as a function of exposure dose rate, cell temperature, angle of incidence of radiation, and photon energy. Work is now under way on an examination of the response of silicon solar cells to high-energy gamma rays at high exposure dose rates, with special consideration of the influence of radiation damage on the response characteristics of such cells.

Neutron Physics. In research supported by the Atomic Energy Commission and the Defense Atomic Support Agency, the Bureau is conducting fundamental experiments on neutron penetration and neutron cross sections. This research provides information important for the protection of personnel, for investigation of the interaction of radiation with materials, and for understanding nuclear structure.

The NBS standard thermal neutron flux geometry was recalibrated in terms of the thermal neutron absorption cross section of gold by activating thin gold foils in the thermal flux and then measuring their absolute activity. The activity was determined by counting the coincident beta particles and gamma rays from the gold decay in a 4π geometry. This method of measuring absolute activity obviates knowledge of such things as the actual probability for detection of either the beta particles or the gamma rays. This new calibration reduced the uncertainty in the value of the thermal flux from about 2 to 1 percent.

Apparatus necessary for performing three other neutron experiments was completed. These experiments include a study of the polarization of neutrons of about 3 to 4 Mev energy, measurement of fast neutron dose from a D(d, n) source in water with a calibrated dosimeter, and measurement of neutron elastic and inelastic scattering in calcium in the energy range from 12 to 18 Mev.

2.8. CHEMISTRY

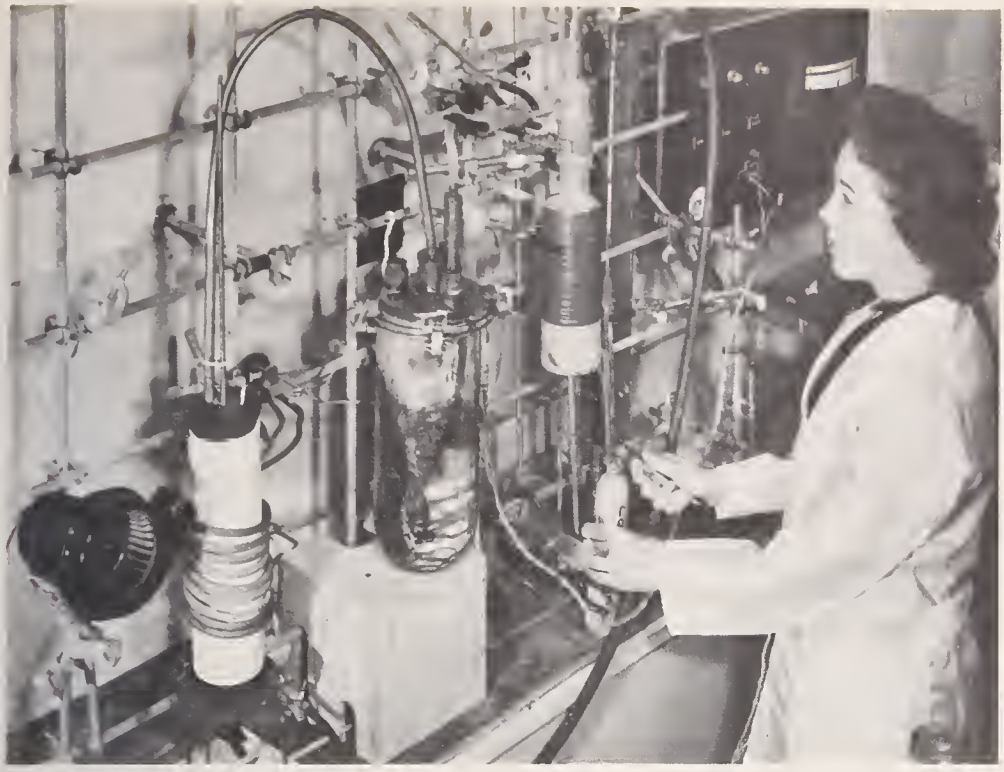
The Bureau develops and improves methods for the measurement of the chemical properties, composition, and behavior of substances; prepares standard substances of known composition or properties; makes accurate measurements and collects data on chemical systems; studies the properties of molecules and atoms in their relation to chemical reactions; maintains competence in specialized areas of modern chemistry; and provides technical and advisory services pertinent to its responsibilities.

The special investigations pursued during the past year in inorganic, analytical, organic, and physical chemistry included studies of new methods for chemical analysis by emission and absorption spectroscopy as well as by conventional chemical means. Substances of high purity were prepared and criteria developed for measuring purity. Chemical constants and thermochemical data were determined, while the mechanisms of organic reactions and photochemical processes and the electrochemical phenomena at electrodes and membranes and in ionic solutions were studied. Radioactively labeled sugars as well as composition standard samples, standard thickness samples for electroplated coatings, and standard gas mixtures were produced and certified.

Deposition of High-Purity Tungsten. Technological developments in the space age require materials which can withstand high temperatures and maintain a measure of structural strength at the same time. Among the small number of applicable materials, tungsten is unique, as it has the highest melting point of all the metals (3,400 °C, 6,120 °F). However, until lately, the high-temperature properties of tungsten could not be effectively utilized. Its brittleness and hardness prevented it from being machined by conventional methods while its weight restricted its uses in aeronautical equipment. For these reasons, efforts were made to develop a practical method for depositing tungsten coatings.

As a result of this work, high-purity tungsten can now be easily plated on metal surfaces by using a vapor deposition process developed independently by the Bureau, under Navy sponsorship, and by the Bureau of Mines. The method involves reducing gaseous tungsten hexafluoride with hydrogen by passing it over the heated object to be plated. At temperatures above 300 °C, tungsten is deposited on the hot surface, and the only other reaction product, hydrogen fluoride, passes out with the excess of hydrogen.

With this method pure tungsten coatings with thicknesses up to $\frac{1}{8}$ in. can be deposited in a fairly smooth condition. It is possible to coat a variety



A recently developed method for plating objects with tungsten has overcome many of the difficulties involved in using tungsten in high temperature engineering. Tungsten is an ideal material for high temperature applications because of its extremely high melting point, but its brittleness has prevented its machining into desired shapes (page 72).

of metals and ceramic surfaces such as rocket and missile nozzles and jet engine parts. Since a thick coating can be formed, this technique also lends itself to the fabrication of tungsten articles, and this may be the only way that complicated shapes of tungsten can be formed.

Tube Plating Devices. The development of an electronic thickness gage for measuring the thickness of chromium inside gun-tube bores has made possible a rigid inspection of internally plated tubes. Since tube-plating fixtures of standard design yield large circumferential variations in plate thickness, the Bureau, under sponsorship of the Army, designed fixtures which would be easier to assemble, give longer life, and result in improved plate concentricity.

Thermochemical Properties of Boron Oxides. In the combustion of certain high-energy fuels now used in advanced aircraft and rockets, boric oxides and metaboric acids are formed. Because data on the heats and free energies of formation of the combustion products of boron-containing fuels are essential to the proper evaluation of these fuels, recent studies were conducted for the Wright Air Development Center.

Three crystalline forms of metaboric acid with slightly different energies exist. Methods for the preparation of all three forms in quantities of 50 to 100 g were developed, and flotation procedures for the rapid identification

of orthoboric acid and the metaboric acids were devised. The heats of formation of the metaboric acids were then derived from calorimetric measurements of the amount of heat evolved or absorbed when the crystalline acids were dissolved in water or were neutralized with a solution of sodium hydroxide. The data obtained are of considerable theoretical as well as practical interest.

Radiation-Induced Chemical Reactions. Information on elementary reactions is necessary in order to understand more complex phenomena such as oxidations and thermal decompositions. Thus a demand has arisen for the systematic identification of elementary processes occurring when radiation and matter interact and of secondary chemical processes induced by radiation with ultraviolet and gamma rays. In a program jointly sponsored by the Atomic Energy Commission and the National Institutes of Health, research is being conducted on systems consisting of both vapor and liquid-solid phases. In addition to providing important data on kinetic parameters, these experiments have yielded valuable information on the importance of ion-molecule reactions, the behavior of radicals in the gamma-ray track, and the state of the excited molecules involved in intramolecular rearrangements. The use of deuterium-labeled compounds has greatly simplified the interpretation of the data. The results of experiments on esters, ketones, and hydrocarbons indicate that the dissociative processes in photolysis and radiolysis both involve electronically excited molecules. The stabilities of several carbonyl radicals have been redetermined and the new values should aid in evaluating alternative tables of bond strengths.

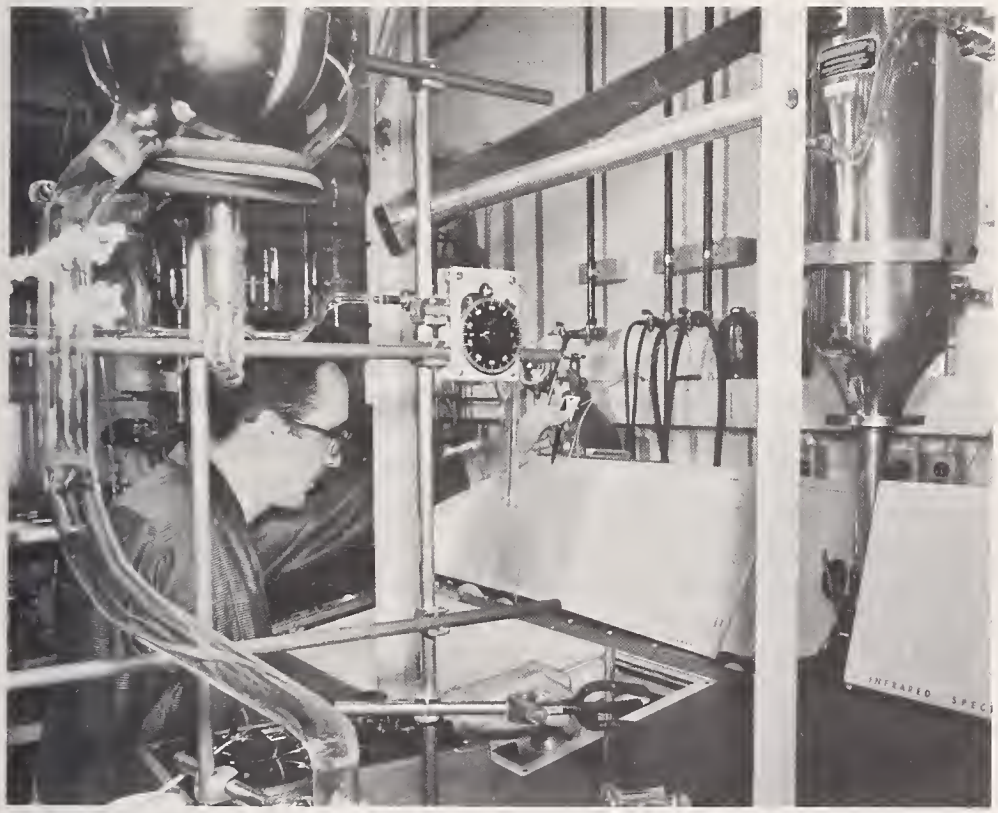
Nuclear Magnetic Resonance Studies. Nuclear magnetic resonance is now being used to probe the subtleties of molecular structure. The extreme sensitivity of the technique to the nature of the molecular environment permits study of details of molecular structure and interactions entirely inaccessible by other methods.

During the past year, high-resolution studies of diethyl- and di-*n*-butyl sulfites and of 0,0-diethylmethylphosphonothioate have revealed new features of the bonding of the alkoxy groups to sulfur and phosphorus. The patterns of the spectra and the differences in nuclear resonance parameters demonstrated the nonequivalence of the alkoxy groups in each class of esters. A fundamental dissymmetry of the structures of molecules which contain the same type of bonding orbitals appears to cause this anomalous behavior. When the syn-anti isomerism of several aliphatic ketoximes and ketoxime ethers was studied, simultaneous existence of two forms was found for several unsymmetrical ketoximes as well as for their ions formed in solutions containing an acid or base. This discovery suggests that the technique of nuclear magnetic resonance may find an important application in monitoring the degree of separation of isomeric mixtures.

Isotope Effects in Tracer Studies. With radioactive isotopes substituted for an atom or in a molecule, the course of a substance can be traced through an entire series of complex chemical processes. However, because

an isotope often acts differently from the normal atom, the validity of conclusions drawn from such experiments depends on a knowledge of the behavior of the isotopic atom compared with that of the normal atom. Any difference between the behavior of the isotopic atom and that of the normal atom is called an isotope effect. As part of a continuing program—sponsored by the Atomic Energy Commission—to synthesize and use labeled sugars and sugar derivatives, the Bureau is studying numerous isotopic reactions. For example, isotope effects were reported to occur in the crystallization of D-glucose-*l-t*. Such an effect, if present in the crystallization process, would invalidate certain methods of analysis used in tracer studies. When the reaction was carefully examined, no isotope effect was found to exist.

A technique was devised for studying isotope effects by labeling one of the carbon atoms of the reacting substance with carbon 14 and one of the hydrogen atoms with tritium. Any isotope effect during the reaction is determined by a change in the C^{14}/H^3 ratio. This technique was applied to the oxidation of D-glucose with bromine and with chlorous acid. In both reactions, oxidation is accompanied by a large isotope effect. It appears that the carbon-tritium bond is broken during the rate-determining step. In the clorous acid reaction, the rate-determining step in the chlorous acid



Apparatus used to detect unstable species produced by photochemical reactions at low temperatures. Information on the processes occurring when radiation and matter interact often aid in understanding more complex phenomena such as oxidations and thermal decompositions (page 74).

oxidation had formerly been considered to involve formation of the open-chain sugar. No rupture of the carbon-tritium bond would have occurred if such a formation existed. Thus, the test proves that the earlier concept of the reaction mechanism is not valid. Other mechanisms are now being tested.

Barium Titanate Semiconductors. Addition and detection of precisely predictable quantities of known activators are necessary for the study of high-purity materials. Two important results have been achieved in this area during the past year. First, rare-earth elements can now be added during the precipitation of barium titanyl oxalate. By controlling the precipitation procedure very closely, a predictable amount of rare earth can be incorporated in the product. Second, the rare earths in barium titanate can be separated and analyzed. By this procedure rare earths in the range of 0.01 and 0.1 mole percent can be determined with an accuracy of 2 to 4 percent of the actual amount present. In general, the method involves liquid-liquid extraction with various organic reagents at different *p*H values and the subsequent colorimetric determination of the rare-earth element.

Separation of Titanium, Zirconium, Iron, and Aluminum. The continuing expansion of high-temperature and nuclear technology constantly requires new materials to serve as standards of composition. This, in turn, necessitates the continuing development of new or improved analytical methods. A new system of analytical chemistry was devised for separating and determining titanium, zirconium, iron, and aluminum in solutions containing the four metals. Through the use of the reagents 1-nitroso-2-naphthol, 8-hydroxyquinoline, ethylenediaminetetraacetic acid, and cupferron under conditions of controlled acidity or alkalinity, extremely sharp separations could be obtained of these otherwise difficultly separable elements. Designed originally for analyzing barium titanate ceramic dielectrics, the method is applicable to a wide range of analytical problems.

Water-Vapor Detector. Minute quantities of water vapor in compressed gases have presented a serious problem for many years. With the increasing complexity of pneumatic control systems and other components requiring dry gaseous atmospheres, it has become extremely important to measure the exact water content of these gases. Although several methods for determining the dryness of gases are available, the agreement among the various methods is not sufficient to allow complete confidence in the results obtained.

At the request of the Navy Department, a simple, accurate water-vapor detector—similar to one previously developed at the Bureau—was designed and built for operation at pressures up to 6,000 psi. This detector, which is now being used as a calibration instrument for comparing other types of water-vapor detection, can determine exceedingly small amounts of water in a concentration and pressure range where other instruments are inadequate.

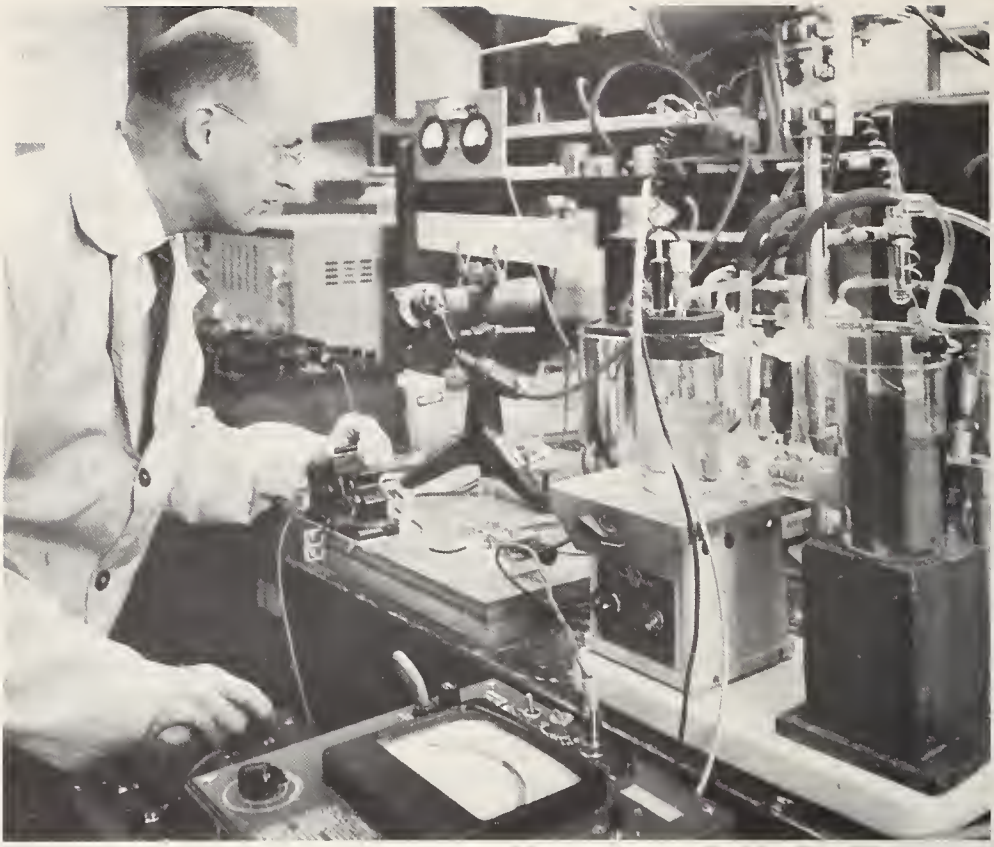
The instrument contains a pressurized saturator which serves as a source of gas of known water content. This saturator can be operated over a range of pressures to produce a wide range of water concentration. Thus, in principle, the water content of gases is determined by comparing the electrical conductivity of a hygroscopic film—which is in equilibrium with the water in the gas to be analyzed—with the conductivity of the same film exposed to a gas of known water content.

As part of this program, a frost-point chart was compiled giving the theoretical frost points of compressed gases at pressures from 1 to 400 atm (6,000 psi) and at temperatures from 70 to −200 °F.

Determination of Minor Elements by X-Ray Fluorescence. Because X-ray fluorescence provides somewhat greater precision in determining major constituents of materials than does optical emission analysis, an investgation was made to extend X-ray analysis to low concentrations. The X-ray spectrometer used in these experiments contains 15 fixed spectrometers and an adjustable spectrometer unit which can measure 10 elements simultaneously. In this study, detection limits and interferences were examined for 20 elements: Arsenic, cobalt, chromium, copper, germanium, manganese, molybdenum, niobium, nickel, lead, sulfur, selenium, silicon, silver, tin, tantalum, titanium, vanadium, tungsten, and zirconium. For most of the elements, the detection limit is below 0.01 percent, which is sufficient for control analysis. Interferences or interelement effects in low-alloy steel, although encountered, were not found to be serious. It was shown that the Bureau spectrographic standards of low-alloy steels in disk form are well suited for calibrating the X-ray spectrometer used in determining most of the elements investigated.

Coulometric Titrations. A coulometric analytical method and a coulometric-titration coulometer—each providing a precision of a few parts in 100,000 for analyzing acids and bases—were developed. These tools for electroanalysis were designed for use in establishing the purity of chemical standards and reference materials. The method is based upon the exact relationship between the amount of electricity used in an electrolysis and the amount of chemical reaction produced. In the case of an acid, for example, hydrogen ion is reduced at the cathode of an electrolysis cell, liberating hydrogen gas, until all of the acid has been neutralized. The number of equivalents of acid originally present is found by dividing the amount of current required by the faraday constant. Analytical results, based entirely on electrical measurements, equal or exceed those of the more laborious classical analytical procedures.

Primary Standards of Nitrogen, Phosphorus, Potassium. Because nitrogen, phosphorus, and potassium are essential elements in agricultural fertilizers, reliable methods and standards are essential for their determination. The use of highly purified ammonium and potassium hydrogen phosphate as primary standards depends on the ability to analyze these highly purified substances for the elements concerned. Because of the circuitous route involved in the usual analysis for nitrogen, it is difficult to determine the ammonia with an accuracy greater than 1 part in 1,000.



Coulometric titration apparatus capable of analyzing and evaluating chemical standards and reference materials with a precision of 1 part in 100,000 (page 77).

However, a new method was devised in which the ammonia is distilled into hydrobromic acid, after which the solution is evaporated at 60 °C to eliminate water and excess hydrobromic acid. The resulting residue is weighed as ammonium bromide. Determinations of nitrogen in single-crystal ammonium dihydrogen phosphate gave results indicating an accuracy of 1 part in about 15,000. The percentage of phosphate was established with an accuracy of about 1 part in 8,000. Work on potassium dihydrogen phosphate, expected to yield a standard for potassium, is still in progress.

Metal-Organic Standard Samples. For many years chemists in the petroleum industry have needed accurate standard samples for determining metals in petroleum products. From the spectrographic determination of the metals that accumulate in crankcase oils, engineers can judge engine wear and anticipate trouble prior to engine failure. The method requires standard samples containing known quantities of the elements in question. Determination of metallic constituents in petroleum products is also highly important in refining processes and in the use and control of materials added to oils to improve lubricating properties.

A set of 24 standard samples of metal-organic compounds suitable for spectrographic and chemical analysis of petroleum products, is now available. These stable, oil-soluble substances are the result of 3 years of research and

development conducted for the American Petroleum Institute. Standards containing the following elements are now available: Aluminum, barium, boron, cadmium, calcium, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, mercury, nickel, phosphorous, potassium, silicon, silver, sodium, strontium, tin, vanadium, and zinc. All except six of these elements are incorporated in the form of the metal salt of cyclohexanebutyric acid. The other elements are dispensed as menthyl borate, *tris*(*O*-hydroxyacetophenone) chromium III, triphenyl phosphate, octaphenylcyclotetrasiloxane, dibutyltin *bis*(2-ethylhexoate), and *bis*(benzoylacetonate)-oxovanadium IV.

2.9. MINERAL PRODUCTS

To provide basic information on a wide variety of inorganic, nonmetallic substances, the Bureau conducts a two-fold program. One aim of this program is to obtain precise values of specific constants and fundamental data that are important to the scientific community. Related standard samples and information on engineering research are developed as required. A second aim is to devise techniques for preparing materials and measuring their properties under carefully controlled conditions. This work includes the extension of physical property measurements to the extremes of high and low temperature, to high pressures, and into the realm of very pure substances. Methods are now being developed for producing very pure materials and for growing single crystals of controlled purity and crystalline perfection.

Crystal Growth. Many important advances in the chemistry and physics of the solid state have arisen from studies of pure single crystals. Consequently, in every branch of research concerned with the solid state, there is a persistent and increasing demand for single crystals of controlled purity and perfection. However, except for a few substances, large single crystals of high-melting substances are not generally available. Therefore, the Bureau is developing techniques for growing well-characterized single crystals of nonmetallic, inorganic substances. Resulting studies include research on growth of such refractory oxide crystals as aluminum oxide (Al_2O_3), titanium dioxide (TiO_2), and other titanates.

The Verneuil technique is being used to produce TiO_2 crystals with the unique crystallographic direction both parallel and perpendicular to the direction of growth of the crystal. Studies were initiated to replace the flame as a heat source in this technique and to determine the effect of the atmosphere surrounding the growing crystal on the perfection of the crystal.

To investigate imperfections in crystals, Al_2O_3 single-crystals containing a few percent TiO_2 (star sapphire) were annealed at about 1,500 °C in air. It was found that the TiO_2 precipitate moved from the interior into protrusions on the surface. These protrusions appeared to decorate scratches on the surface, as if they marked the ends of dislocation lines intersecting the surface. At the same time, complicated interactions developed between

these protrusions and steps on the surface apparently generated by thermal etching. Work on this behavior is leading toward a better understanding of the properties of the crystals.

Elastic Properties of Oxide Single Crystals. The mechanical properties of refractory oxides at elevated temperature have recently received increased attention. In particular, knowledge of the way in which materials respond to stress and temperatures is necessary to develop suitable substances and components for high-temperature, high-pressure applications. Recently, advances were made in relating the anelastic and creep behavior of refractory oxides with specific structural defects. The elastic constants of pure and highly perfect single crystals vary with temperature as a result of anharmonic terms in the potential energy. Although no satisfactory quantitative theory exists as yet, the Bureau has developed an apparently general empirical equation that accurately describes much of the data. Equipment was constructed for measuring changes in Young's modulus of elasticity with a precision of 1 part in 10,000 over the temperature range 77 to 850 °K. Measurements have been made on single-crystal aluminum oxide and on polycrystalline aluminum oxide and thorium oxide. In each case the results fit the generalized equation. Measurements on other materials are in progress to investigate the range of validity of this equation.

Surface of a heat treated aluminum oxide single crystal containing a few percent of star sapphire (TiO_2). The sapphire can be seen as needle-like particles within the protrusions, which form on the surface during annealing. Such imperfections are important factors in the physical behavior of the crystal (page 79).

Low-Temperature X-ray Diffraction. Present knowledge of the crystal structure of some of the most common low-temperature solids is seriously inadequate. Although it is comparatively easy to obtain data at 4.2, 20, and 77 °K—temperatures corresponding to the boiling points of helium, hydrogen, and nitrogen respectively—it is more difficult to maintain intermediate temperatures for as short a time as the minimum 3-hour period required to obtain complete X-ray data. Moreover, the study of elements or compounds which are gaseous at room temperature is complicated because the samples tend to evaporate during an experiment even at comparatively low temperatures.

To enable more detailed X-ray diffraction studies of low-temperature solids,

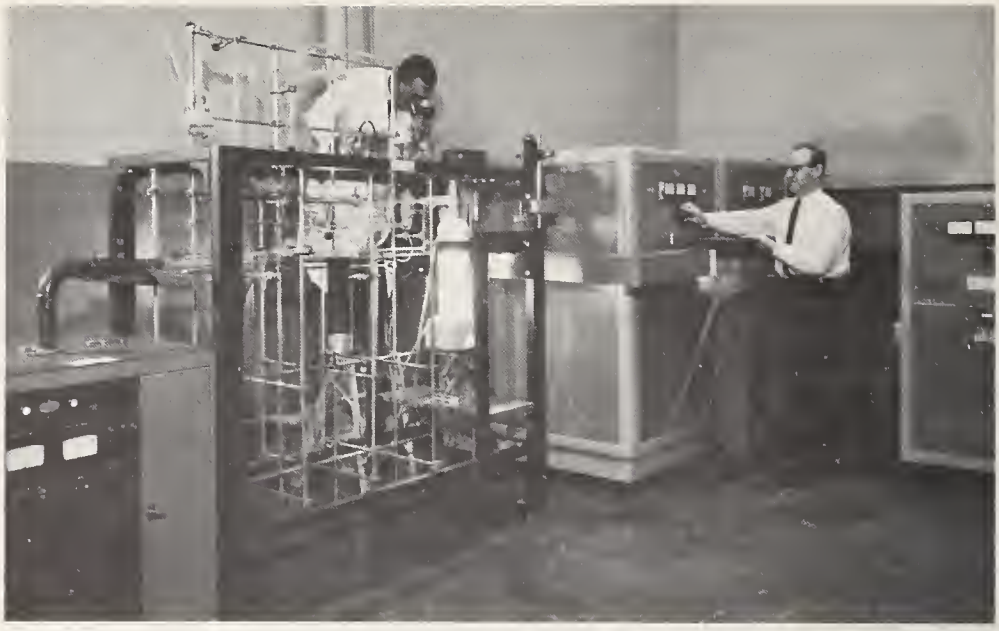
a previously developed X-ray specimen cryostat was extensively modified as part of a program for the Department of the Army. Now the temperature of the specimen in the range of 4 to 300 °K can be controlled within 0.1 °K and, in addition, the specimens can be prepared and annealed under controlled pressure to prevent evaporation. Thus, complete X-ray patterns can be obtained on certain phases which exist only at low temperatures and over a narrow range. Measurements of the lattice constants and thermal expansions of the "noble gas" elements were completed using the new apparatus.

Future plans include the study of polymorphism in solid oxygen and the investigation of any structural changes associated with the specific heat anomaly preceding the α-β transformation in solid nitrogen.

Phosphate Crystal Structures. Progress was made toward further understanding of the phosphate chemistry in solids by determining the structure of α-$Na_3P_3O_9 \cdot 4H_2O$. This is the first meta phosphate on which a detailed structure analysis has been made. High-speed automatic computation aided in precise placement of the ions.

Ferroelectric Materials. Recent studies on complex titanate systems have revealed the presence of ferroelectricity in compounds of the approximate composition $Ba_6(Nb_8Zr_2)O_{30}$, which exhibit X-ray powder patterns very similar to those shown by the alkali tungsten bronzes such as $K_6W_{10}O_{30}$. These ferroelectric compounds were found to be very tolerant of replacement of the ions present, while at the same time maintaining their ferroelectric nature. In particular, it is possible to replace some of the barium ions present with rare earth ions and the zirconium with a combination of niobium and iron. In this way, compounds can be formed whose composition is expressed by $(Ba_{6-2x}R_{2x})\ (Nb_{9-x}Fe_x)\ O_{30}$, where x ranges from 0.7 to 1.0 and R denotes the rare earths: Neodymium, samarium, europium, or gadolinium. These replacements introduce magnetic ions into the structure, and some compositions were found which show both ferroelectric and ferrimagnetic properties in the same ceramic body. Because of the possible formation of $BaFe_{12}O_{19}$, a known ferrimagnetic compound, it is not yet certain whether both the ferroelectricity and the ferrimagnetism are to be associated with the same crystallographic phase.

Ion Exchange Properties of Clays. The physical and chemical nature of the surfaces of clays are of fundamental importance in understanding the properties of systems containing these materials. In an effort to determine the role of surface area in controlling the chemical properties of clays, area and ion-exchange studies were made of several natural clays of variable crystallinity. These clays were of relatively simple chemical composition, and were practically monomineralic. On the basis of X-ray studies, it was felt that the poorly crystalline samples might contain structural defects which could account for their relatively high ion-exchange capacity. Results obtained indicate that the chemical reactivity of simple kaolinitic clays may be attributed to surface effects and is not dependent upon internal structural defects (isomorphism).



Inductively heated vacuum microbalance used for measurements of rates of vaporization of refractory materials. Quartz beam microbalance is contained in the rectangular box above the growing furnace chamber. Specimens have been studied up to 2,500 °C with this apparatus (page 84).

Standard Glass for Measurement of Physical Properties. When a laboratory designs and constructs equipment for measuring a given property, a few determinations are usually made on a standard material to establish the limits of accuracy. At present, there is a need for many types of standard glasses of known chemical composition and with measured properties. These glasses would be used for calibrating instruments which measure viscosity, surface tension, or other properties of glasses at various temperatures—especially at elevated temperatures. In addition, a series of simple two- and three-component glasses could be used by a number of participating laboratories in studies of properties that can yield information on the structure and constitution of glass. Therefore, the Bureau is continuing to develop standard samples of glass.

The properties of a soda-lime-silica glass are now being measured. Viscosity measurement were made at intermediate and elevated temperatures. Apparatus to measure surface tension at elevated temperatures is now being constructed.

A second standard glass, a lead-type glass of optical quality, is being obtained and will undergo the same precise measurements of its physical properties as the soda-lime-silica glass. A third multicomponent glass will probably be selected as a standard before work is started on the high-purity simple glasses.

Interatomic Bonding in Glasses. A familiar concept of the molecular structure of silicate and other inorganic oxide glasses is that of an extensive three-dimensional network of atoms interconnected by bonds of mixed ionic and covalent nature. Extensive continuity of some kind of interatomic bond-

ing is consistent with existing knowledge of certain other types of glass-forming substances. An outstanding example is the network, or polymeric, structure that is known to exist in organic polymers, which are often vitreous in their plastic form. Because it is not known whether glass formation is necessarily associated with some type of extensive continuity of interatomic bonding, the Bureau is attempting to determine this relationship by using kinetics of vaporization processes from glasses.

Measurements on arsenic oxide and arsenic sulfide glasses show that these glasses have extremely low rates of vaporization as compared with the rates which might be expected on the basis of the vapor pressures. Low values usually indicate an extensive continuity of interatomic bonding although exceptions to this occasionally occur when the products of vaporization are not simple monomers. Thus measurements of vaporization rates from glasses, coupled with determination of the vaporization products, may serve as a general method of examining the possible continuity of interatomic bonding in glasses. Such investigations are being undertaken on a number of different glass-forming substances.

Thermal Radiation of Space Crafts. The Bureau is continuing its program for the National Aeronautics and Space Administration to evaluate the total hemispherical emittance of potential materials for space vehicles. Data on heat radiation—or thermal emission—is needed because radiation, the only mode of heat transfer to or from a traveling satellite or space vehicle, influences the equilibrium temperature attained during flight. Thus, a number of materials have been evaluated by the hot-filament method. Those investigated so far include numerous metals and alloys, with polished, sandblasted, and oxidized surfaces, and with a number of different ceramic coatings applied by conventional and flame-spray techniques.

Infrared Studies on Inorganic Solids. Reactions produced at high temperatures and high pressures often result in dense phases or polymorphic forms which usually have uniquely different properties than those of the parent materials. Because temperature and pressure change the atomic environment and consequently produce shifts in the infrared spectrum, the infrared absorption spectrum is used to determine the interatomic motions in molecules, force constants, and bond energies. The direction and magnitude of these shifts may be used to evaluate the influence of neighboring molecules on bond energies.

The recent development of a diamond cell provides a rapid, easy way of studying inorganic solids by infrared spectra. This cell can be operated at temperatures from -30 to 200 °C and at pressures up to 50,000 atm. It can be used throughout the visible and ultraviolet regions on solids and extremely corrosive liquids in a strictly routine manner. Data were obtained on the various forms of ice, on polymorphic changes with pressure in the nitrates and carbonates, and on the high-temperature forms of alkali nitrates. The results, which give direct evidence on type and energies of bonding, are being correlated with the structure as determined by X-ray diffraction.

Vaporization of Refractory Substances. Thermodynamic data, essential for the prediction of chemical reactions at high temperatures, is incomplete on light-element compounds and other refractory substances. To study the vaporization of such substances, the Bureau established the reliability of a vacuum-microbalance technique based on the Langmuir method. The equilibrium vapor pressure and the heat of vaporization of platinum was determined with this apparatus, with results in good agreement with previously reported data. The vapor pressure of rhodium and iridium were also determined and the emissivity of iridium is being measured to yield a more certain value for its heat of sublimation.

The ability to measure the vaporization properties at high temperature was extended by the design and construction of a Knudsen cell. This apparatus is currently being applied to the measurement of the vapor pressure of alumina. Solid gas reactions involving oxygen and water vapor are now being studied with a modified commercial arc-image furnace. Specifications were prepared for a mass spectrometer for determining simultaneously the vapor pressures and vapor species in equilibrium with condensed re-

Vacuum microbalance used to determine the oxidation rate of niobium under various temperature and pressure conditions. Niobium has great potentialities as a high-temperature structural material. However its usefulness is at present restricted by its tendency to oxidize rapidly at temperatures as low at 450 °C (page 85).

fractory substances at high temperature. Prospects for adapting image-furnace techniques to the mass spectrometric investigations seem promising.

Mechanisms of Elementary Reactions. As part of a basic investigation on mechanisms of reaction between simple molecules, rearrangements of atoms in a single hydrocarbon molecule were studied during reactions. Ethane molecules labeled with deuterium were found to expel molecular hydrogen when subjected to far ultraviolet radiation. Most of the molecular hydrogen consisted of two atoms initially bonded to the same carbon atom. Free propyl radicals which were specifically labeled with deuterium were observed to decompose thermally with no detectable transfer of hydrogen from one carbon atom to another. This discovery is contrary to generally accepted theories.

Oxidation of Niobium. Niobium is potentially an excellent metal for structural applications in aircraft, nuclear reactions, and other high-temperature equipment because of its high melting point, relative ease of fabrication and low neutron-capture cross section. However, because it oxidized rather rapidly in air even at temperatures of 300 to 400 °C, its usefulness is at present severely restricted.

Therefore the oxidative behavior of niobium was investigated for the Air Force Office of Scientific Research to obtain fundamental information concerning the various steps of the oxide-niobium-oxygen interaction. The rate of sorption of oxygen under various conditions of temperature and pressure was determined by a specially constructed vacuum microbalance which measures a specimen's weight gain of oxygen as a function of time.

It was found that in the initial stage of the process this oxygen gained in the specimen is a logarithmic function of time. In this stage the rate-controlling process is apparently the diffusion of dissolved oxygen into the metal. Also in this stage, a film of oxide—which is soluble in the metal—forms on the metal surface.

This initial reaction stage is followed by a transition to a stage in which the oxidation rate is constant, and considerably faster than in the first stage. As shown by electron diffraction patterns, the rate transition is associated with the appearance of niobium pentoxide. During the transition, the increased rate of oxidation seems to be proportional to the continued nucleation and growth of porous niobium pentoxide, which causes a continuously refreshed surface of niobium metal to be exposed to oxygen. It is thought that the formation of the pentoxide occurs because of a structural or compositional change in the surface of the metal phase, rather than from a new surface reaction with oxygen which begins after an induction period.

The effect of high temperature on the bonding process and the disposition of the oxide formed is being studied in other refractory metals such as molybdenum, vanadium, titanium, and tungsten.

2.10. ORGANIC AND FIBROUS MATERIALS

The properties of organic structures such as rubber, fibers, paper, leather, and plastics depend on the size, shape, distribution, and flexibility of the macromolecules of which the structures are made, and on the interactions of the molecules with each other. To advance fundamental knowledge of these industrially important materials, the Bureau investigates detailed molecular behavior of substances under a variety of environmental conditions, and develops methods for measuring the properties of these substances. The data thus provided are useful in the synthesis of new polymeric materials and in the utilization of materials presently available.

Typical research during the year included studies of the orientation and size of crystallites in axially oriented polyethylene, and studies of the kinetics of polymer decomposition. Stable free radicals were produced in high-energy irradiation experiments at low temperatures. New precision methods were developed to measure the viscoelastic properties of liquid polymers and the velocity of strain waves in fibers under impact loading. Determinations were made of the noble metal content of dental alloys and of the functional groups in cellulose. A machine, developed to measure the rate of wear of tire treads, was found to give better reproducibility and faster and more economical results than can be obtained in actual road tests. Among the properties of materials investigated were the tensile strength and smoothness of paper and the thermal stability of heat-resistant polymers.

Measuring the Aging of Rubber Vulcanizates. The aging of rubber vulcanizates is usually determined from the changes in tensile properties found after the rubber has been subjected to elevated temperatures. A recent study of these changes, partially supported by the Navy Bureau of Weapons, showed that elongation at failure is the only reliable tensile property for assessing deterioration caused by thermal aging. Furthermore, the change in elongation at failure was found to change with time in a consistent manner for vulcanizates of various rubbers. Although this change over prolonged periods could not be expressed by a simple mathematical equation, elongation at failure decreased approximately linearly with the square root of time during most of the useful life of vulcanizates.

Precision Viscoelastometer. A concentric-cylinder rotational viscoelastometer was developed to measure the flow and time-dependent elastic recovery of liquids with a viscosity in the range of 10^6 to 10^{12} poises. In the instrument, the liquid is contained between an inner cylinder (rotor) and an outer cylinder (stator); the latter is a precision-bore glass tube permitting visual observation of the sample. An arrangement of 90 mirrors on the rotor shaft and a photoelectric recorder permit continuous recording of the rotor position. A sample can be maintained at temperatures from -70 to $+160$ °C. Frictional torques, instrument compliances, and end effects can be measured or estimated. This new device makes measurements of viscoelastic properties with an accuracy and precision not previously attained.

Analyzing Copolymers by Combustion. Combustion analysis of compounds for carbon and hydrogen content permits the determination of the composition of copolymers made from monomers that differ appreciably in carbon-hydrogen ratio, for example, butadiene and styrene in SBR synthetic rubber. In these analyses, the standard deviation of a measurement of carbon-hydrogen ratio is about 0.0010, independent of styrene content. This deviation corresponds to a standard deviation of 0.018 to 0.036 percent bound styrene. In one series, the observed carbon-hydrogen ratios for four out of five samples of polybutadiene differed from the calculated value by less than a standard deviation. The method used is well adapted to measuring the copolymer composition of reference samples that are intended for standards and in developing new procedures such as those based on the relationship of refractive index to composition.

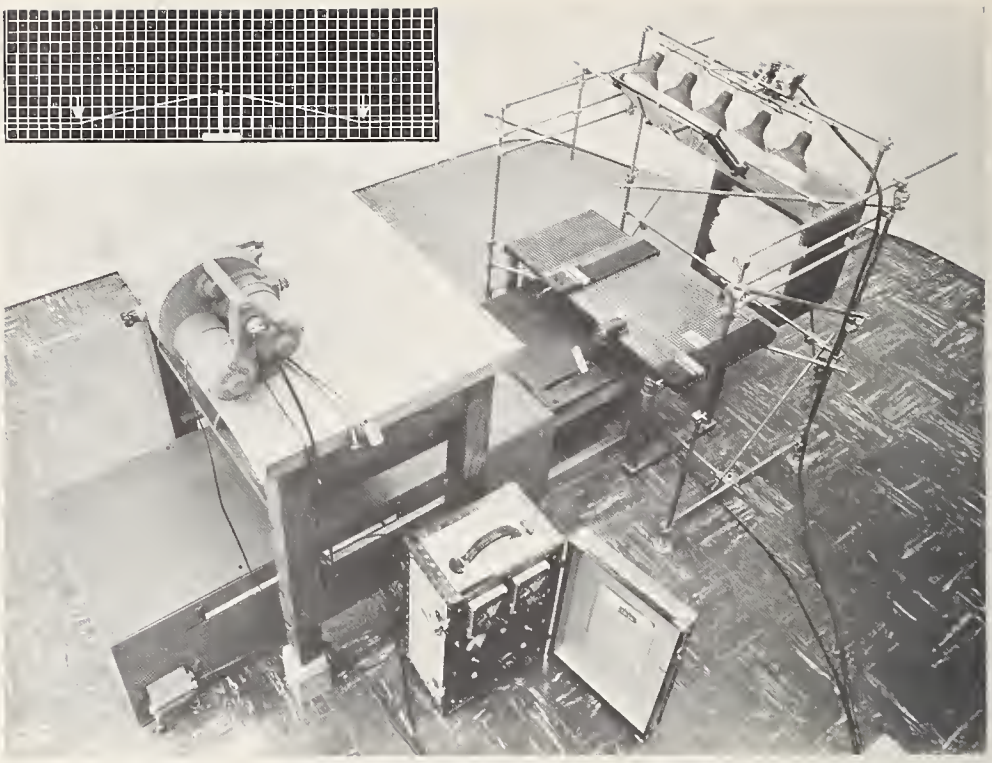
Strain-Wave Propagation in Fibers. When a textile fiber is subjected to high-speed transverse impact, strain waves and transverse waves are initiated, which travel along the yarn away from the point of impact. While each strain-wave front travels at constant velocity, a transverse-wave front changes its velocity when it meets a reflected strain-wave front. This effect is used as the basis of a new method developed at the Bureau for measuring strain-wave propagation velocity.

In this procedure, textile yarns 2 meters in length are clamped at each end and impacted transversely at the midpoint at a speed of 50 m/sec. The subsequent configurations of the yarn are recorded with a high-speed camera at a rate of 15,000 pictures per second. Strain-wave velocities thus obtained range in value from 1,400 m/sec for undrawn nylon to 5,000 m/sec for high-tenacity rayon and glass fiber.

Measurements of this kind not only have practical applications in the design of parachute shroud lines and webbings and flexible body armor, but they also provide basic information on the structure of fibers. This information serves as a valuable guide in the development of fibers and yarns of superior impact properties.

Cellulose Analysis. Cellulose samples from different sources may differ widely in their composition. The significance of minor functional groups such as aldehyde, ketonic carbonyl, and carboxyl, and their roles in many applications of commercial importance, are only beginning to be appreciated. The reliability of methods of analysis is one factor in assessing the effect of these functional groups on the properties of cellulose, so the Bureau, with the International Committee for Cellulose Analysis (ICCA) and other technical organizations, is making a method survey.

Using reference samples furnished by ICCA, laboratories in several countries evaluated eight methods for the determination of carboxyl groups. The results made it possible to select the best methods for use in specific situations, and to recommend certain methods as official standards. A similar study led to a satisfactory method for the determination of pentosans in cellulose.



Apparatus used to observe the behavior of textile fibers when subjected to a sudden transverse impact. The fibers are struck by a flying projectile and the fiber's behavior is recorded in high-speed motion pictures. Inset: Fiber 0.13 milliseconds after being struck at its center by the projectile. Arrows indicate fronts of strain waves traveling from the point of impact (page 87).

Physical Properties of Paper. During the past several years, the increasingly stringent requirements imposed by modern high-speed manufacturing and converting processes, the extension of uses of paper under extreme climatic and other conditions, and the development of radically new types of paper have intensified the need for standardizing the methods used in measuring the physical properties of paper. To facilitate this work and at the request of the American Paper and Pulp Association and the Technical Association of the Pulp and Paper Industry (TAPPI), the Bureau has undertaken development of a standard paper sample for calibrating a method for measuring internal tear resistance. Interlaboratory experiments, with over 40 industrial laboratories cooperating, showed that the use of a tentatively selected standard sample greatly reduces variation in experimental results among laboratories.

Work was also completed on the effect of speed on the precision of the tensile test of paper, and on the measurement of the smoothness of papers—the latter, an important property to printers. The results of this research are being used to revise the standard methods of the American Society for Testing Materials and TAPPI.

Pendulum and Inertialess Paper Testers. Because inertialess testers are being increasingly used for paper quality control, a comparison was made of the test data thus obtained with the results from conventional pendu-

lum testers. Breaking strength and elongation were determined on the two types of machines for five representative papers varying considerably in strength and elongation. It was found that the results for breaking strength on the inertialess tester were in close agreement with those obtained on the pendulum machine over a wide range of testing speeds. A systematic bias in the extensometer design of the pendulum tester caused the results for ultimate elongation to be slightly lower on the inertialess tester than on the pendulum machine.

Statistical Data Interpreted. In a common type of investigation, a property is studied as a function of two or three factors. For example, the power loss of tires depends on speed, load, and inflation pressure. The statistical designs used in such studies are generally of the factorial type with occasional use of Latin or Greco-Latin squares.

The Bureau recently examined the statistical analysis of data conforming to these designs. In the case of properties studied in terms of two factors, a method was developed to break down the so-called interaction term into two meaningful components, one due to nonadditivity of the effects of the two factors, the other to random error. The study proved useful in providing a framework for evaluating measuring processes.

Indoor Tester for Treadwear of Tires. Under the sponsorship of Army Ordnance, the Bureau designed and developed indoor tire-testing equipment for determining treadwear under controlled and reproducible conditions. Previously, the estimation of the rate of treadwear of tires had been determined only by means of road service tests, despite the poor reproducibility of test conditions and the large uncertainty in the results.

In the present study it was found that when tires have markedly different coefficients of friction, the manner of testing affects road service results. To obtain correlation under various road service conditions, the indoor equipment was modified to give information both on the cornering forces developed by tires and on the effect of these forces on treadwear.

Thickness Measurements on Floor Coverings. The dial micrometer and microscopical methods for measuring the thickness of felt-backed floor coverings were evaluated in an interlaboratory study. Although these measurements are used to study physical properties such as indentation, recovery, and resistance to abrasion, results obtained by both methods have sometimes been at variance. In the present evaluation, test data were analyzed statistically in a number of ways. The analysis showed that when experienced personnel made the measurements, there was no significant difference in the two methods. Data from all the participating laboratories were found to be in good agreement.

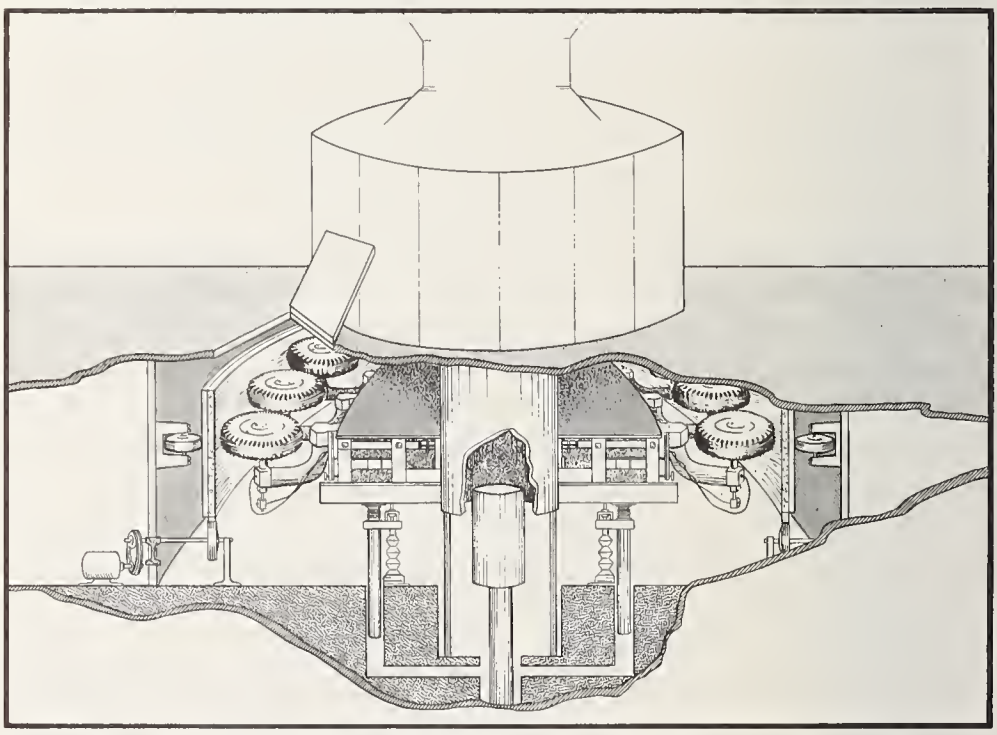
Heat-Resistant Polymers. In exploratory work on high-temperature-resistant polymers, sponsored by the Navy Bureau of Weapons and Office of Naval Research, recent efforts were turned towards the accumulation of basic thermal stability data on the small molecules that contain the basic structure of the polymers. Some newly synthesized compounds were obtained from

industry while others were synthesized at the Bureau. Thus far several phosphinoborines have been investigated, as well as telomers of hexafluoropropylene and decafluorodiphenyl, tetrakis (pentafluorophenyl) silane, tris (pentafluorophenyl) phosphine, pentafluorophenyl phenyl ether, and pentafluorophenyl benzene. Of these compounds, the decafluorodiphenyl was found to be the most thermally stable.

Low-Temperature Irradiation of Polymers. In studying the low-temperature exposure of polymers to high-energy radiation, electron spin resonance was found very useful in determining the quantity and, very often, the identity of the free radicals formed. Similar irradiation studies were made on small molecules to ascertain the role played by small species like hydrogen or fluorine in chemical changes such as crosslinking and scission brought about by high-energy irradiation.

This work, sponsored by the Department of Defense, showed that the very active species (atoms or free radicals) produced in solids when materials are exposed to high-energy radiation can be stabilized for long periods of time. Also, very small radicals such as hydrogen and nitrogen atoms and methyl radicals give relatively clear-cut resonance spectra, but the temperatures required for their stabilization are very low, varying from about 4 to 20 °K.

Polymer Decomposition. The availability of stable polymers at high temperatures would greatly enhance the capabilities of modern technology, but the production of new polymers is hampered by the limited mechanistic, energetic, and thermodynamic data now available. To obtain such data, knowledge of the mechanisms of the polymer decomposition is needed.



Drawing of a new facility developed as part of a test method for measuring the rate of treadwear on vehicle tires in service. Tests on this indoor "road" can be controlled much more closely than can actual road tests (page 89).

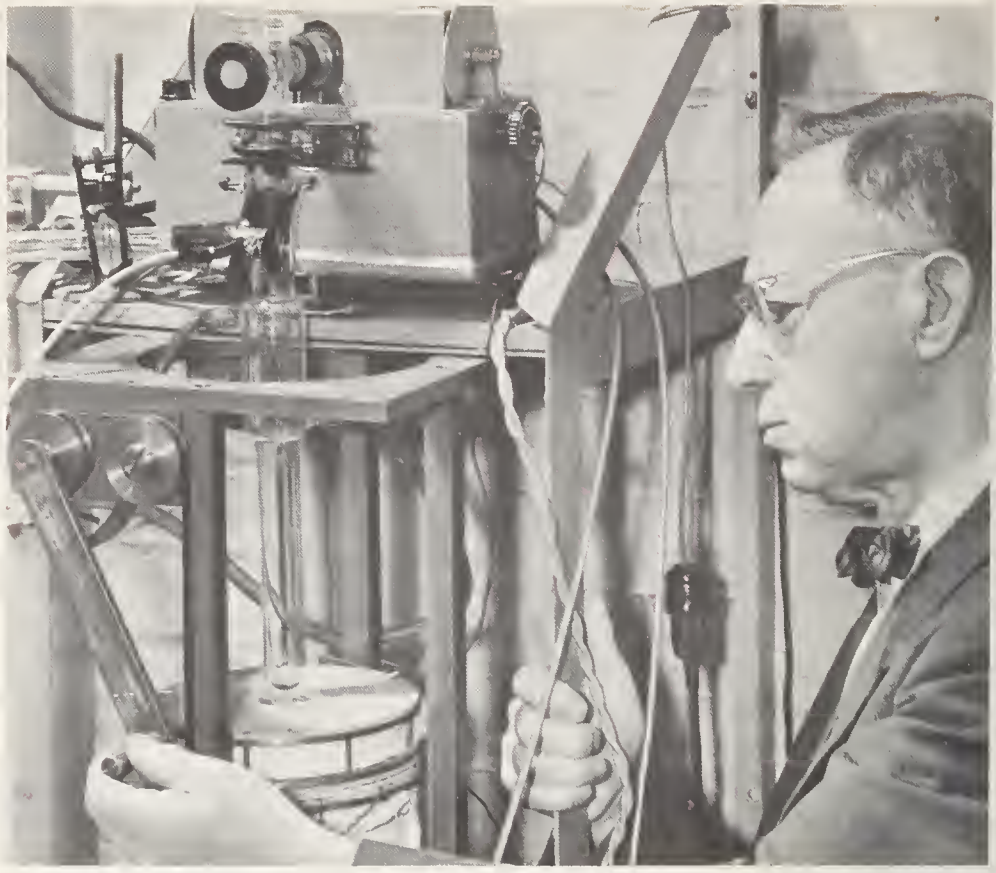
In a recent investiagtion in this area, experimental measurements of the rates of thermal decomposition of polymers, both during and after exposure to ultraviolet light, provided information concerning the details of the decomposition mechanism. It was found that decomposition phenomena in unusual environments, particularly those of an extraterrestrial nature, may be anticipated with the aid of these measurements.

Low Angle X-ray Diffraction of Fibrous Polyethylene. In X-ray diffraction studies, highly axially oriented fibers of linear polyethylene had four orders of well-defined, meridionally directed diffraction maxima corresponding to a fundamental spacing of 408 A. The relative macroscopic length of the fibers was systematically altered both by simple thermal treatment and by crosslinking, melting, and recrystallization. The magnitude of the X-ray spacings observed did not bear any direct relationship to the length change incurred, but reflected the change in crystallite size that developed either because of annealing, partial melting, or the introduction of crosslinks. In a completely shrunken fiber, discrete low angle diffraction maxima, circular in shape and corresponding to a periodicity of 255 A, were observed. Intermediate types of line shapes were found to depend solely on the crystallite orientation and not on the method by which the orientation was developed.

Pyrolysis of Polyamides and Polyolefins. Pyrolysis experiments on polyamides and polyolefins demonstrated the importance of trace impurities. With polyamides it was found that traces both of the acid-polymerization catalyst and of moisture considerably lowered the thermal stability of the material. Sufficient moisture was generally retained by polyamides to play a significant role in their pyrolytic decomposition in vacuum. On the other hand, traces of the Ziegler-type catalyst system used to prepare polyolefins caused a retardation of thermal decomposition. A study of various molecular structures in polyolefins, in which the number and length of side branches were altered, showed that the pattern of degradation varied for different structures. The rate of decomposition in the early stages increased with the degree of branching in the structure. This work is part of a continuing project on thermal stability of polymers sponsored by the Air Force.

Properties of Monolayers of Polymers. The surface pressure-area isotherms of linear saturated polyester films spread as monolayers on aqueous subphases were determined in an investigation sponsored in part by the Navy Bureau of Weapons. It was found that the isotherms varied from an expanded-type curve for poly(trimethylene adipate) to a very condensed-type curve for poly(neopentyl succinate). The study showed the properties of the monolayers to be closely related to the geometric structure of the polymer repeating units, the intermolecular attractions, the packing of the polymer chains, and the interaction of the polymer with the substrate.

Fluorescence of Polymeric Materials. A recent study of a series of cellulose derivatives showed that their chemical structure is related to the wavelength and intensity of their fluorescence emission spectra. It was also



Sensitive electronic apparatus used to maintain constant temperature and obtain continuous, accurate weight loss in studies of thermal degradation in polymers. Data obtained in such studies should be useful in the development of new polymers which are stable in high-temperature environments (page 90).

possible to react cellulose with various chemical reagents and to follow these reactions by fluorescence measurements, and to observe the degradation of cellulose from ultraviolet radiation by changes in its fluorescence spectra.

Noble Metal Content of Dental Gold Alloys. A rapid accurate method for determining the noble metal content of dental gold alloys was developed. The procedure makes use of portions of the Gilchrist method for the complete analysis of a dental gold alloy. It differs, however, in that glass electrodes instead of indicator solutions are used to establish the *p*H of solutions. Gold was found to precipitate completely from solution at a *p*H of 3.0 with sodium nitrate. The new method reduces the time required for analysis by about one-half and is considered to be accurate to within 0.1 percent. This study was conducted in cooperation with the American Dental Association and the Federal dental services.

Isomers of Zinc Oxide and Eugenol. Mixtures of zinc oxide and eugenol have found a wide variety of applications in dentistry since they are probably the most innocuous of all dental restorative materials. An investigation of the setting mechanism, sponsored by the American Dental Association and the Federal dental services, demonstrated the formation

of a chelated zinc eugenolate that acts as matrix for the zinc oxide. The reaction of a group of chelating agents with metal oxides was also investigated to study the scope of the hardening reaction. Mixtures of *o*-ethoxybenzoic acid and zinc oxide were found to be most promising because of their increased hardness, adhesion, and density.

Position isomers of eugenol capable of forming chelates were synthesized in order to correlate structure and properties, and to study the effects of neighboring groups on the properties of these isomers. It was found that the reactivity of the vicinal trisubstituted isomers was much lower than that of the asymmetrically substituted compounds. "Tailor made" chelating agents are now being prepared which possibly will react with metal oxides to form cements of high-strength and low-water solubility.

Tensile Properties of Dental Amalgam Alloys. A method for measuring the tensile stress-strain properties of small specimens of silver-tin amalgams was developed in research sponsored by the American Dental Association and the Federal dental services. Strain is observed by a ¼-in. strain gage attached directly to a small dumbbell-shaped specimen. Stress is applied at a controlled rate by a low-capacity testing machine, and head speed is varied from 0.003 to 0.050 in. per minute. Tensile properties were determined on three alloys representative of American Dental Association approved materials and one alloy containing 35 percent of tin.

The ultimate elongations of these alloys were not more than 0.5 percent, indicating brittleness. Further studies will be conducted because this property is considered one of the contributing factors to the chipping of fillings in service.

2.11. METALLURGY

Metallurgical research at the Bureau is directed toward a better understanding of the properties of existing metals in order that improved metals and alloys may be developed to meet new requirements or to give better performance. Much of the work is designed to furnish basic information on metals and alloys in terms of their constituent atomic units. The studies also include the effects of treatment, fabrication, and conditions of service on the structure, behavior, and properties of metals. Particular emphasis is placed on problems related to metals subjected to high temperatures, corrosion, and fatigue; metal physics; and to the preparation of pure metals.

Metal Creep Investigated. A comprehensive investigation of the creep characteristics at 300, 700, 900, and 1,200 °F of high-purity copper nickel, and two alloys of these elements is nearing completion. The creep resistance of each of the pure metals was significantly increased by alloying with 30 percent of the other metal. At each temperature range, the 70 Ni—30 Cu alloy had the highest creep strength. Creep resistance of the specimens was materially increased by cold drawing when crystallization did not occur during creep. However, this increase was usually accompanied by a corresponding decrease in ductility.

Die Steels for Aircraft Components. Studies were continued to determine the suitability of hot-work die steel of the 5-percent chromium type, for use at temperatures up to 1,000 °F in aircraft components. Thus far the work shows that the yield strength at room temperature of heat-treated tensile specimens is materially increased (without a loss in ductility) by stressing at room temperature under high loads for a period of 1,000 hours. This procedure may provide a means of increasing the useful working strength of these steels.

Stress-Corrosion Research. Complete stress-corrosion failures, at stresses considerably lower than the yield strength of the metal, were obtained on type 304 stainless steels when a newly designed specimen was exposed to chloride corrodents at 575 °F. The effect of notches was found to be a significant factor in the stress corrosion of low-carbon steels, with the time to failure decreasing markedly as the sharpness of the experimental notches was increased. The Corrosion Research Council and the Atomic Energy Commission are partially supporting the stress-corrosion studies now under way.

Equipment Developed for High-Temperature Research. Work on a uranium-platinum series of phase diagrams was accelerated by recently designed equipment that is especially applicable to high-temperature studies. One instrument utilizes the electrical resistance of a specimen so that when an electric current passes through the specimen (held between water-cooled electrodes) it may be heated to 1,500 °C and above. Quenching of the specimen is quickly accomplished by turning off the current. This device has the advantage of operating without a ceramic crucible, thus avoiding the undesirable alloy-crucible reaction which is extremely common when conventional apparatus is used at high temperatures.

To study alloy reactions at temperatures up to 1,400 °C, a thermal analysis furnace was constructed. This apparatus has a controlled heating and cooling rate between 1 and 5 °C per minute and can be operated either under vacuum or with an inert atmosphere. The apparatus was modified to permit the quenching in oil of a specimen after being slowly heated or cooled to a temperature near a phase reaction.

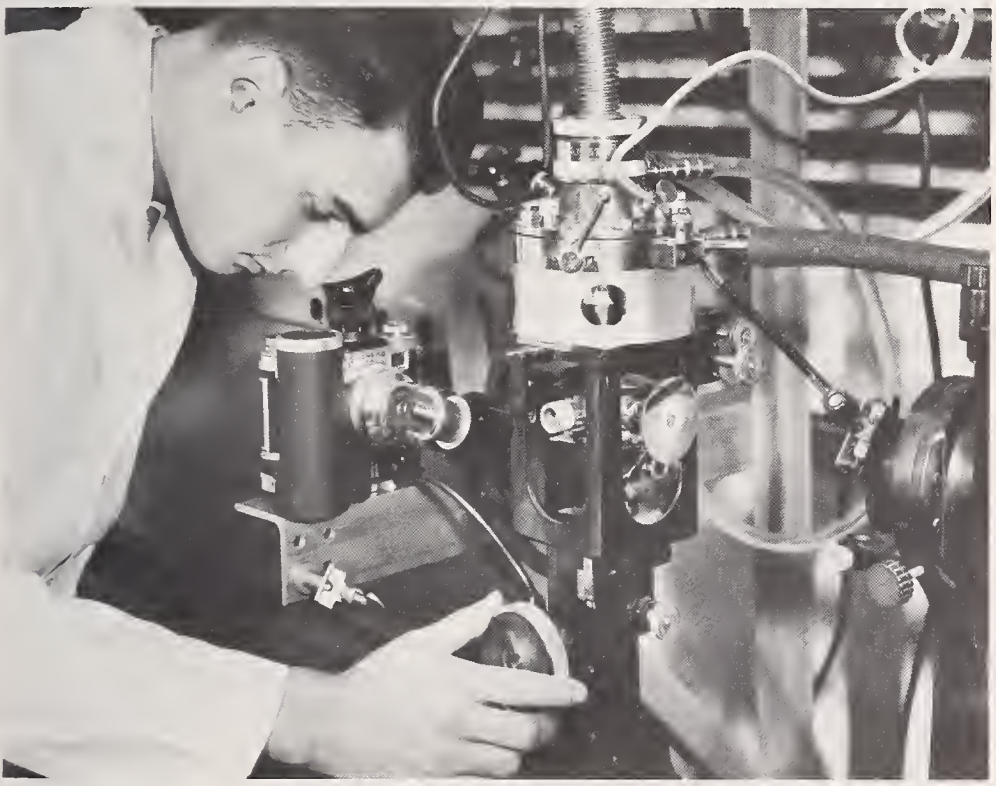
A high temperature microscope stage, that will reach 1,500 °C in vacuum or 1,150 °C in an argon atmosphere was equipped with a long working distance objective and with a camera for time-lapse photography. In normal operation, the maximum permissible heating rate is 15 °C per minute. A rapid quench can be obtained by turning off the power and flushing the chamber with helium. The vacuum is in the 10^{-6} mm of mercury range, and gases are purified by passing through activated aluminum and hot titanium turnings.

The high-temperature stage was used in a recent study of the decomposition upon heating of the nitrided case of a titanium alloy. It was found that nitriding the alloy in purified nitrogen for 48 hours at almost 1,000 °C resulted in a thin surface layer containing elongated nitride grains, oriented

at 45 degrees with the surface and extending down into the matrix. Upon reheating in the stage these elongated grains usually decomposed into a lamellae structure parallel with the long axis of the original grain. This work was sponsored by the Navy Bureau of Weapons.

Diffusion in Crystals Studied. Theoretical studies of the details of atomic jump sequences in diffusion processes in crystals were continued with emphasis placed on correlation effects. The studies showed that a flow of vacancies in a crystal may greatly affect the diffusion process. For example, such a flow can increase considerably (1) the Kirkendall Shift and the interdiffusion coefficients for alloys; (2) the drift mobility for an ion diffusing under the influence of an electric field in an ionic crystal.

An electronprobe microanalyzer was designed and built primarily for use in the Bureau's long-range diffusion program. It will be used to determine the composition gradients in diffusion couple specimens from which portions of phase diagrams may be assembled. Although the principle of obtaining phase diagram data through diffusion studies is very old, the use of the electronprobe makes the method more practicable. With this instrument the chemical composition *in situ* at the 1-micron level of spatial resolution may be determined. The resolution is determined by the diameter of the electron beam, which is focused onto the surface of a specimen by two electromagnetic lenses. Characteristic X-rays emitted by the specimen are measured and recorded with focusing spectrometers. With a light optical system



Physicochemical and structural changes occurring in metals at elevated temperatures are observed and recorded by means of this metallograph equipped with a vacuum high-temperature stage (page 94).

centered on the axis of the electron beam the microstructure of the specimen may be continually observed.

Work with Single Crystals Progresses. Recent studies of metal single crystals showed that the stressing of a surface parallel to one crystal face in a definite crystallographic direction resulted in a radically different type of distortion from that formed by stressing a similar surface in a different crystallographic direction. The corrosion of these surfaces was found to vary with the distortion.

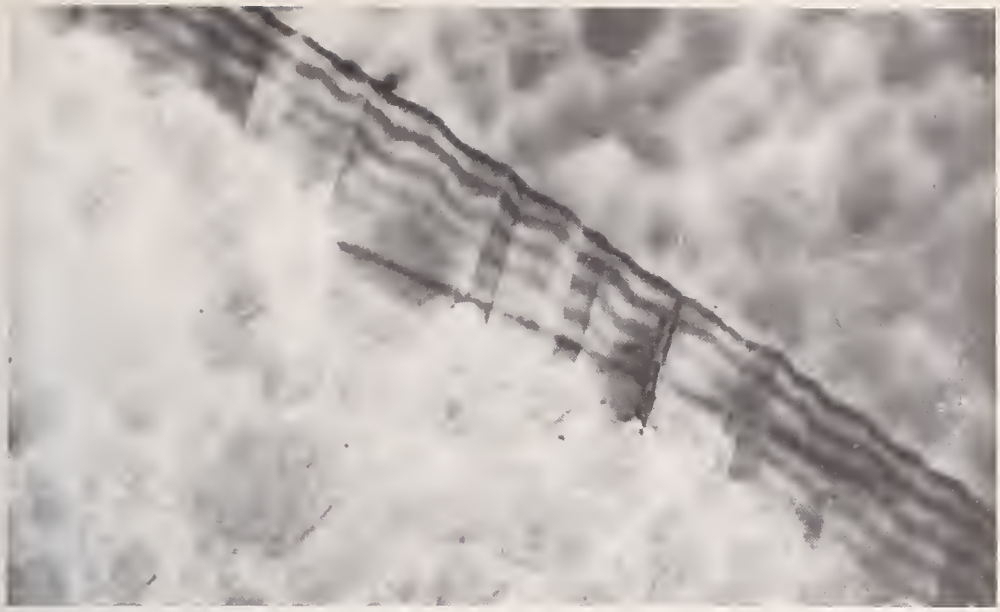
The rate of film formation on iron single crystal surfaces in passivating solutions was found, with an ellipsometer being used to measure film thickness. Simultaneous electrochemical potential measurements showed that the film responsible for changing the potential from active to passive was 15 to 30 A thick irrespective of crystallographic orientation. A new decoration technique indicates that passive films break down at discrete sites.

The interaction of mixtures of oxygen and nitrogen passed through a microwave discharge with single crystals of copper was studied at temperatures down to 4.2 °K. Some films of reaction products were produced on the crystals by all mixtures of condensed gases but the thickest films—more than 100 A—were produced by mixtures containing less than 10 percent of nitrogen.

Dislocation movements and twin boundaries in copper foils about 500 to 1000 A thick are being studied. Techniques were developed for preparing these foils as single crystals of predetermined orientation, the main feature of which is the growing from the melt of an appropriately seeded copper single crystal only 0.004 in. thick. The foil is then produced by electropolishing. Various etching procedures are being applied to establish a correlation between the etch pits developed and the dislocations present in the foils.

Stability in Gage Blocks. Periodic measurements of nitrided 410 stainless steel gage blocks show that their excellent dimensional stability characteristics were retained, and the slight growth observed in a 2-year period is linear at the rate of 0.2 microinches per inch per year. As this growth is possibly due to a change in the carbides in the steel, additional nitrided blocks of a stainless steel with a lower carbon content are being incorporated into the study. Heat-treated gage blocks of 52100 steel were also observed for a 2-year period, and some of the results indicate that a high degree of dimensional stability—especially when the blocks are tempered to a Rockwell C–60 hardness—may be attained. However, some of these blocks showed a relatively rapid decrease in length during the first 6 months after heat treatment, and the cause of this behavior is now being sought.

Important Data from Fractured Titanium Specimens. A study of the fractured surfaces of notched tensile specimens of titanium tested at 100, 25, −78, and −196 °C provided valuable information on the effect of notch geometry on the initiation and growth of the fracture cracks. The position of the initiation and the propagation of a fracture were readily and accurately determined.



Transmission electron microscope photograph reveals twin boundary in a 1000 A copper foil. The fringes running along the boundary are the result of an electron interference effect. Studies of such discontinuities in structure give information on the mechanical behavior of metals (×63,000) (page 96).

Design criteria are often based on the assumption that approximately 2 percent plastic strain is sufficient to remove the embrittlement due to the initial stress concentration at the root of a notch of ductile materials. Contrary to this assumption, the results of the present investigation on initially annealed commercially pure titanium and a titanium alloy containing aluminum and manganese definitely showed that this notch embrittlement was not entirely removed, even with deformations up to 50 percent reduction in area. The fracture of sharply notched specimens was initiated at the root of the notch, and propagated diametrically across the minimum cross sections; however, the fractures obtained in other notched specimens with large root radii were initiated near the specimen axis. In general, ductility was considerably lower for the sharply notched specimens than it was for those with large root radii. These results again emphasize the importance of eliminating sharp notches wherever possible in designing for use of titanium materials.

Preparation of Pure Metals. A halide "hot-wire" reduction unit was built to prepare tungsten rods for further purification in a large floating-zone refiner recently constructed. A supply of highly purified halide contained in a quartz flask is attached to the bottom of a quartz reaction chamber in the reduction apparatus. The halide is warmed while a low-pressure stream of mixed argon and hydrogen is pumped through the system. Halide vapors are carried in the stream until they encounter a hot filament of the same metal. At this juncture, the vapors are decomposed and cause the pure metal to be deposited onto the filament. In order to maintain a uniform temperature of decomposition, the heating current is increased as the de-

posited metal increases the rod diameter, and thus the deposition continues until a rod from $\frac{1}{10}$ to $\frac{1}{4}$ in. in diameter has been formed.

Several tungsten rods have been produced in this manner and are being further purified in the floating-zone refiner. In the refiner, contamination of the rods is avoided by using electron beam heating. This program is under the joint sponsorship of the Wright Air Development Center and the Bureau.

Metal Crystals Grown from Their Vapor. The rate of growth of zinc crystals from their vapor was measured as a function of supersaturation. The results support the Burton, Cabrera, and Frank theory of crystal growth which holds that measurable growth rates are observed even at supersaturations as low as 0.01. The zinc crystals, which can be nucleated on either tungsten or Pyrex glass, have the form of truncated hexagonal pyramids, about 2 mm high and 3 mm in diameter at the base. These are the first measurements made on a physical system approximating the model assumed in the theory of Burton et al., and thus far they agree with the predictions made.

Nuclear Magnetic Resonance of a Tantalum Nucleus Observed. In measurements made on a tantalum compound, the magnetic resonance of the Ta^{181} nucleus was observed for the first time. From the experimental data derived in the study, a value of the magnetic moment of the nucleus was calculated to a more accurate degree than previously possible. The Knight Shift of the Ta^{181} resonance in a foil of the pure metal was also determined.

Reversed Plastic Deformation. By means of X-ray diffraction techniques, many investigators have studied the manner in which a metal crystal lattice is distorted during plastic deformation. Little work has been done, however, to determine whether this distortion can be reduced when the direction of deformation is reversed. To obtain quantitative measurements of reversible distortion, a double-crystal goniometer was designed and constructed which permits measurements of intragranular misorientation.

In recent studies with cartridge brass specimens, misorientation was found to be very sensitive to small amounts of plastic deformation, but a large part of the misorientation produced by deformation in one direction was eliminated by reversing the direction of the strain. This work is continuing and the results may aid in understanding phenomena such as the Bauschinger effect and the fatigue failure of metals.

Mechanical Properties Determined for Metal Foils. In studying the effects of heat treatment, it is often advantageous to use metal foils so that temperature equilibrium may be quickly reached. However, it is often difficult to obtain accurate data on the mechanical properties of foil specimens. In a current study of precipitation-hardening stainless steels, a hydraulic bulge tester was used to determine these properties in foil specimens. The instrument conveniently measures the pressure and the height of bulge on loading $\frac{3}{4}$ in. diameter disks clamped at the edge. It was possible to determine the yield strength, burst strength, and ductility of

these specimens at a much lower cost than analogous properties can be determined in a conventional tensile test.

Apparatus for Controlled Slack Quenching. The best combination of high strength and ductility in structural steels is usually obtained by rapid quenching to a fully martensitic structure followed by tempering. But such a structure is often unattainable commercially because of the economy of using steels low in alloying elements and the difficulty encountered in cooling large components rapidly enough to harden them completely through the entire cross sections. Structural steels are therefore often used in the slack-quenched conditions which consist of mixed structures of ferrite, pearlite, bainite, etc. To establish a definite relation between such structures and their tensile properties, the Bureau recently developed an inexpensive method for producing uniform and controlled amounts of mixed structures in tensile specimens. Correlations are now being made between these structures and the tensile properties of steels of medium hardenability.

Service Failures Investigated. A number of government agencies requested the metallurgy laboratories of the Bureau to examine metal parts that failed in service during the year. As in the past, a major part of this work was performed for the Civil Aeronautics Board and the Navy Bureau of Weapons. The results of the examinations aid in elucidating the cause and development of metal failures.

Careful NBS studies of metal parts that have failed in service provide important data on the causes of such failures. These data are useful in development of improved materials and design criteria **(page 99).**

2.12. INSTRUMENTATION

Measurement precision depends on two factors: The natural limitations of the measurement process, and the realizable performance of measuring instruments. Under a broad instrumentation program, the Bureau investigates both of these factors to improve its measurement capability in research and calibration activities. The fundamental properties and limitations of instruments, their components and materials, and measuring, recording, and signal-processing methods are studied. The program also includes a study of basic phenomena that may be usefully applied to instrumentation.

Modern instrumentation frequently uses electronic techniques, even when the initial measurement problem is not fundamentally electrical. The electronic program includes investigation of the materials used in vacuum and semiconductor electron devices, study of the characteristics and capabilities of electron devices themselves, the development of improved electronic instruments to meet the needs of the Bureau's research program, and a variety of projects undertaken for other Federal agencies.

Mechanical instrument activities include development of standard hygrometers and humidity generators, calibration methods for pressure and displacement transducers, and instruments needed specifically by other Federal agencies.

To avoid duplication of scientific research effort, it is necessary to keep abreast of the instrumentation art. The Bureau maintains an extensive reference file of literature on instruments and measurement methods, and the file itself is designed so that its data can be retrieved by partly mechanical means.

The Resistor Noise Test Set. The resistor noise measurement concept was modified slightly and the previously conceived measure of resistor current noise, conversion gain, was replaced by a new index, microvolts per volt in a frequency decade. This new index, like the original one, is dimensionless. A noise test set, developed for the Navy Bureau of Ships, capable of measuring resistor current noise in terms of conversion gain, is equally capable of measuring noise in units of the new index, since the two are related by a constant. The original noise test set was assembled from modified commercially available instruments. A commercial organization now has available a new test instrument to the NBS specification. The new test set contains in a simple instrument all of the functions previously supplied by a number of instruments in the older test set. With the ready availability of this instrument, the Bureau can now encourage the International Electrotechnical Commission to adopt the NBS test method as its international standard.

Electron Devices Data Service. With the publication of the Tabulation of Data on Receiving Tubes as Handbook 68, data on 5,000 additional devices including microwave tubes and semiconductor diodes have been placed on punched cards. The Data on Microwave Tubes is being published as Handbook 70.

New electronic devices are continually being added to the presently tab-

ulated groups. These data are reissued from time to time to keep up to date. Industry is developing new devices at the rate of several thousand a year; the files currently are estimated to contain data on more than 25,000 separate items.

Electrical Properties of Semiconducting Materials. A method for measuring the lifetime of minority carriers in semiconducting materials has been developed as an outgrowth of the work on electroluminescence and because of the need for a method applicable to the new large energy-gap materials. When alternating current is applied to a semiconductor through poor rectifying (injecting) contacts, the electroluminescent intensity remains approximately constant as the frequency is increased until the frequency becomes comparable with the minority carrier lifetime. The electroluminescent intensity then decreases according to a specified relation involving frequency and lifetime.

This method has been used to determine the lifetime in such materials as silicon carbide and boron phosphide. It is especially applicable for measurements of lifetimes in the millimicrosecond range in samples having arbitrary dimensions and small size. The method has been checked on samples of silicon whose lifetime was measured by conventional means.

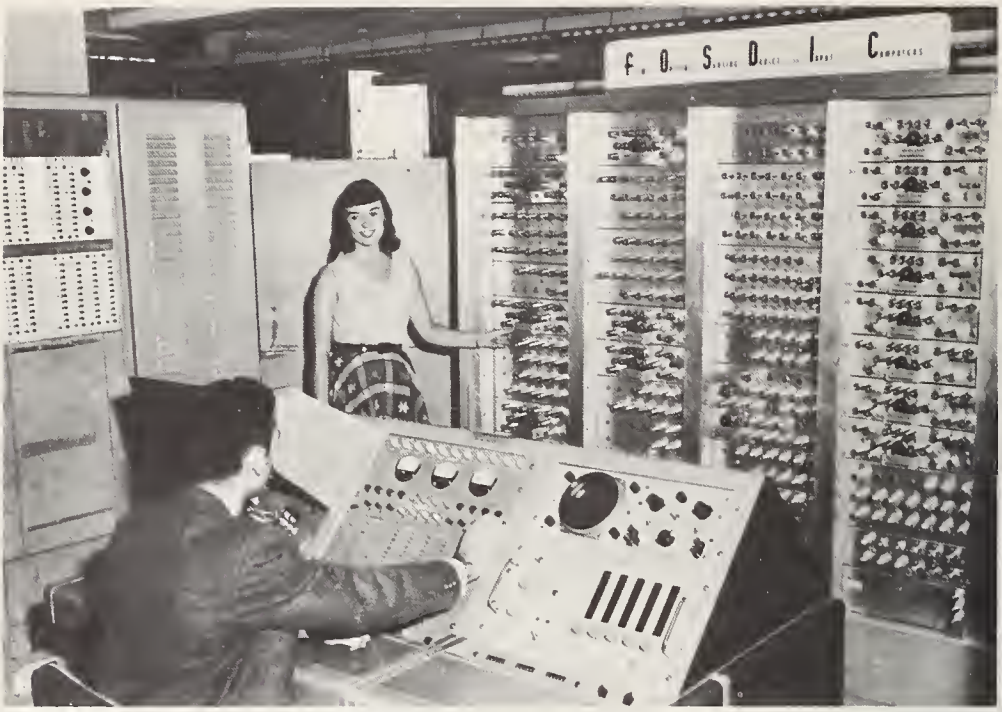
A new family of low contact-resistance alloys for use on ferrites and controlled valency semiconductors was developed.

Properties of Mica Essential to Electron Tube Use. Large quantities of mica are consumed each year in the manufacture of electronic and electrical equipment. However, the great variation of type and quality in which the material naturally occurs and the degree to which its properties appear to be dependent upon type and quality have made proper processing and extensive classification necessary. Little correlation has been found in the past between quality and observed properties.

Under the sponsorship of the General Services Administration, the present program, with emphasis on use of the material in electron tubes, has shown how optical, electrical, and structural properties are related. Color structure, one of the least understood properties, has been identified with a definite spectral characteristic, which correlates with optic angle and density.

Electronic Scanning Microscope. An electro-mechanical scanning microphotometer was constructed for analyzing spectrographic plates easily, rapidly, and accurately. A small area of a spectrographic plate is scanned at one position of the plate and converted into an X-Y coordinate display of wavelength versus density. The coordinate display is presented on a cathode-ray oscilloscope as a steady-state pattern with a stable, electronically generated fiducial line. A mirror-image presentation may be superimposed on the normal X-Y plot.

Resolution to better than 0.001 mm on the wavelength scale is consistently obtained, while the fiducial line remains stable to this accuracy for several hours. The integrating effect of the "line" scanner resolves faint lines in the spectrum which are nearly invisible in the visual microscope.



FOSDIC—Film Optical Sensing Device for Input to Computers—developed and maintained for the Bureau of the Census, is playing an important part in the 1960 census (page 102).

Electronics for Rubidium Vapor Frequency Standard. A prototype frequency standard is being developed for the National Aeronautics and Space Administration for possible use in an earth satellite determination of the gravitational frequency shift. A rubidium vapor gas cell is being tested as a frequency standard, and the optical pumping techniques involved are being studied.

The electronic circuitry of this transistorized standard contains a 5 to 60 Mc/s frequency multiplier, a diode modulator, and a servo system which consists of a 10 c/s oscillator, tuned amplifier, and phase detector. The rubidium gas cell is located in a microwave cavity (see also page 65).

FOSDIC. The 1960 decennial census documents are being read electronically by FOSDIC (Film Optical Sensing Device for Input to Computers). Developed for the Bureau of the Census by NBS, these electronic machines rapidly read microfilmed census documents and transcribe the data on magnetic tape for direct input to an electronic computer. The documents are read by scanning microfilmed images using a cathode-ray tube as the light source and a photoelectric cell as the receiver. The equipment has undergone numerous evaluation tests at Census and appears to be a valuable tool in Census procedures, offering large potential savings to the Government. Four similar machines are currently under construction by Census under NBS supervision. Indoctrination of Census personnel in the maintenance of FOSDIC has been a continuing activity.

Hygrometry. To meet the need for a basic reference for humidity measurements, the Bureau developed a gravimetric hygrometer that determines the moisture content of known gas volumes with high precision. Considerable effort was devoted to locating and evaluating the sources of error in this hygrometer. Operational procedures have been improved. Preliminary calibrations were made for one of the Bureau's humidity generators.

An improved circuit has been developed for radiosonde use in telemetering upper atmosphere humidity data sensed by a fast-responding electric hygrometer element. The circuit and the hygrometer were developed under the sponsorship of the Bureau of Naval Weapons as part of a program of improving humidity measuring equipment for meteorological use.

Telemetering Pickups. Telemetering pickup elements are essential for remotely measuring the performance and environment of aircraft and guided missiles in flight. Under the joint sponsorship of the Navy Bureau of Weapons and the U.S. Air Force, the Bureau investigated the characteristics of telemetering transducers and developed improved testing equipment and calibration devices.

A dual centrifuge for testing and calibrating accelerometer transducers was designed and built. It provides a frequency range of 0.5 to 30 c/s and acceleration amplitudes from ± 0.25 g to ± 100 g. Work is under way in extending the frequency range to about 10,000 c/s so that vibration transducers can be evaluated.

Preliminary investigation of the effects of thermal shock on pressure transducers indicates that, under conditions much less severe than those encountered in liquid-fuel rocket engines, zero shifts as much as $\frac{1}{3}$ of the instrument range may occur with flush-mounted diaphragm gages. The magnitude of the zero shift appears to be nearly proportional to the rate of heat transfer through the flush diaphragm.

An improved transistorized circuit was developed for a radiosonde for telemetering upper-air meteorological information (page 103).

Instrument Reference Service Enlarged. Industrial and government scientists must know what has been done in developing instruments in order to establish effective designs without duplication of effort. The Bureau's basic instrumentation service provides reference and consultation services for all scientists who work in research and development of scientific instruments.

The Bureau enlarged its card index of instrumentation literature by selecting, analyzing, coding, and recording additional information in a special punched-card system known as Microcite. A large number of inquiries were answered by use of references already stored in this index system and by other means.

Work continued on developing methods of replicating the punched cards used in the Bureau's instrument reference files. Construction of an electromechnical device to increase the speed and efficiency of searching the instrument index is nearing completion.

2.13. APPLIED MATHEMATICS

The Bureau's central applied mathematics facility conducts basic and applied research and renders advisory services in various mathematical fields. These services are available to other government agencies as well as to the Bureau's staff. Modern computing equipment aids the facility in supporting its research and development program.

During the past year the Bureau continued to place emphasis on statistical and numerical analysis and on mathematical physics. Extensive assistance was rendered in these areas and in digital computation. Special attention was given to problem formulation and analysis to select and develop numerical methods suitable for the solution of engineering and physical science problems on both automatic and nonautomatic computing machines. An appreciable share of the mathematical program was devoted to problems encountered in business management and operation, sometimes referred to as "data processing" problems. Significant progress was achieved in the exploration of the utility of modern digital computers in the mechanical translation of scientific publications, for which there is an extremely urgent need.

As in previous years, the Bureau's applied mathematics program was strengthened by the active interest and support of other government agencies. The Office of Naval Research and the USAF Office of Scientific Research supported fundamental and applied research in numerical analysis and mathematical physics. The National Science Foundation continued to support the compilation of a handbook of mathematical tables and mathematical research related to information retrieval.

Combinatorial Analysis. Combinatorial analysis is the branch of mathematics which studies the various arrangements of finite sets of objects. It finds application in selecting the best pattern of linkages in transportation or communication networks, in selecting the most efficient method for encoding messages to provide automatic correction of possible transmission

errors, and in designing experiments to maximize the useful information obtained from a given number of measurements. Attempts were made at the Bureau to introduce the notion of abstract spaces into combinatorial analysis. Studies of the structure of such spaces is a continuing project. In developing the theory of incidence spaces, a method of constructing them by use of permutation groups was found to be an effective tool.

Eigenvalue Theory. The determination of eigenvalues for operators is of great importance in mathematical physics but frequently involves considerable numerical difficulty. A new scheme was devised for the calculation of upper and lower bounds for the eigenvalues of the associated Legendre equation. An error bound was derived for the Rayleigh-Ritz approximation of eigenvectors.

Matrix Theory. The problem of bounds for various quantities related to matrices still attracts many investigators. New bounds were obtained for the characteristic roots, the determinant, and the P-condition number of matrices.

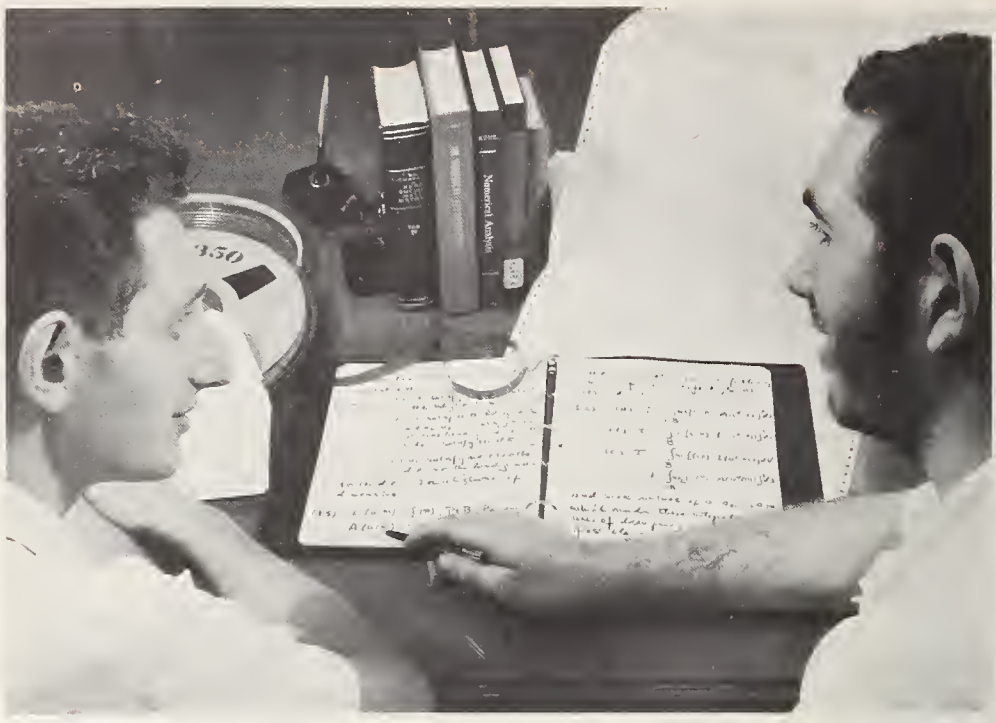
Approximation Theory. Although approximation theory is fundamental to much of numerical analysis, not much research has been conducted in the important but difficult area of nonlinear approximation. The Bureau made extensive investigations of best approximation by nonlinear families.

Numerical Experimentation. In many areas of numerical analysis where no theory exists or existing theory is merely suggestive, numerical experimentation provides some insight into a given method of problem solution. Extensive experiments were conducted in the numerical solution of elliptical boundary value problems by means of orthogonalized particular solutions. A considerable body of numerical data is now available which can be applied to practical problems; for example, in harmonic approximation to boundary functions of different continuity classes and harmonic interpolation.

The accuracy of Monte Carlo methods in computing finite Markov chains was investigated. Statistical theory confirmed the observed Monte Carlo data, which can therefore form the basis for an estimate of accuracy in computations of large chains not solvable by matrix methods.

Machine Translation. Significant progress was made on the automatic Russian language translation scheme being developed by the Bureau for the Army Office of Ordnance Research. In contrast with other machine translation projects, the Bureau project is characterized by emphasis on syntax in the conventional sense and by a system of predictions. A Russian word in a sentence "predicts" certain other grammatical forms; for example, a transitive verb predicts a direct object.

The program first instructs the computer to transform the words of a Russian sentence into a highly condensed representation for matching in a glossary, then to recognize the syntactical relations between the Russian words, and finally to arrange the corresponding English words into a meaningful sentence.



The Bureau's applied mathematics facility conducts basic and applied research and provides advisory services to the NBS staff and to other government agencies. Here two mathematicians discuss new methods for solving differential equations (page 105).

Improvement in Facilities. The capacity of the electronic computing facility was increased through the addition of a tape-controlled, high-speed printer. The computer remained on three-shift operation, performing computations arising in the work of the Bureau, carrying the main computing load of some other government agencies, and serving as a standby facility for the Weather Bureau.

Digital Computation. Increasing the accessibility of the problem formulator to the computer by means of efficient programing methods is an important part of the research activity in digital computation. A particularly worthy recent development is the Black Box Computer—a tool devised to speed a problem from originator to machine. Actually, the Black Box Computer is a man-machine operation in which the machine, its operators, card handlers, and coders constitute the "computer." For the types of problems presently within its scope—reading, computing, and printing tables of numbers; numerical integration, differentiation, and interpolation; least squares fit of numerical data, as well as curve plotting directly from the printer—the elapsed time between the presentation of a feasible problem and the return of the desired results is a matter of only hours. This accelerated service is now provided at the Bureau on a routine basis, thus minimizing both machine and personnel time on any given problem and maximizing the productivity of the facilities.

Digital computers were applied in both the scientific and the data processing fields. Some scientific applications were determination of gas tube

characteristics, calculations on scattering of electrons by hydrogen atoms, determination of microwave absorption in ferrites, analysis of color fading, studies of dielectric relaxation in gases, molecular collision studies, and calculation of ionospheric properties. Important problems in data processing included allocation of oil supplies, assignment of radiofrequencies, analysis of electrocardiograms, traffic studies, mathematical investigations related to postal operations, housing analysis, and simulation of military engagements.

Experiment Designs. A new theory was developed on the construction and analysis of asymmetrical factorial experiment designs. In many physical science and engineering experiments it is desirable to study the effects of varying two or more factors through a finite number of levels of each. An experiment is termed a factorial experiment when it is designed to test all possible combinations of the factors and levels; it is termed an asymmetrical experiment when the levels over which a factor is varied are not the same for each of the factors. The literature on asymmetrical factorial designs is somewhat limited. The main advantages of the newly developed theory and methods are: (1) They are applicable to any asymmetrical factorial experiment arranged in accordance with a wide class of partially balanced incomplete block designs, thereby allowing greater flexibility in adjusting the experimental design to fit the physical situation; (2) there is no restriction that the levels must be a prime (or power of a prime) number; (3) the reduction of the data from an asymmetrical factorial so designed is relatively simple no matter how many factors or levels are involved; (4) the analysis is independent of the concept of "confounding" in the sense that one can compute the best linear estimates of all main effect and interaction terms without knowing which of the terms is "confounded" with any of the others; and (5) the analysis is strictly algebraic in nature and avoids difficult combinatorial arguments that would otherwise be required to treat cases involving partially balanced incomplete block designs with more than two associate classes.

In addition, application of mathematical methods of combinatorial analysis led to a nearly complete enumeration and construction of a new class of balanced incomplete block "weighing" designs that promises to be of exceptional value in the calibration of groups of standards of nominally equal magnitude.

Life Testing and Reliability. Intensive studies were made of the behavior of a number of current life-testing procedures when applied under conditions different from those assumed in their development. Almost all the statistical procedures in current use for evaluating the reliability of components or equipment rest on the assumption that the failure times follow an exponential distribution. However, in practical situations, rarely are there enough data to determine whether this assumption is correct. The behavior of several popular statistical life-testing procedures was investigated under the supposition that the true failure law was one of the Weibull family of distributions, which includes the exponential distribution as a special case. It was found that the statistical techniques are very sensitive to de-

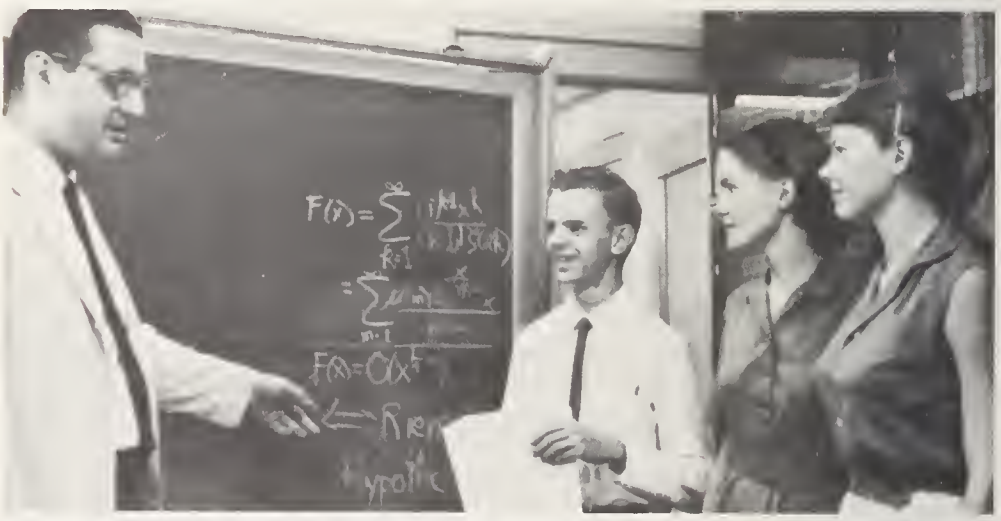
partures from the exponential assumption, and that application of these techniques to life-test data when the exponential failure law is not satisfied may result in substantially increasing the probability of accepting components or equipments having poor mean-time-to-failure characteristics.

Probability and Mathematical Statistics. Considerable progress was made on a unified exposition of the Method of Least Squares consistent with the modern theory of statistical estimation, with special attention to matrix methods and automatic electronic digital computation. Three selected bibliographies of publications during the period 1930 to 1957 on "Correlation and Regression Theory," "Time Series," and "Limit Theorems" were completed and published. An "Index to the Distribution of Mathematical Statistics" was completed.

Mathematical Physics. Research in mathematical physics and related fields continued during the year with emphasis on the formulation of mathematical theories basic to the development of theoretical physics and engineering science. Investigations included a quantum theoretical generalization of the foundations for plasma theory, studies of plasma dynamics, and applications of magnetohydrodynamics to astrophysics.

With the support of the USAF Office of Scientific Research, a program of research was conducted on satellite orbits. Attention was given to the solution of the kinetic equations of motion for a satellite orbit expressed in spheroidal coordinates. Also investigated was the feasibility of using a new set of orbital constants to facilitate further calculations in terms of elliptical integrals.

Other work included analysis of the solution of the Chapman-Kolmogoroff functional equation governing one-dimensional Brownian motion, study of the mechanism of shielding in three-body plasma statistics, and development of bounds in the Cauchy problem for the biharmonic equation essential in the treatment of certain elastic plate problems.



A senior mathematician explains a mathematical theorem to summer undergraduate trainees. During the past year, 195 students in mathematics, physics, chemistry, and engineering took part in the Bureau's summer training program. **(See page 159.)**

2.14. BUILDING RESEARCH

Advances and new developments in science and technology often can assist in solving problems related to building materials, structures, equipment, and facilities. A major objective of the Bureau's building research program is therefore the development of new knowledge through research in chemistry, physics, and engineering. Another important objective is development of measurement and testing methods needed before some of the modern knowledge can be applied to the building industry. To facilitate the use of new knowledge, the Bureau provides aid to other laboratories by devising techniques for accurate measurements, by developing and supplying calibrated laboratory reference standards, and by participating in interlaboratory programs for checking the precision of measurements. The Bureau also provides advisory and consultative services on building problems to government agencies and others. It cooperates with public and private organizations in formulation of specifications and national standards affecting the building industry.

During the year, the Bureau was designated to centralize an accelerated program of fundamental fire research on a national scale. Meanwhile, in one phase of fire research, the Bureau developed a quantitative method for measuring the potential heat of building materials in fires. Fire behavior in rooms was studied. The Bureau also prepared samples of material of measured flammability and made them available for purchase.

In other projects:—Conditions that a family would face in a small underground fallout shelter were studied. Performance of residential heat pumps was investigated. Further study of reinforced concrete beams determined the effect of magnitude of stress in the reinforcement on the bond of deformed reinforcing bars. New data were obtained in experiments through which better and more economical design criteria are being sought for plumbing systems.

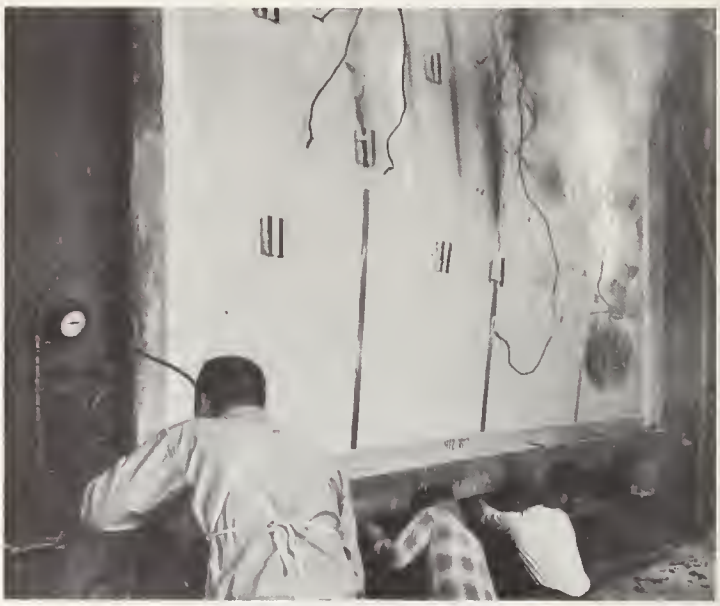
Program of Fire Research. The Bureau was selected as a central agency for fundamental fire research in the physical sciences and was asked to provide a mechanism for dissemination of information on fire research programs. The designation of the Bureau for this coordinating activity followed a study by the Committee on Fire Research of the National Academy of Sciences. The Committee's recommendations were considered first at an interagency conference and then by the Federal Council for Science and Technology. To enable prompt initiation of the new program, funds were made available to the Bureau by the Department of Defense and the Office of Civil and Defense Mobilization. Most of these funds were used to support fundamental research at other laboratories.

Potential Heat of Materials in Building Fires. Although the extent to which building materials burn and add heat to building fires is of importance, the commonly used methods of measurement often show the flammable, smoldering, and heat release properties of a material, with no clear-cut indication of potential heat. However, a differential bomb calorimetric

method developed by the Bureau now appears to provide a quantitative method of measuring potential heat.

The method, which is similar to one used by the French Government, involves determinations of the heating value of the material in a high pressure oxygen bomb calorimeter, both before and after exposure to a "standardized fire." The difference in values represents the heat released during exposure to the fire, or the potential heat. To insure combustion of small quantities of combustibles in otherwise inert materials, a combustion accelerator is added to the samples, and a correction for the heat released by the accelerator applied to the results. A two-hour exposure to air in a muffle furnace at 750 °C serves as the fire exposure. From determinations on a wide variety of building materials the method appears to provide a useful tool for the quantitative measurement of the liberated heat.

Behavior of Model Crib Fires. Fires in buildings are extremely complex and there is a dearth of basic knowledge on fire growth and propagation. Moreover, because of excessive cost of performing full-scale tests of fires involving rooms and buildings, techniques are needed for use of models in fire research. Employing this model-study approach, the Bureau is engaged in a program of research on the factors influencing fire behavior in rooms. As an initial step, experiments were performed in which geometrically similar unenclosed cross piles of wood were burned under controlled conditions.



Prefabricated wall panel at the time of failure in a fire endurance test. The panel is of a special lightweight construction designed for use in arctic regions (page 109).

Flammability Standard. The radiant panel method of measuring surface flammability of materials, previously developed by the Bureau, is being adopted by the American Society for Testing Materials as a tentative standard method of test. Meanwhile demand has developed for a material of known flammability for comparison purposes. The Bureau accordingly has prepared a supply of specimens of measured flammability. Samples of this Flammability Standard No. 1002 are available for purchase.

Underground Fallout Shelters. A study of environmental factors of temperature, humidity, heat transfer, and ventilation in a family-sized underground fallout shelter was carried out for the Office of Civil and Defense Mobilization. Using simulated occupants to represent the metabolic heat release of six adults, the investigation measured the heat transferred to the surrounding earth and to the ventilating air, for maximum summer and minimum winter temperatures. Further analysis of the data will be undertaken to develop more generalized relations between the earth characteristics, the above-ground weather conditions, and the internal heat input in similar shelters.

Heat Pumps. Studies of residential heat pumps were completed, to determine the effects of changes in the rate of air flow through the indoor coil on the coefficient of performance for heating and cooling. The studies also covered the effect of changes in the refrigerant charge, outdoor and indoor temperatures and humidity. Heat losses in refrigerant lines and four-way valves were also explored, and data were obtained on the effect on heating capacity of winter defrosting of the outdoor coil. These design data are being prepared for publication.

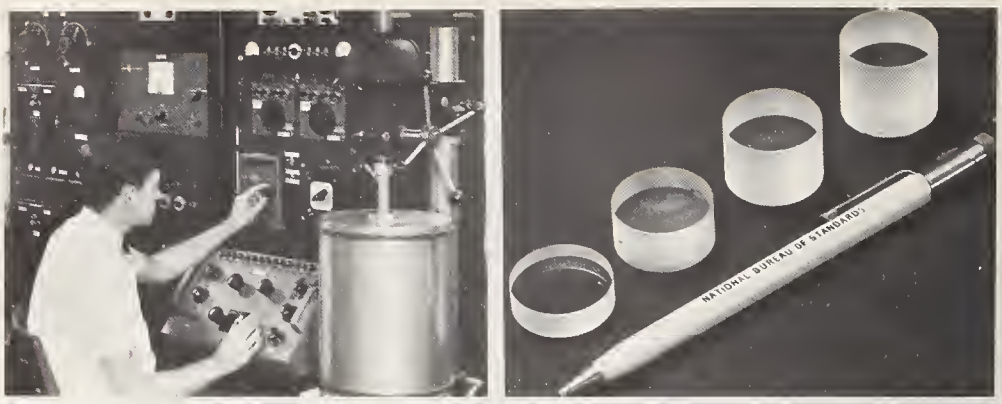
Studies are in progress on improving measuring techniques for determining heating and cooling capacity of the heat pumps. These efforts are directed toward greater precision in measurements of wet- and dry-bulb temperatures in a moving air stream and toward better mixing of the air stream whose conditions are measured.

Thermal Conductivity of Semiconducting Materials. Currently there is widespread interest in thermoelectric materials used for direct conversion of heat energy to electricity. The thermal conductivity of these materials has an important effect upon efficiency of the process. However, accurate measurements of the thermal conductivity over the temperature ranges of major interest cannot be made by methods commonly used, because the materials of greatest interest often are available only in specimens much smaller and of different shape than needed for existing equipment.

Under the sponsorship of the Navy Bureau of Ships, a method and apparatus were developed for steady-state thermal conductivity determinations at temperatures to 800 °C and above on small specimens (½-in. by 1-in. diam disks). The objective is to supply samples of materials to other laboratories for thermal conductivity reference specimens for investigations of solid semiconductor materials.

To permit operation up to 1,200 °C, the high temperature working parts of the apparatus are being changed from stainless steel to 60 percent platinum-40 percent rhodium alloy. It is expected that thermal conductivity calibration samples for use at temperatures from 100 to 1,000 °C will soon be available.

Bond Between Concrete and Deformed Reinforcing Bars. The increase in availability of commercial grades of high-yield-strength deformed bars is stimulating interest in use of high stresses in tensile reinforcement. Because the integrity of a reinforced concrete structure depends upon the



Thermal conductivity studies of small solid specimens using specially developed equipment. Specimens such as those shown at right have been studied at temperatures up to and above 800 °C (page 111).

strength and permanence of bond between the concrete and reinforcement, an investigation was carried out to determine the effect of the magnitude of the stress in the reinforcement on the bond of deformed bars. Bond strengths were determined in a series of beam and pullout specimens with deformed reinforcing bars having a nominal yield strength of 100,000 psi. The new data provided information not previously available on the bond properties of modern deformed reinforcing bars when subjected to very high tensile stresses.

Physical Properties of Masonry. Portland cement-base masonry cements are being used extensively for mortars in masonry construction. Freshly mixed mortars containing these cements include considerable entrained air in the form of many very small bubbles or air voids. To determine properties of these modern air-entrained masonry mortars, a comprehensive study was carried out at the Bureau with over 40 portland cement-base masonry cements. The properties studied were water retentivity, workability, compressive strength, and bond with various masonry units. Some of the masonry mortars were used to build large walls which were tested for compressive, racking, and flexural strengths. The data obtained will be included in publications being prepared.

Asphalt Degradation. New procedures were investigated with 24 coating-grade roofing asphalts to obtain information about processes of deterioration and to determine possible correlations of laboratory data with durability under exposure to the weather. Among the most promising correlations were: Solubility parameters, filtration rates, infrared spectral characteristics, thin film oxidation rates, voluminosities, and viscosity-gravity constants.

Aging Effects in Hydrated Cement. Gas adsorption techniques, similar to those which have been developed to study catalysts and other colloidal solids were used at the Bureau to show that hydrated portland cement undergoes changes in structure similar to the changes of aging in other colloidal solids. This process involves an irreversible coalescence of the submicroscopic primary particles to form agglomerates of some kind, and it results

in a decrease in colloidal surface area. It was concluded that aging effects undoubtedly play a role in shrinkage and creep, as well as in the development of strength in concrete.

Magnesium Oxysulfates. The thermochemical properties, and in particular the heats of formation, of substances occurring in cementitious systems are being investigated. Data of this nature, helpful in predicting stability when combined with other measurements of thermodynamic properties, are relatively few. Currently work is being done on the magnesium oxysulfates, and measurements are essentially complete on the compound, $4Mg(OH)_2 \cdot MgSO_4 \cdot 8H_2O$, stable in magnesium sulfate solution at room temperature and hence a potential product of the setting of magnesium oxysulfate cement.

Calcium Aluminate Complex Salts. Tricalcium aluminate combines with various calcium salts in aqueous solution to form a group of hydrated compounds which are important in hydration and hardening of cements. Several members of this group, particularly the carbonate and sulfur derivatives, are being investigated. The two calcium aluminate carbonate hydrates were prepared and studied by microscopic, X-ray diffraction, and other methods. A thermochemical study of the calcium aluminate trisulfate was completed.

Cement and Concrete Reference Laboratory. The Cement Reference Laboratory expanded its activities to include concrete as well as cement. This service, jointly sponsored by NBS, the Bureau of Public Roads, the Corps of Engineers, and the American Society for Testing Materials, seeks to increase the dependability of tests used in concrete design and in assessment of the finished product. The new name, Cement and Concrete Reference Laboratory, was adopted.

Cement Reference Samples. Highway laboratories of 46 States as well as Federal agency laboratories engaged in cement testing are participating in an NBS program designed to evaluate testing laboratory competence. Samples from uniform lots of cement are submitted in pairs to each laboratory at two-month intervals. The paired-sample technique can indicate the degree of variation of results at the different laboratories, and also which test procedures need improvement. Laboratories showing considerable inconsistency are offered assistance through correspondence or through the services of the Cement and Concrete Reference Laboratory.

Floor Friction Standards. These studies are related to measurement of slipperiness of floors, walkways, and highway surfaces. Reference plates, each with a fine, medium, or coarse cut—on hard, heat-treated steel—were constructed in an attempt to fill the need for surfaces of different degrees of roughness. These surfaces in turn are designed to serve as standards in the calibration of instruments for measuring the coefficient of friction of floor, walkway, and highway surfaces. The surface characteristics of these standards will be transferred to secondary standards of other materials, including softer metals, for use by selected laboratories with a variety of instruments for measuring slipperiness. The dependability of the plates as

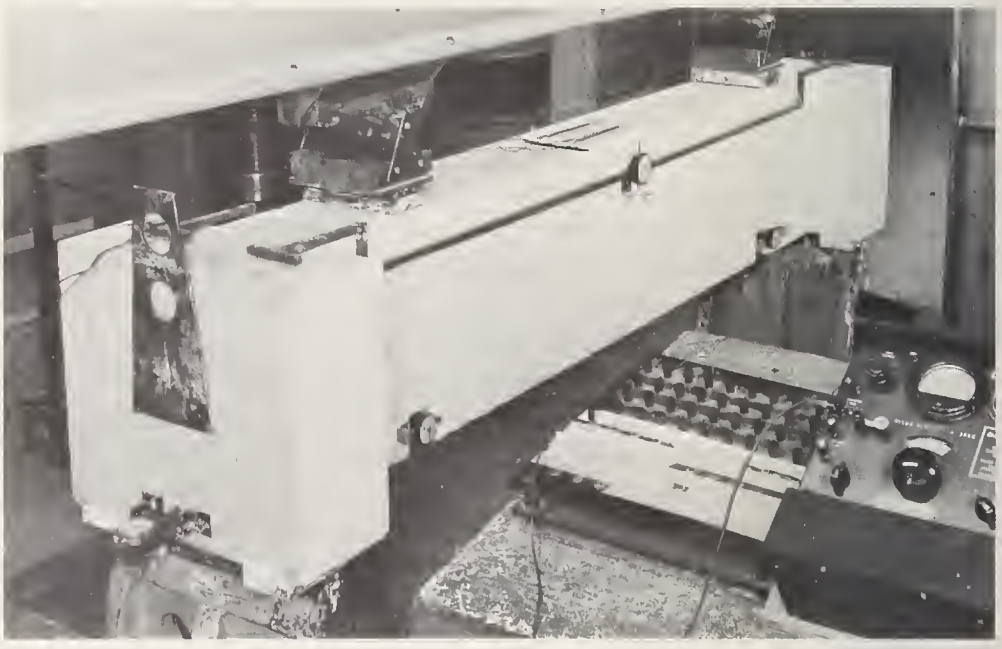
calibration standards and their reproducibility will be checked further by detailed measurements of the geometry of the surfaces, and by investigating the uniformity of plates made at different times.

Abrasion Resistance of Protective Coatings. The Bureau made a number of improvements in its methods for measuring the abrasion resistance of protective coatings. An abrasive jet apparatus developed at the Bureau is used in these measurements. The changes did not alter the basic manner of operation but increased speed, ease, and precision. Several subtle sources of error in the original method were identified and eliminated. Practical operating limits were established. Within these limits good precision can be expected over a wide range of test conditions.

Studies showed that the method is not limited to the organic coating materials for which it was originally designed. It also is applicable to ceramic, porcelain, and anodic coatings, as well as to films and tapes when attached to a rigid substrate. Sheet metal of aluminum, brass, or steel may also be tested. Moreover, a good qualitative correlation was observed between test results and the service performance of protective coatings applied to military aircraft.

During the year, the abrasive jet apparatus was demonstrated and advice and assistance were given to industry and governmental laboratories on construction of the apparatus and training personnel in its use.

Design Loads for Plumbing Systems. Although present knowledge of the physics of plumbing systems and of the typical loads to which such systems are subjected is inadequate for development of realistic design criteria,



Testing a reinforced concrete specimen to determine the strength of the bond between the concrete and deformed reinforcing bars. The integrity of a reinforced concrete structure depends upon the strength and permanence of bond between the concrete and reinforcement (page 112).

progress was made in obtaining new data on the factors affecting the surge flow capacities of nominally horizontal drains. Recently completed experiments indicate that reasonably accurate estimates of capacity can be made by taking account of the slope and diameter of the drain, the roughness of the pipe material, the duration of the surge and the relationship between the volumes of flow in the main and the branch drains.

2.15. DATA-PROCESSING SYSTEMS

The Bureau's program in data-processing systems includes research, development, systems design and analysis, and technical advisory services in both digital and analog computer technology. The Bureau serves the Government as a central agency for providing comprehensive and readily available information in both the development and application of high-speed automatic data-processing systems. Many requests are received from other government agencies for assistance and advice relative to their data-processing problems in engineering, management, and operations research, as well as control systems and simulation. These advisory activities strengthen the Bureau's basic computer program, which ranges from research in components, circuits, systems, and simulation to advanced work in new computer applications.

Among the accomplishments during the past year were continued applied research and development on components and circuits applicable to improved operations of the basic units of data-processing devices and systems, the engineering and construction of a flexible multipurpose high speed digital data processor, the machine processing of voluminous logical design data to automatically create manuals and indexes for a large-scale installation, the development of special-purpose information storage and retrieval devices, and technical assistance on the application of automatic data-processing techniques and equipment to government problems. Of particular significance was extensive assistance to the Bureau's own research laboratories in identifying problem areas where experimental data could be automatically prepared for direct computer input. The range of data-processing applications for the Bureau and other government agencies increased materially during the past year.

SEAC and Analog Computing Facilities. SEAC has continued to be used as a high-speed digital research facility for experimental investigations of specialized information processing, data conversion and reduction, real-time simulation, and picture-pattern processing. In some instances processing these problems required modifications that improved the utility of the machine. For example, provision was made to accept six-bit information from a magnetic tape unit in the analog computer room controllable from the SEAC console. Engineering of a multichannel magnetic tape unit system was completed, in preparation for installing four high-speed recording units. New silicon photocells were installed on the high-speed photoelectric punched paper tape reader, which has had error-free performance since its modification.

The output format capability of the Bureau's analog computer was extended by the addition of a manual keyboard to a 10 in. × 15 in. recorder to permit point-by-point plotting of data in digital form, and a logarithmic converter was obtained to permit semilog plotting of either digital points or analog curves.

The Bureau's simulation facility, which includes SEAC, the analog installation, and appropriate display devices, was used to demonstrate some of the functional requirements for air traffic control equipment as applied to airways traffic in the Washington, D.C., area.

PILOT Data Processor. The NBS PILOT Data Processor, a highly flexible research tool developed for investigating new and unusual data-processing problems for government, is nearing completion. Power distribution, clock distribution, circuit protection, and all the printed circuit connectors were installed in the 24-rack assemblies. Approximately half of the logical wiring was completed, and all of the printed circuit packages required for the initial installation were delivered and inspected. The console also is nearing completion, and the associated input-output typewriter, wire drive, paper-tape punch, paper-tape reader, and high-speed punch are ready to be connected. Three plugboards were installed and connected, and a light panel containing approximately 1,000 pilot lights was connected into the system.

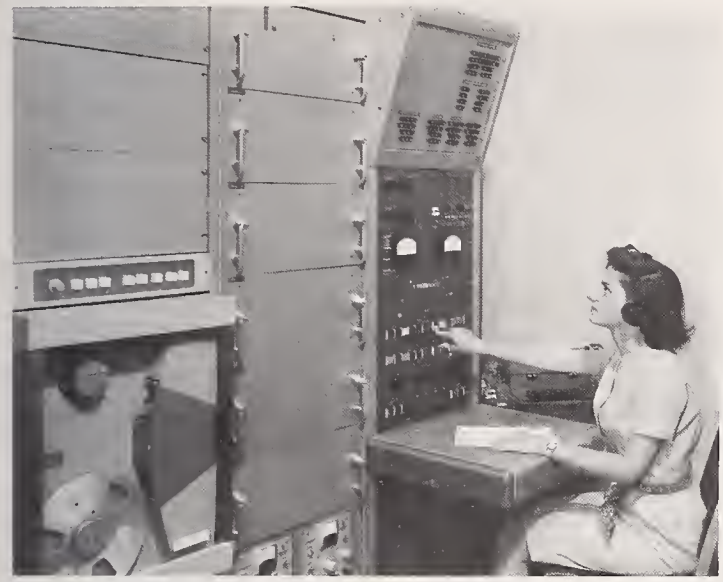
Technical Assistance for Data Processing. A continuing survey of laboratory operations throughout the Bureau revealed a variety of data-processing tasks, some of which had special data conversion problems. In some instances, technical assistance was provided through study of the problem to determine whether analog or digital techniques were applicable and to demonstrate the feasibility of such applications. Additional assistance was given in the design and development of special data logging equipment. as needed to convert the data to acceptable input form for the computer. Some of this was constructed in the user laboratories with advice in the utilization of NBS packaged circuitry.

Typical problems included design of a bandpass filter for use in a seismic galvanometer, determination of rate of oxidation of niobium, determination of the parameters defining the refractive index of crystalline material, mathematical analysis of lens quality by multiple ray-tracing techniques, temperature distribution throughout a cylindrical ceramic rod, measurement of thermal expansion in dental amalgams, the production of Mollier charts representing solutions of equations relating pressure, temperature, and volume for gases at very high temperatures, and the production of isoenergy curves on the intensity/angle field from the electron scatter measurements.

Components and Techniques. The development of faster, more complex computers and data processors requires the judicious choice of new components and better understanding of existing ones. In both cases, measurement of properties of components is fundamental. Improvements in computer performance can be expected from the utilization of components that make novel application of physical phenomena. For example,

because evaporated nickel-iron films show promise as very fast memory and switching elements, a large evaporator was placed in operation and instruments were set up for measuring thickness, coercivity, anisotropy, and reversal time for films.

Investigation of the operation of medium-speed alloy junction transistors in large-signal switching circuits was continued. New techniques were developed for applying the general nonlinear equivalent circuit devised to describe the large-signal switching behavior of transistors to circuit design problems, and a circuit optimization procedure is being programed for a digital computer.



Special-purpose computer, AMOS IV, developed for the Weather Bureau for use as the central element in an automatic weather station. The computer collects and processes the data picked up by the station before it is transmitted (page 118).

Techniques for measuring the parameters of high-frequency semiconductor devices are under investigation, concurrent with a literature survey on tunnel diodes and mesa transistor types, in anticipation of extending the application of the large-signal equivalent circuit and simulation studies to these components.

Under the sponsorship of the U.S. Army Signal Corps, several new transistor circuits were designed by means of the equivalent circuit technique and added to the series of medium-speed logical building blocks.

Digital Circuitry. The design and development of improved digital circuits for use in advanced digital computing and information handling systems and for performing switching and memory functions was continued under the sponsorship of Air Force Cambridge Research Center and U.S. Army Supply Agency. An instrument was developed for quickly and accurately setting phases on a set of clock signals in a five-phase system by comparing all other phases with one arbitrarily chosen phase. Prototype assemblies of shift registers and counters were devised and constructed on very thin flexible fiber glass laminate. These assemblies were then rolled into compact cylindrical modules for evaluation. Electrical performance was measured and found satisfactory in an experimental sub-unit of typical

digital equipment in which density of 10 components per square inch was achieved with singlesided printed circuit wiring.

Investigation of the switching behavior of small ferrite cores, potentially useful for increasing the speed of large random access memories, was continued. The investigation was directed at evaluating the properties of the core itself. Some of the parameters describing core switching were defined and important mathematical relationships between them derived. In addition, a useful graphical representation of core switching behavior was made. This information will be useful in the development of the necessary high-speed and high-reliability circuits needed for the functions of driving, selection, and detection in a large fast memory.

Digital Systems Research. In information retrieval systems, the tasks of locating, manipulating, and producing the sought-for information may be assigned to several independent devices that can search, process, and display data automatically. All of these different devices must be organized to interact together, cooperatively and concurrently, in an effective ensemble operation. In order to establish priority methods for establishing clearly the necessary and sufficient order of precedence among the different devices at every step, further applications of techniques of graph theory and Boolean matrices to the organization and programing of large-scale information retrieval systems were studied under the sponsorship of the National Science Foundation. Results indicate how these methods can be used to detect errors in programs, and what further study must be made to lead to methods of optimum scheduling.

Special-Purpose Digital Computer. Under a program sponsored by the Weather Bureau, a special-purpose digital computer, AMOS IV (Automatic Meteorological Observation Station), was developed as the central element in an automatic weather station to collect and process weather data prior to transmission. This computer permits a considerable reduction in peripheral equipment and many simplifications in the input instruments. The computer is built around a drum memory operating at 1,800 rpm and having a capacity in excess of 20,000 three-digit words. It uses transistorized circuitry built of standardized compatible 50-kc/s building blocks.

Data Transmission Link. Because of the widespread interest in the development of more effective, economical means of transmitting digital data between remotely located high-speed digital computers, a two-way digital data link from magnetic tape to magnetic tape via a microwave path was established between the commercial computer at NBS and the Weather Bureau in Suitland, Md. The work was completed by an outside contractor, under the Bureau's technical guidance.

Fallout Predictor. The prototype model of a special-purpose analog computer was developed and constructed for the U.S. Army Signal Corps. The instrument, an outgrowth of an earlier Bureau development, predicts radioactive fallout for any selected locality in about 5 seconds after entry of input data on approximately 100 parameters, such as direction and velocity of the winds and the distribution of radioactivity within the cloud. This

model has such special aids as a monitoring oscilloscope and a plotting table to permit rapid marking of the fallout pattern on a standard Army map.

Biomedical Data Processing. At the request of the Air Force's Office of Scientific Research, the design specifications for a system developed earlier for processing electrocardiograph data were modified for processing psychological data at Georgetown University Hospital. Transducers to convert psychological reactions to analog voltages were tested.

Computer Systems Evaluation. Assistance was provided the Bureau of Naval Weapons in evaluating proposed computer methods and equipment for a real-time computation system for the Pacific Missile Range. The system must provide real-time computation of missile and satellite trajectories, predicted impact point, vehicle control functions, and target acquisition aids for remote tracking equipment. A related telemetry digitizing system now being designed will process telemetry data either during or after a missile flight and include such functions as channel selection, sampling rate and sampling times under control of a general-purpose digital computer.

Analog-Digital Differential Analyzer. Two integrator units and two multiplier units of a novel form of combined analog-digital differential analyzer are under construction. The advantages and limitations of this system will be evaluated for applicability to test-range instrumentation.

Automatic Mail-Sorting Developments. The Bureau is continuing to assist the Post Office Department's Research and Engineering Division in its objective of applying automatic equipment and data-handling techniques to the improvement of the mail-sorting operation. A plan for conducting the tests and demonstrations of the prototype code-sort equipment was developed, including a distributor and file directory which were designed by an outside contractor. The primary purpose of the plan is to obtain basic statistical data on important human factors through controlled operation of the installation. Procedures for setting up efficient mail distribution schemes to be used with code-sort equipment and for preparing scheme data for the file directory were developed, and a scheme for using code-sort equipment to sort the present manual and the proposed keysort distribution schemes at the Washington, D.C., Post Office was specified in complete detail. Preparation of the detailed file directory data was initiated, to be available when the equipment is ready for operation.

Mechanization of Patent Searching. The cooperative program with the Patent Office for mechanizing patent search operations was continued. Major emphasis was devoted to the preparation of a representative data file and to the planning, developing, programing, and checking out of data-assembly and data-checking routines. In connection with the generating, sorting, and compiling of patent data into a format that meets HAYSTAQ requirements, a routine for the sorting and assembly of new data was completed and checked out. In addition, an error expurgation program routine was programed and partially tested and checked out. Plans have been prepared for large-scale tests using diverse types of realistic questions in

order to determine the practical applicability of these chemical search strategies.

Studies were also continued on several possible ways of writing a grammar for English that can be mechanized in the form of a computer program. Some of this work was directed at grammars for the whole English language and others at certain specialized dialects of English.

Pictorial Data Processing. Under the sponsorship of the U.S. Naval Training Device Center, a study was undertaken to develop a technique that can digitally scan aerial stereo-photographic information and, with proper computer programing, translate this information into elevation profiles. In the course of this development three-dimensional models of a terrain were constructed, photographed, scanned, and digitalized with SEAC. A program was completed to derive from these digitalized stereopairs measurements of the height of simply recognized features in the terrain.

Prototype model of a special-purpose analog computer which predicts radioactive fallout for any selected locality in about 5 seconds after the input of data on approximately 100 parameters. It was developed for the U. S. Army Signal Corps (page 118).

Research Information Center. The collection and organization of literature and bibliographic references covering a wide range of interests in information storage, selection, and retrieval for the Research Information Center and Advisory Service on Information Processing was continued under sponsorship of the National Science Foundation. Information was also assembled on current and proposed research projects and workers in the field. In addition, interdisciplinary research areas were studied to identify techniques which are potentially applicable in solving complex problems in information processing and literature retrieval, and a primary review of overall problems, and a suggested framework for research in mechanized information selection system was presented to the sponsor. Spe-

cial state-of-the-art reviews on mechanized chemical information searching and the states of character recognition developments were completed.

Simulation of Traffic Flow. At the request of the Bureau of Public Roads, a program for simulating municipal traffic flow by means of high-speed automatic data-processing and display equipment has been under way as a basis for the design of more efficient highway signaling. A computer program prescribing the rules for the simulation of the movements of both cars and trucks along nine blocks of a Washington, D.C., street was completed. This program generates vehicle positions and writes the coordinates on a magnetic tape output. A SEAC program then converts the vehicle position from the tape over to an oscilloscope and also actuates a camera to photograph the displays of successive traffic configurations. The result is a motion picture film that projects in real time the traffic movement for a three-minute period.

Statistical Data-Processing Installation. The U.S. Army Chemical Corps requested the Bureau to undertake a study of the performance requirements, evaluate available data-processing systems, and recommend suitable equipment in the moderate price range to meet the statistical requirements for processing results of tests and experiments in support of their research and development program. This collaborative program resulted in the recommendation and purchase of a commercial computer, which was installed and accepted at Fort Detrick in February 1960.

Communications Data Processing. The Federal Communications Commission requested the Bureau's advice and assistance in applying automatic data-processing techniques and equipment to improve the efficiency in handling their massive paperwork operations. Following completion of the initial information gathering phase, a joint study was conducted to determine the data-flow pattern and the procedural activity of each functional area. Through this joint study, the tentative conclusion was reached that automatic data processing techniques are applicable, and systems design work was then undertaken. Concurrently, computation of antenna signal intensity patterns was programed as typical of the way in which technical data enter into the Commission's activities. This program for the computations of antenna pattern has been completed and is now available for production runs on a computer. In each area the data were classified according to the FCC function being carried out and whether they were in the form of source documents, permanent records, intermediate records, or final reports. This inventory was used to chart, for each function, the flow of information from the source documents to the final documents on which the decisions reached are recorded.

Additional Data-Processing Applications. The task of mechanizing personnel data recording and reporting was continued. Data describing each NBS employee, as well as each research associate and guest worker, were encoded and recorded on a magnetic tape. This tape will be updated each month and various reports generated from the data. Present plans include

the programing of 44 regularly recurring personnel reports and 1 budget report. Codes for about 15 of these reports are now written, and an auxiliary routine to be used for generalized editing was designed and partially programed.

Continuing technical assistance and advice was provided to the Federal Home Loan Bank Board in connection with the processing of data from reports of savings and loans associations. These monthly reports serve as one index of the status of the national economy. Since personnel of FHLBB are now in a position to prepare their own codes, only the Bureau's computational services are presently required.

At the request of the General Services Administration, assistance was continued in the final evaluation of proposals for an automatic data-processing system to integrate management control over the Federal Supply Services network of stores depot. A series of training sessions was conducted for top management, systems analysts, and computer managers in the techniques of automatic data processing.

The U.S. Public Housing Authority constantly reviews and edits a substantial volume of reports of eligibility for continued occupancy of low-rent housing. Under preliminary studies, the Bureau had concluded a feasibility study of machine editing of report data for internal consistency. Subsequently, changes in rules and regulations extended the volume of data to be edited. In addition, machine editing facilitates administrative reviews that cannot otherwise be made on an adequate sample of the reports. The PHA data for the entire year were edited on the 704 computer, query output was processed and machine-prepared letters were printed on the off-line printer.

Under the sponsorship of the National Institutes of Health, a preliminary study to investigate data processing techniques having adequate growth capability to maintain and select information on the NIH grant program was instituted. NIH administers the Government's support of medical and biological research through grants to universities and other research organizations, and the objective is to develop automatic means for storing, sorting, and retrieving information concerning the program.

The Maritime Administration has large and complex data handling problems arising from its regulatory activities for ship operation and construction. At the request of the Maritime Administration a preliminary study of the overall data-processing functions and engineering calculations was instituted for the purpose of determining the feasibility of and identifying specific areas for further detailed applications studies.

2.16. CRYOGENIC ENGINEERING

The Bureau's activities in cryogenic engineering, a rapidly growing specialized field, center at the Boulder Laboratories. The Bureau provides information needed for practical applications of materials, systems, and techniques at very low temperatures, and assists Government and industry with problems arising in this field.

Demand for assistance in projects involving cryogenics has increased greatly as a result of missile and space programs which rely on cryogenic liquids as propellants. Meanwhile the growth in acceptance of the importance of cryogenic engineering has been accompanied by emphasis on purely scientific programs in which the use of extremely low temperatures can be an important aid. To cooperate in the above activities, the laboratory conducts research on the physical properties of materials and properties of fluids, as well as on cryogenic processes and equipment. In addition, it maintains a national Cryogenic Data Center where information on cryogenic engineering is collected and organized for use by other government agencies, industry, and the public.

Cryogenic Engineering Data. The Cryogenic Data Center currently has nearly 10,000 listings of published literature and reports useful in the cryogenic engineering field. Over 7,000 of these now are primary-coded on manual punched cards for storage and retrieval. All citations with characteristics of the documents are being assembled in a catalog of references soon to be available. Bibliography service is being furnished on request to the Bureau staff and to a limited extent to outside groups. Plans were made during the year for early conversion from manual operation to a mechanical system. This will permit extension of the reference service, with some increase in scope, to the cryogenic engineering industry.

The evaluation and compilation of cryogenic data, another activity of the Cryogenic Data Center, is being expanded to permit more exhaustive correlation of data. A compendium of Properties of Materials at Low Temperature (phase 1), prepared under sponsorship of the Wright Air Development Division of USAF, was completed.

Low-Temperature Transformations in Steels. Austenitic stainless steels are widely used in cryogenic equipment because of their retention of toughness at low temperatures. While it is known that plastic deformation of these steels tends to produce the martensite phase with consequent modi-

Martensite band produced spontaneously on cooling an unstable AISI 304 steel to 76 °K. The conversion of austentic steels to martensite at low temperatures modifies their mechanical properties (page 123).

fication of their mechanical properties, the nature of this inter-relationship is not always clear, nor are the mechanisms for formation of the new phase.

As part of a larger program, sponsored by the Department of Defense, the alloys, AISI 304, AISI 202, AM 350, and USS Tenelon, were tested in tension and impact at temperatures down to 20 °K. The first of these alloys, AISI 304, is already widely used in cryogenics. The strength data obtained in these tests will be useful to equipment designers.

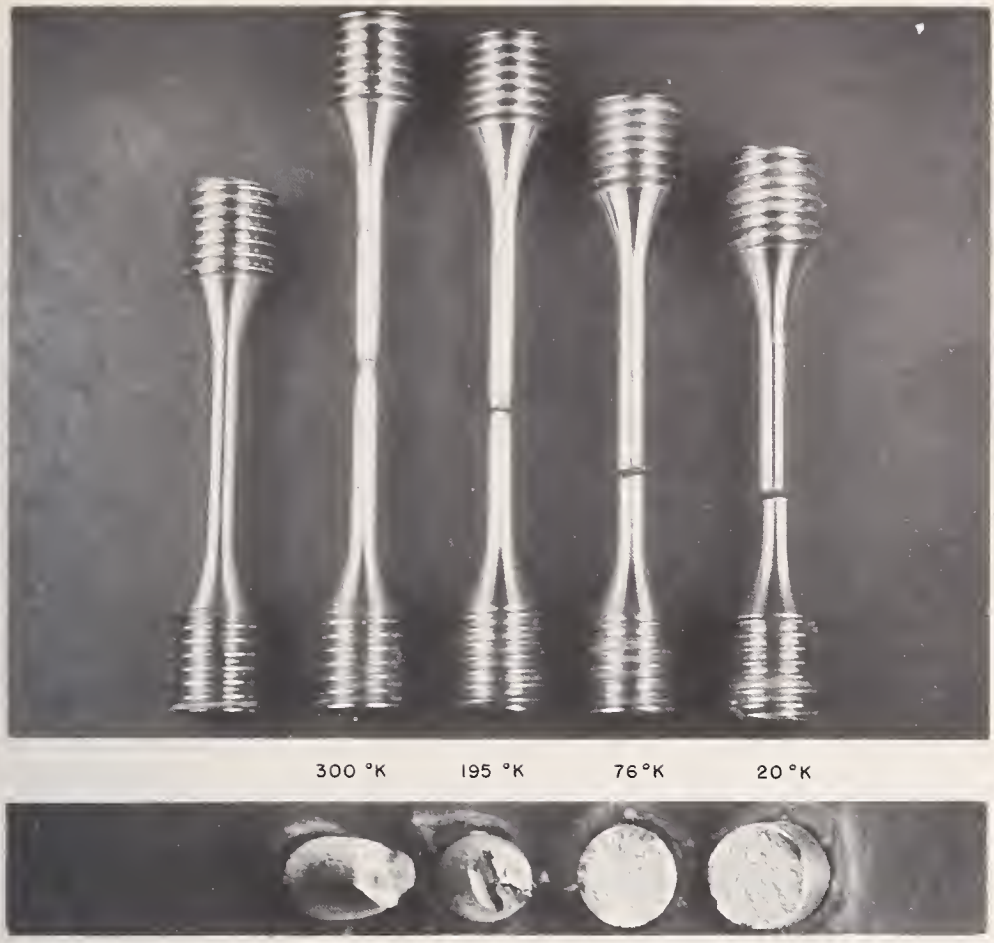
In addition, magnetic analyses for martensite helped to explain the observed dependence of the mechanical properties on temperatures. The mechanism for martensite formation in AISI 304 is being studied by dislocation etch pit and X-ray techniques.

Thermal Insulation. Last year the discovery of evacuated laminates giving revolutionary improvement in insulating efficiency was reported by the Bureau. These "super insulations," which have wide applications in the cryogenic industry, have now been thoroughly examined, and the choice of materials and the techniques for installation suitable for achieving the best results have been established. The effectiveness of this kind of insulation was found to depend strongly on the mechanical loading and on the care taken to preserve the continuity of the laminae when installing over surfaces of complicated shape.

Reactor Materials. A rocket powered by a nuclear reactor receives optimum thrust if the propulsion fluid is the low molecular weight substance, hydrogen. However, the hydrogen must be carried as a liquid in order to achieve compactness in a light-weight container. In liquid form it can also provide cooling for the reactor and other components of the rocket.

The physical properties of the reactor materials at low temperatures are therefore of considerable interest. In cooperation with the Los Alamos Scientific Laboratory of the AEC, the Bureau measured the mechanical properties and the thermal conductivity of beryllium, molybdenum, tungsten, and graphite, and the thermal expansion of graphite down to 20 °K.

Thermocouples for Low-Temperature Use. Thermocouples are widely used for temperature measurements where compactness and quick response are desired and where moderate accuracy of the order of 0.1 deg is acceptable. Moreover, the rapid expansion of liquid hydrogen technology has created a demand for thermometers that are usable in the region of 20 °K. Because conventional thermocouples are insensitive at such low temperatures, a thermocouple composed of gold-cobalt alloy versus copper or a silver-gold alloy has come into use. The Bureau completed a study of the temperature-emf relation, the homogeneity, and the stability of these thermocouples, including for comparison a similar study of the commercial thermocouple, copper versus constantan. Detailed reference tables for these instruments were given widespread advance distribution in response to numerous inquiries from users. Work also is in progress on the low temperature characteristics of other established thermocouples that find occasional use in special cryogenic applications at temperatures below their



Specimens show how ductility of annealed AISI 202 steel decreases as its temperature is lowered. Unbroken specimen at left shows original size (page 123).

usual range of applicability. Meanwhile new thermocouple materials are being investigated in the search for higher sensitivity, improved homogeneity and stability, and lower thermal conductivity.

Cryogenic Fluid Flow. Knowledge of phenomena which occur when cryogenic fluids are flowing is essential to the understanding of almost all cryogenic equipment. Several of these phenomena were studied during the year. The Bureau completed its experimental studies of pressure drops in steady, two-phase, single-component fluid flows; data obtained with highly diabatic flows confirmed the conclusions drawn from previous tests with trichloromonofluoromethane—that the Lockhart and Martinelli correlation can predict these pressure drops. Work completed thus far on choking two-phase flows shows that, contrary to widely held beliefs, the critical pressure ratios are significantly larger than those for the pure vapor phase alone. This result is expected to influence the design of many transfer systems.

The electrokinetics of flowing oxygen were studied to assess the actual hazards resulting from electrostatic charges. It was found impossible to create d-c potentials from pure liquid, pure vapor, or pure two-phase oxygen

flows; however, a-c potentials were created in two-phase flows when the liquid-vapor interface traversed the electrodes. On the other hand, more than 10,000 volts dc could be created when the oxygen was contaminated with solid particles. The hazards due to this effect will be better understood when present experiments which are determining the energy that can be stored by this effect and the energy required in an electric discharge to initiate combustion of the contaminant, are completed.

Heat Transfer. A comprehensive survey of heat transfer between fluids and solid surfaces was completed. Available data for cryogenic systems were evaluated, and pertinent theoretical and empirical formulations were compared with the data. The results were prepared in a readily usable form.

Investigations of the effects of ambient conditions (wind velocity, air temperature, and humidity) on heat transfer to uninsulated liquid oxygen containers showed that wind velocity is the dominant parameter, although for large changes in air temperature (e.g., 32 °F compared with 70 °F), the temperature effect is significant. Since the formation of frost on the exterior surface of these containers is a controlling phenomenon, theoretical and experimental studies of frost formation on surfaces at minus 297 °F were carried out.

The behavior of liquid and gas in a relatively well-insulated hydrogen container when the container is pressurized, permitted to remain pressurized, and then rapidly emptied, was investigated. It was demonstrated that the temperature history in the liquid can be closely predicted from the one-dimensional, unsteady heat conduction equation.

Cryogenic Equipment. The Bureau is constantly working on innovations to make cryogenic equipment more reliable, rugged, efficient, and economical to fabricate and operate. The ruggedness and reliability of some demountable transfer lines utilizing condensing-vacuum insulation and a simplified bayonet coupling with a metallic piston-ring nose seal were demonstrated through field use. A double bayonet coupling was invented and tested; this coupling has the advantages of having a single parting plane and being neuter.

Low-Temperature Seals. Practically all cryogenic engineering applications benefit from successful use of low temperature seals. For example, most equipment such as pumps, valves, transfer lines, and storage Dewars can be simplified by these seals.

Techniques were developed in cooperation with the Boeing Airplane Company which make it possible to use ordinary elastomeric O-rings to make excellent static seals between high vacuum and moderately high pressures at all temperatures between 20 °K and ambient. It also was found that high-strength plastics such as nylon can be used as thin flat gaskets.

Emphasis is placed on determination of pertinent physical properties which will aid in predicting seal effectiveness. Moreover, for a better understanding of the mechanical behavior of elastomers under the highly stressed conditions which are required to make a seal, additional attention is being given to thermodynamic and molecular phenomena.

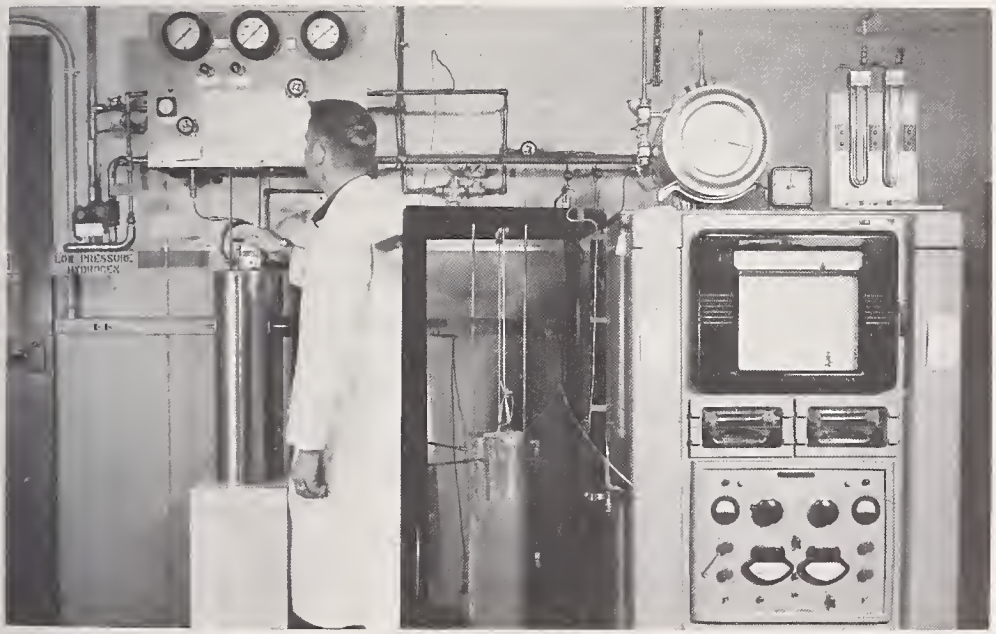
Refrigeration Processes. Many devices such as masers, bubble chambers, computer elements and electro-magnets need a very-low-temperature environment for successful operation. Various kinds of refrigerators capable of maintaining low temperatures continuously, are therefore required.

With these refrigeration needs in view, the most recent and reliable thermodynamic data available for many low-boiling fluids over widely varying temperature and pressure ranges were tabulated for use in computing refrigeration processes. A great many processes using helium gas as the process fluid were programed and calculated using one of the Boulder Laboratories' computers.

Studies of cryogenic machinery and certain machinery elements, such as bearings suitable for use in refrigeration processes, also are in progress.

Physical Equilibria. A major problem in liquefaction of gases is that of preventing the equipment from being fouled with solid impurities which are likely to be frozen. Research is therefore necessary in physical equilibria to establish accurately the exact design for impurity removal. To help meet this need, a comprehensive literature search for material on the physical equilibria and related properties of some cryogenic systems was completed and the bibliography made available to researchers in this field.

In a related program, a theoretical and experimental study of the adsorption of impurities at low temperatures was pursued. The study concentrated on the removal of methane, nitrogen, and carbon monoxide from hydrogen by adsorption. Valuable experimental data were obtained, and an important first step in developing the theory of multicomponent adsorption was taken.



Studying the low-temperature adsorption of impurities from high-pressure hydrogen gas streams. This program provides data necessary for the design of efficient gas purification systems (page 127).

In addition, theoretical and empirical studies were carried out on the behavior of fluid gas systems, and methods of predicting equilibria were developed. Methods of computing vapor pressure, heats of vaporization and heats of sublimation from a minimum of information were developed. This work was accomplished at the Georgia Institute of Technology under an NBS contract.

Gas Liquefaction. Production of liquefied gases was reduced as a result of liquid hydrogen being furnished to local government contractors from other government plants. Approximately 105,000 liters of liquid hydrogen, 800,000 liters of liquid nitrogen and 3,400 liters of liquid helium were produced. Over 2 million standard cubic feet (scf) of hydrogen gas was recovered from on-site handling and use of liquid, thus reducing the need for commercially supplied gas to about 1 million scf.

There was an increase in the number of users of liquid helium supplied this year. However, because of the termination of the NBS Free Radicals Research Program in Washington, the total volume of liquid delivered was somewhat less.

A continued decrease in requirements of those using liquid hydrogen is expected this coming year because of the increasing availability from other plants. This is expected to make the Bureau's liquefaction facilities more conveniently available for special runs and for evaluation and development of cryogenic equipment and processes. The availability of liquid helium from other sources, on the other hand, is not so imminent. As a consequence, for this phase of the program, there may be some increase in production requirements.

2.17. RADIO PROPAGATION

The Central Radio Propagation Laboratory, located at Boulder, Colo., has the primary responsibility within the U.S. Government for collecting, analyzing, and disseminating information on the propagation of radio waves at all frequencies along the surface of the earth, through the atmosphere, and in outer space. To carry out its responsibility, this Laboratory conducts research on the nature of radio waves and the media through which they are transmitted, the interaction of the waves with the media, and the nature of the radio noise and interference effects. A network of field stations is operated from the Arctic to the tropics, and data are exchanged with other laboratories throughout the world. The work of the Laboratory is divided into four areas: Ionosphere research and propagation, radio propagation engineering, radio communications and systems, and upper atmosphere and space physics.

Ionosphere Research and Propagation

Within the field of ionosphere research and radio propagation, the Bureau conducts and coordinates basic research on the propagation of radio waves as affected by the ionosphere and on the special factors which

can cause large departures from the normal behavior; investigates the nature of the media through which these radio waves are transmitted and the interaction of radio waves with the media; prepares predictions of radio wave propagation and warnings of disturbances; acts as a central repository for data, reports, and information in the field of ionospheric radio wave propagation; and provides consultation services on the characteristics of the ionosphere and on radio wave propagation to other government agencies and industry.

VLF Propagation Deduced from Lightning Discharges. Considerable electromagnetic energy in the very-low-frequency region of the frequency spectrum is radiated into the atmosphere from lightning discharges. Most of this radiated energy is contained between the earth and the ionosphere and propagates to great distances in a waveguide type mode.

Various propagation characteristics were determined by analyzing the broadband waveforms of atmospherics recorded at different distances along a propagation path. The attenuation rates and phase velocities as a function of frequency were analyzed to yield the complex (amplitude and phase) spectra, and the spectral values were compared. This analysis was made on many waveforms simultaneously recorded at a network of stations. The characteristics were averaged for propagation from East to West.

F-Region Scatter in the Far East. An interesting finding of IGY work at the Bureau was the discovery of a new mode of propagation above the *F*2 MUF in the Far East originating in the *F* region of the ionosphere. This propagation mode, which has been called the Far Eastern anomaly, was the subject of an expedition in September to October 1959. Signals were determined to be coming from high in the *F* region (400 to 500 km) and to the west of the great-circle-path. These measurements showed that the phenomenon could be observed at a radius of about 2,000 miles around the transmitters in the Philippines and in Okinawa, indicating that the phenomenon does have substantial geographical extent. As the phenomenon was not observed in the Carribbean (at 50 Mc/s), it apparently has a very strong longitude effect.

World Maps for the Prediction of F2 Propagation. For measuring ionospheric characteristics, a network of observing stations is maintained in many countries. A major objective of this network is the development of an optimum global representation of the ionosphere for use in long distance communications in similar applications. Until such a representation is available, ionospheric predictions must be made by interim methods.

The Bureau issued 222 world maps that make up the first portion of a semipermanent representation of average propagation characteristics of the *F* region in the summer of 1959. These maps, based on data from the world network, give characteristics for alternate hours, Universal Time, for six selected months. Data for an additional six months have now been completed and will be issued shortly.

Polar Blackout Film. An animated motion picture film was prepared showing the sequence of events during five periods of worldwide blackout.

Angle of arrival antennas on Okinawa for use in studying an unusual mode of radio propagation occurring only in the Far East (page 129).

The film portrays the changing patterns and apparent motion of blackout areas over the northern hemisphere. Although the data used for making the film are far from ideal, the sequence of events shown for each of these five periods, especially in the initial stages of development, is thought to represent accurately the physical phenomena actually occurring in the upper atmosphere.

New Fading-Spectrum Representation. A unique fading-spectrum representation was developed wherein the amplitude and phase of the fading signal is displayed in detail for substantial periods of time. One day's representation of fading spectrum occupies typically about four feet of facsimile paper. This technique makes possible the recording of the complete fading spectrum for long periods of time in a very compact form without going through intermediate and arbitrary steps of determining a fading rate for a complex fading signal. The technique has many other possible uses such as the study of geomagnetic pulsations and subaudible acoustic variations. At present, a resolution of better than 0.1 c/s is possible at 20 Mc/s.

Morphology of the Daytime Equatorial F2 Layer. The formation mechanism of the $F2$ region of the ionosphere has been a major problem of ionospheric physics for many years. A new model involving only photoionization, recombination, and temperature variations, was developed to explain the main features of behavior of the daytime equatorial $F2$ layer. The new model does not rely on electromagnetic drift. By including the diffusion of charge under pressure and concentration gradients, the model can be expected to account for the main features of the middle latitude $F2$ layer as well.

True Height of the Ionosphere. When high frequency radio waves are used to probe the ionosphere, their group velocity varies with the electron density on the ray path and with the intensity of the earth's magnetic field. Thus the echo heights from conventional ionospheric soundings are

virtual heights, and the true heights of reflection can be determined only by complicated calculations.

The most recent developments have been a great increase in the volume of computations possible through the use of a much larger and faster computer, and the computation of a new parameter—the quarter thickness of the F layer near the maximum density of the $F2$ layer. This scale height could make possible an estimate of the temperature in this region.

Radio Propagation Engineering

More efficient use of the radiofrequency spectrum is the aim of the Bureau's program in radio propagation engineering. This objective requires a basic understanding of radio-wave propagation, noise, and interference. To this end, statistical samples of data on radio-wave propagation and radio noise are collected so that the underlying phenomena may be accurately described. Methods are developed for using these samples to predict the statistical characteristics of propagation and noise variables required in engineering applications.

Ground Communication Systems. Present-day communication requirements demand the utmost in reliability and information capacity. At the same time the demands on radiofrequency spectrum space have been increasing over the past few years at a phenomenal rate. The preparation of performance standards in the form of handbooks will assist the Air Force, as well as other users of communication circuits, to plan, design, and operate various systems in the most efficient and effective manner.

The first six volumes of material was completed. These six volumes will cover the respective communication media of VLF–LF ground-wave and ionospheric transmission, MF and HF ground-wave and ionospheric transmission, ionospheric scatter transmission, tropospheric beyond-the-horizon and line-of-sight transmission, and metallic circuit transmission. One of the volumes will introduce the material in the remaining five.

One volume deals with tropospheric beyond line-of-sight and within line-of-sight transmissions. The subjects covered include complete discussion of propagation characteristics, meteorological considerations, reliability and bandwidth factors, equipment, prediction formulas, siting considerations, and miscellaneous supplementary data and examples. The remaining five volumes are expected within a few months.

Long Distance Propagation Studies at 9100 Mc/s. A narrow band 9100 Mc/s receiver has been designed and constructed together with a 2 kw, 9100 Mc/s transmitter, each using a crystal oscillator that has a frequency stability on the order of a few parts in 10^{10} per day. With this equipment, reliable information can be obtained on the utility of this frequency range over larger distances than possible with earlier equipment. Such studies are expected to lead to a more efficient use of the radiofrequency spectrum.

Path Length for Tropospheric Scatter Circuits. Recent developments in phase measuring techniques of signals propagated through the atmosphere led to a system which should enable an accurate determination

of the physical radio path length in a beyond-the-horizon transmission. An accurate measure of this length will determine the actual location of that portion of the scattering volume which plays a role in this phenomenon. Such a measurement is expected to increase the theoretical understanding of the scattering concept.

Equipment used to investigate the effect of atmospheric turbulence on radio direction finding and guidance systems. Measurements are made of the phase stability of radio signals propagated over line-of-sight paths (page 133).

Airborne Television Studies. Methods of describing the coverage to be expected from a system of UHF airborne television transmitters were developed and used in evaluating the potential of such a network. This study, sponsored by the Ford Foundation, was undertaken because of the recent interest in this means of transmission for educational purposes. Actual on-the-air tests of a single station will begin in 1961 under the direction of the Midwest Program on Airborne Television Instruction at Purdue University.

A wide range of system conditions and mutual interference situations is being investigated. Comparisons can be made of the effectiveness of ground and airborne systems and of the results of varying different system parameters. Predictions are made of the frequency spectrum and equipment requirements for systems designed for coverage of the entire area of the continental United States.

Computations, in statistical terms, have been made for aircraft at altitudes of 7,500 and 10,000 meters, with interference from a single station or

from stations in a triangular lattice. Service probability contours and effective areas are the principal devices used for showing the results. Comparable predictions for transmitting heights of 300 and 450 meters were also made.

Energy Spectrum Recorder. An instrument for slowly scanning the radiofrequency spectrum and recording the energy every 200 c/s was developed and is being field tested prior to installation in a worldwide network. The instrument scans the spectrum from 200 c/s to 550 kc/s in a five-day period. Using a bandwidth of 200 c/s, the equipment records for 2.5 minutes on each of 2,750 frequencies 200 c/s apart. Over the scanning range, spectrum occupancy of signals are recorded and radio-noise levels are recorded between signals. Positive frequency identification is coded on the record every 10 kc/s and each 200 c/s step is indicated. Accurate frequency identification of the recorded signals can thus be made. Therefore, not only will valuable information as to spectrum occupancy and radio-noise levels be obtained, but identification of individual signals and their received field strength will give a wealth of information for the study of propagation over a very large number of signal paths.

Radio Ray Refraction. Work was completed on the numerical determination of radio ray refraction in standard atmospheres of exponential form. In addition, a detailed analysis of the radio refractive index climate at ground observing level was made for the United States, based on 8 years of individual weather observations. This work is believed to be the first treatment of the radio climate of any country.

Phase Stability. Measurements of phase stability of radio signals propagated over line-of-sight tropospheric paths were undertaken to evaluate the limitations imposed by atmospheric turbulence on direction finding and guidance systems. The investigation is expected to provide basic knowledge of turbulence, in general, and such other engineering applications as electronic distance measuring techniques. The experiments, made for the U.S. Air Force, include frequency effects, various types of propagation paths, and a wide variety of weather conditions.

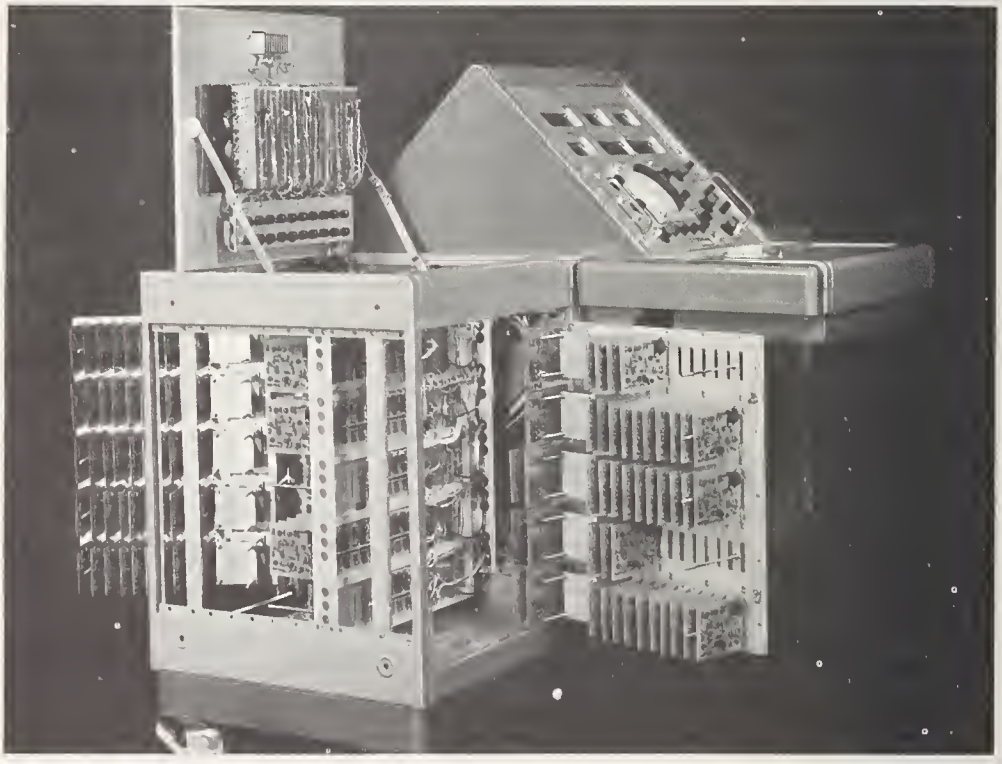
The data obtained so far permit reasonably accurate estimates of the phase stability of line-of-sight tropospheric paths from knowledge of their general terrain characteristics and meteorology. Phase fluctuations are significantly correlated with radio index of refraction variations on a time scale consistent with the path length. For many purposes, the variations of both phase and index can best be described by the slope and intensity of their frequency spectra. The most significant changes in these spectra with time appear to be in the intensity, the slopes remaining relatively unchanged.

Tracing Radio Rays Through Model Atmospheres. Simple graphical methods were developed for tracing radio rays through an arbitrary exponential atmosphere to define the geometry appropriate for actual terrain profiles. Very general ray-tracing methods were also programed on a digital computer to determine the angular distance, defined as the angle between rays projected beyond the radio horizons of two antennas.

Long-Term Transmission Loss Data. Approximately 700,000 hourly median values of VHF and UHF radio transmission loss were grouped into summer and winter periods and cumulative distributions have been obtained. The mean and the median for each clock hour and each month were calculated and listed for each propagation path, as well as the variance of these means and medians for each year. These lists give summer and winter hourly median values of field strength and transmission loss exceeded for 1, 10, 50, 90, and 99 percent of the time.

Engineering Standards for Tropospheric Transmission. A description of how various terrain and atmospheric conditions affect the performance of quick-fix and long-distance tropospheric circuits was made available in a handbook to help with the design, installation, and operation of such circuits. This description includes methods for calculating line-of-sight, knife-edge, smooth and rough earth diffraction, and forward scatter transmission loss.

Mobile Radio Noise Recorder. Recording equipment was installed in a panel truck to study the effects of locality on manmade radio noise. The equipment records the average voltage of the noise received on a seven-foot vertical whip antenna mounted on the roof of the vehicle. Measurements of noise were made on a 4,000-mile trip from Boulder, Colo., to Washington, D.C., and back, a route that included a variety of types and sizes of cities. Recordings were made on a Sunday and a Monday in the same



A Loran-C clock and its associated UHF timing system was developed to achieve time synchronization on the order of one microsecond over long distances, using the existing Loran-C radio navigation system (page 136).

city to determine the effect of a nonworkday and workday on the noise levels. The noise was checked in the same city during the day and during the night to determine diurnal variations.

Radio Systems

The aim of the Bureau's program in radio communication and systems is to develop and disseminate technical information relating to radio propagation factors affecting radio systems. This information is directed toward guiding engineering practices, allocating and using radiofrequencies, and evaluating system capabilities. Standards and measurement methods are developed for radio systems to fulfill the needs of Federal agencies and industry involved in radio operation and regulation. Emphasis is placed on promoting more efficient development and use of radio systems and the radio spectrum.

Arctic Communications. High-frequency transmission loss studies for auroral regions, and propagation studies for evaluation of high-frequency modulation techniques under disturbed ionospheric conditions, continued with the support of the U.S. Air Force. Transmission loss measurements over arctic paths were carried out, and correlated with measurements of auroral absorption by the VHF cosmic noise observation (riometer) techniques. Recordings were made continuously over several paths, including a long path from Barrow (Alaska) to Boulder (Colo.), a short path entirely within Alaska from Barrow to Kenai, and over a path from Thule (Greenland) to Barrow which lies across the polar cap, entirely north of the auroral zone. Statistical predictability of auroral attenuation, and the applicability of the synoptic riometer observations to this problem, are being investigated.

Disturbed Ionospheric Propagation. Observations and analysis of amplitude and phase fluctuations of signals were carried out for the arctic paths over a frequency range from 10 to 20 Mc/s. This work included study of the distribution of duration of fades, and of the fading characteristics of pulse groups at closely spaced frequencies.

Propagation Characteristics of ELF and ULF Waves. The determination of electrical properties of snow and ice for the U.S. Navy was completed. Further studies are planned on radiation fields of horizontal antennas, the electrical properties of the earth's surface at ELF, VLF, and LF, and on the theory of excitation of terrestrial wave guide modes. A new technique for determining the effective conductivity of a radio propagation path at LF and VLF was evaluated by measuring sferic wave forms at two points on a line to deduce the complex propagation constant and finally the effective path conductivity. The method appears to be able to provide information for accurately predicting transmission loss and delay times needed for the LF and VLF systems of position fixing, surveying, and timing.

Seven 5-element Yagi antennas erected at the Bureau's Table Mesa (Colo.) field site. The antennas, in conjunction with an electronic scanning device, are used to pinpoint the direction of radio signals received from forward scatter transmission (page 137).

Transient Propagation at LF and VLF. The analysis of pulse LF and VLF propagation by ground wave and through an electron plasma medium with superposed magnetic field was continued. A theoretical study of LF skywave transmission loss was carried out for the U.S. Air Force. This investigation of LF prediction techniques included the influence of the earth's magnetic field induction, and recent electron density-altitude profiles and collision frequency-altitude profiles.

VHF Ionospheric Scatter. A study of the frequency dependence of *D*-region scattering was completed. Continuous simultaneous observations were made at five frequencies from 30 to 108 Mc/s, using narrow beam antennas scaled in dimensions and height according to wavelength. The path was from Long Branch, Ill., to Boulder, Colo., U.S.A., 1,300 km. Hourly, diurnal, and seasonal variations in system loss were attributed to changing relative roles of turbulence and meteoric reflections. Normal ionospheric absorption was found not to affect scatter signal strength or frequency dependence. Special analysis was made of frequency dependence during weak signal conditions for engineering purposes.

Loran-C Clock. A "Loran-C Clock" and its associated UHF timing distribution system was developed to achieve time synchronization on the order of one microsecond over long distances, using an existing Loran-C radio navigation system. The technique makes use of the accurate knowledge of propagation characteristics of the low frequency ground wave, and the separability of the sky wave from the ground wave. The system provides time code distribution by UHF to peripheral stations near a central

Loran-C Clock station. The program is sponsored by the U.S. Air Force, and is intended to lead to greater precision in time synchronization throughout the Atlantic Missile Range.

Antenna Development. A high resolution electronic scanning antenna having a narrow main beam that scans rapidly over a predetermined sector in azimuth was developed. While initially the importance of this development lies in its application to propagation studies, a number of communication applications are possible. Another project was completed on theoretical design for a low-silhouette, high-gain, low-angle-of-departure antenna for the U.S. Air Force.

Exosphere Propagation. An experiment was carried out to determine whether high frequency waves might be guided through the exosphere along a line of the earth's magnetic field to the magnetic conjugate point of the transmitter where part of the energy would be back scattered, returning through the exosphere to the point of origin. Echo returns corresponding to such a propagation path were observed on several occasions. The technique may provide a new method for study of the electric and magnetic characteristics of the earth's exosphere.

Consulting and Advisory Assistance. A technical adviser was furnished for the U.S. Delegation to the International Radio Conference, held at Geneva, Switzerland, from August through December 1959. In connection with the work of the Interdepartment Radio Advisory Committee's Subcommittee on Frequency Allocation, a preliminary report was prepared on the technical factors affecting frequency allocation in the VHF and UHF portions of the radio spectrum. The FCC and IRAC have requested further work on this program. In connection with the Mercury (Man in Space) program of the National Aeronautics and Space Administration, propagation analysis, and engineering recommendations were made for worldwide ground communication system being set up by a government contractor.

Upper Atmosphere and Space Physics

The aim of the upper atmosphere and space physics program is to increase the knowledge and understanding of the physical properties and processes in the medium surrounding the earth. Such knowledge and understanding is essential to the expanding application of radio communication in the space age.

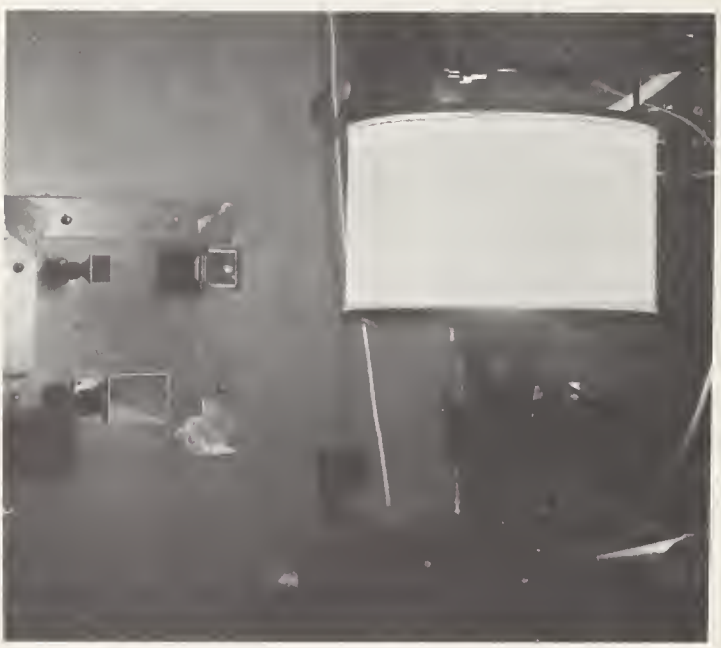
Whistler-Mode Propagation in Thermonuclear Plasma. The whistler mode of propagation was reproduced inside the hot, dense plasma of the British thermonuclear machine, ZETA. This propagation method showed the feasibility of precise measurements of local electron density, intensity, and direction of the magnetic field; and electron temperatures within the dense plasmas produced for thermonuclear research. The results indicate that it will be possible to determine the space distribution and time evolution of these variables. The results also indicate that Cerenkov radiation could be used to detect high-velocity particles moving through the hot

plasma. The cooperation of the British Atomic Energy Research Establishment in this study is acknowledged.

Ionization in Shock Waves. Intense, transient ionization in shock waves was studied by radio-microwave techniques. Properties investigated are the ionization, velocity, energy, and temperature of a shock wave created by discharging a large capacitor bank into a thin metallic wire. The reflection of microwaves by the advancing shock front reveals the presence of ionization, and the Doppler effect gives the velocity of the shock front. Two or more frequencies are used simultaneously in order to compare the properties of the shock waves as a function of frequency. These radio techniques are much more sensitive than optical methods and permitted the verifying of the predictions of cylindrical blast-wave theory by giving wave-front velocity values of three times the speed of sound in air.

Electron Density Measured Directly. The radio propagation parameters that are most useful in communications application are derived directly with fair accuracy from measurements of echo heights by soundings with 1 to 25 Mc/s radio-wave pulses. However, the dynamics of the ionospheric layers can be understood only if the electron density is known at each height. The Bureau's experiments with scatter radar showed that direct measurements can be made of electron densities throughout and well above the ionosphere.

Electron Densities Measured to 750 Kilometers. Radio waves are strongly reflected from ionospheric regions containing enough free electrons so that the plasma frequency is equal to the frequency of the probing radio wave. Radio waves of higher frequencies penetrate this region and travel out into space, but a minute fraction of the energy is returned to the earth by scattering from the free electrons. Experiments performed by the Bureau confirmed the prediction that the intensity of the scatter is pro-



Microwave techniques are used to study the characteristics of the plasma generated by an exploding wire. Using the shock wave developed in a gas-filled, cylindrical container, evacuated to low pressure, temperatures are attained up to and beyond 100,000 °K (page 138).

portional to the density of free electrons. These experiments also showed that the Doppler broadening of the echoes is considerably less than had been predicted. This broadening is explained in terms of scattering from a statistical assembly of free electrons rather than from individual free electrons scattering independently, and a precise theory was developed by several cooperating laboratories.

Experimental measurements of the vertical profile of electron density continued with the Bureau's marginal-sensitivity equipment located near Havana, Ill., although only on a part-time basis, since the transmitter was required for other purposes. Several of the profiles were used to deduce the temperature of the ionosphere above the maximum of the *F* layer.

Ionospheric Mapping. Work is under way to replace cumbersome graphical hand methods of numerical mapping by rigorous and objective operations making use of the best ionospheric data available, the full capabilities of a large-scale computing system, the most suitable methods of numerical analysis and statistics, and the empirical knowledge accumulated in ionospheric studies.

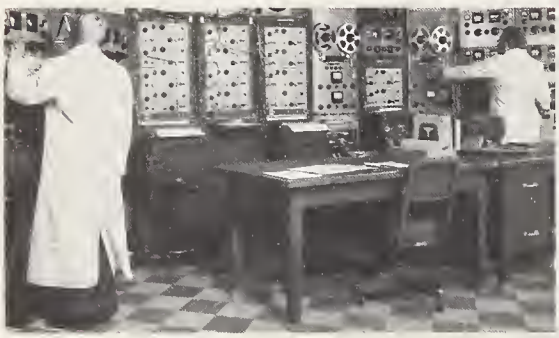
Equatorial Scatter. A series of experiments in Peru at the magnetic equator resulted in obtaining radar reflections from irregularities in the electron distribution of the equatorial electrojet. Contrary to the belief that these irregularities are magnetic field-alined columns of ionization, the observations indicate that they are plane wavefronts alined in the magnetic north-south direction and moving in the east-west plane at various elevation angles. The marked similarity of these equatorial 50 Mc/s radio observations to those of high-latitude radio auroral echoes indicates a strong resemblance between the two phenomena and suggests the need for a new approach to the interpretation of radio aurora.

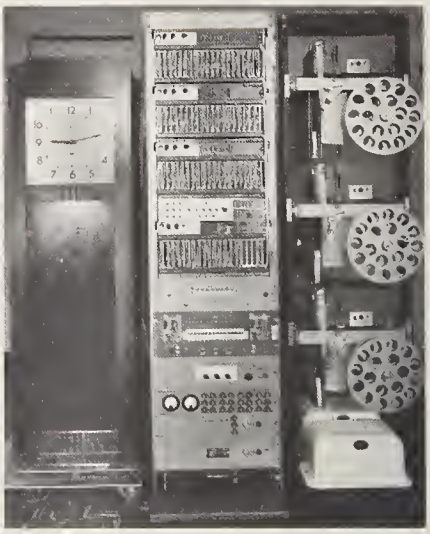
Subvisual Red Auroral Arcs Studied. Investigation of subvisible red auroral arcs showed that they appear to be exclusively enhanced in a particular radiation wavelength, the 6300 A line from atomic oxygen. They also seem to constitute an equatorial fringe to auroras in general; this fringe moves toward the equator during times of strong magnetic activity. They are oriented along magnetic parallels of latitude; individual arcs have been traced over some thousands of miles.

On the night of November 27–28, 1959, one such arc was widely observed in the western part of the United States. From simultaneous observations at three stations (Fritz Peak, Cactus Peak, and Sacramento Peak) the height and geographical position of the arc was determined throughout the night. Its photometric center was at a height of about 400 km; it remained within about 300 km north of Fritz Peak throughout the night.

Interesting observations were made when the satellite Explorer VII passed over the arc several times during a night at heights between 800 and 1,000 km. As it passed over the arc there was a marked increase in the rate at which high-energy particles entered the satellite from the outer Van Allen zone.

Satellite recording shelter (below) at the Bureau's Table Mesa, Colo. field site. Satellites have proved to be useful tools for studying the effects of the ionosphere on radio waves. Right: Meteor data recorder used in research to improve communications systems using meteor trails for the reflection of radio signals (pages 139 and 140).





Digital Recording of Meteor Bursts. During recent years, studies of the possible value of meteor-burst communication (intermittent radio communication between widely separated points via meteoric ionization in the upper atmosphere) have been hampered by lack of information on the statistics of the radio energy scattered by the transient meteor ionization. Therefore, an extensive automatic data-taking and analysis system was put into operation as part of a program of research on meteor-burst propagation characteristics.

The system utilizes three digital data recorders as the primary means for data gathering. Each recorder has three independent data input channels to measure the amplitudes of incoming meteor-burst signals and to record them in binary code on punched paper tape. These tape records are analyzed on an electronic computer which produces various statistical characteristics of the ensemble of burst signals received. The use of automatic digital techniques for this work has provided a flexibility and speed of analysis far greater than that previously considered feasible.

Large Scale Ionospheric Irregularities. Experimental evidence yielded information concerning ionospheric irregularities which are 100 to 500 km in horizontal extent. The angle of arrival of 108 Mc/s waves from a radio star was observed to fluctuate erratically by as much as one-half degree in 20 minutes. The large prismlike structures in the ionosphere which cause such fluctuations are confined to the daylight hours and occur on about one-third of all days. Their effect upon the angle of arrival of extraterrestial radio waves often exceeds the systematic refraction caused by the rest of the ionosphere.

Examination of the Faraday rotation of the plane of polarization of signals from Sputnik III confirms the existence of the large irregularities. As measured by the Faraday-rotation method, the total electron content of

the ionosphere varies by one or two percent across an irregularity. Observations made when the satellite was at different heights in the ionosphere indicate that the irregular structure is not confined to any particular height, but is distributed throughout the *F* region.

D Region Temperature Measurements. In a program carried out jointly with the Geophysical Institute of University of Alaska, the effective electron temperature of the auroral-zone *D* region was studied. Measurements at a frequency of 2.89 Mc/s during both daytime and nighttime disturbances indicated temperatures in the range 200 to 300 °K. These observations showed that, contrary to earlier suggestions, the electron temperatures in the *D* region are relatively unaffected by auroral disturbances.

Magneto-Ionic Ray Tracing. The tracing of the path of a radio ray through an ionized gas in the presence of a magnetic field is of considerable theoretical and practical importance in the study of many propagation and geophysical problems, including whistlers and other conjugate point phenomena. Radio waves from satellites are affected by refraction and by polarization changes; the observed Doppler shift is also affected by the presence of the ionosphere. A major computer program was therefore prepared to calculate accurately ionospheric refraction, polarization and Doppler effects for a satellite moving in a known orbit through a model ionosphere. Since the propagation paths are affected by the intensity and direction of the magnetic field, it was necessary to prepare a program which calculates the geomagnetic vector at any point in the earth's atmosphere or out in space. This program uses spherical harmonic coefficients to the sixth order, rather than the simple dipole field.

Solar Proton Events and Polar Cap Radio Blackouts. As a result of intensive study of the great solar cosmic ray outburst of February 23, 1956, and study since then of the signal intensities on the U.S.A.F. North Atlantic chain of ionospheric scatter communication links, one distinct class of polar radio blackouts was identified and largely explained.

These periods of intense radio wave absorption result from low-level ionization produced by the bombardment of the polar ionosphere by protons ejected from the sun during certain intense flare events. It was shown that these protons, after the first few hours, arrive essentially isotropically. For the few cases where the spectrum of solar protons contained a significant excess of energetic particles over normal cosmic ray background, which could be detected at ground or balloon levels, it was found that the spectrum determined by conventional cosmic-ray techniques is continuous and consistent with the spectrum of the low-energy protons required to account for the observed polar absorption.

IGY World Data Center A

IGY and IGC data continued to be received by the Data Center with no decrease in volume. About 600,000 ft of ionogram film were copied for NBS files, for the exchange with other Data Centers, and to fill requests for copies

of ionograms. A total of over 2,100,000 ft of film copied has been received in the three years of Data Center operation. While most of the IGY data have been received, some material is still coming in.

Three catalogs of the data on file were prepared during the year, two of which were for inclusion in the combined catalog issued at six month intervals, for all disciplines of IGY World Data Center A. During the year, this Data Center began the typing of tables of IGY vertical incidence ionospheric data for publication in the "Annals of the International Geophysical Year."

2.18. WEIGHTS AND MEASURES

One of the statutory responsibilities of the National Bureau of Standards is "cooperation with the States in securing uniformity in weights and measures laws and methods of inspection." The responsibility of regulatory control over commercial weighing and measuring devices and commercial transactions involving quantity has been left by the Congress to the individual States. The Bureau contributes by offering consultative and advisory services to the States and calibration and physical adjustment of State reference weights and measures standards.

This program is implemented through the Bureau's Office of Weights and Measures. The range of services is quite broad, including: (1) Development of model weights and measures statutes, rules, and regulations; (2) properly designed and accurate physical standards of length, mass, and capacity; (3) effective procedures for testing commercial weighing and measuring devices; (4) specially designed testing equipment; (5) plans for systematic and effective quantity checking of prepackaged merchandise; (6) administrative procedures; (7) specifications and tolerances for commercial devices; (8) training schools for weights and measures officers; (9) visual aids; and (10) publications.

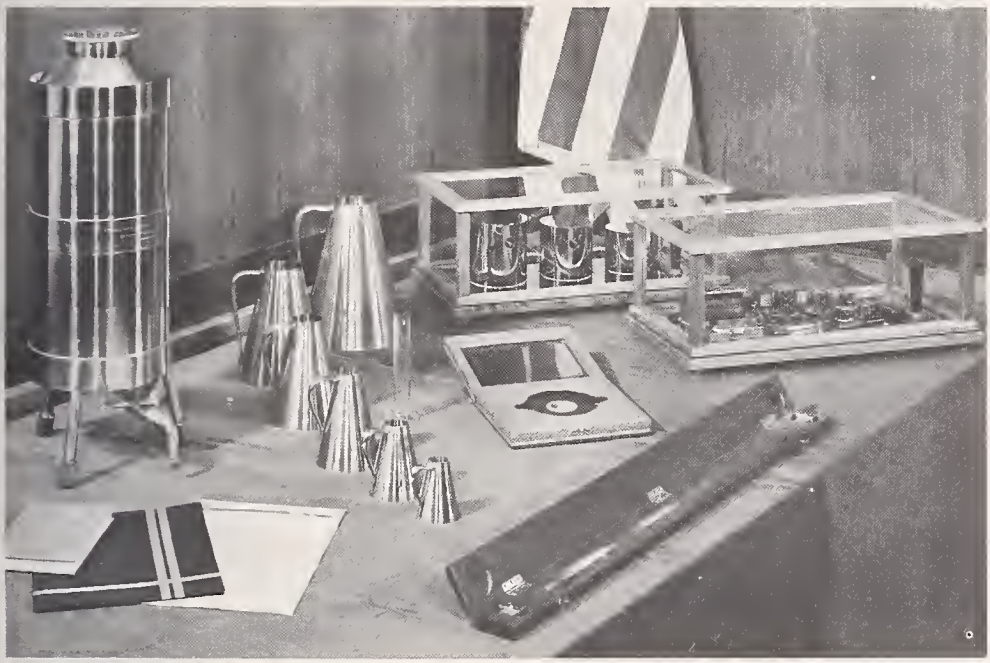
During the past year, a completely new Model Regulation for Packages was developed and modernizing changes were made in the Model State Law on Weights and Measures and the Specifications, Tolerances, and Regulations for Commercial Weighing and Measuring Devices.

The national weights and measures training laboratory facility neared completion. Here technical courses in weights and measures supervision will be offered to supervisory personnel of State weights and measures offices. Requests for Bureau assistance in conducting technical training schools at the State level have increased to the point where the Bureau's limited staff is severely taxed to attempt to fulfill the demand. The training laboratory should ease this situation.

New equipment was designed specifically for testing large weighing scales, fabric-measuring devices, and liquid meters dispensing liquid fertilizers and other ammonia products. Specific procedures were developed to facilitate the use of the testing equipment.

At the request of the National Conference on Weights and Measures and the National Association of State Departments of Agriculture, effort is being devoted to the development of new physical standards of weights and measures for the States—standards that will be more accurate, more constant, and more durable. In 1836 and in 1866, the Congress provided the States with reference standards that became the basis for nationwide uniformity. Since then, through obsolescence and some individual purchases, nonuniformity in the physical characteristics of the standards has developed. The Bureau's current efforts will provide a sound basis for repeating the 19th-century actions, bringing about complete uniformity in State weights and measures reference standards. During the past year, metallurgical studies were completed, specifications drawn, and bids awarded for prototypes of the new State standards, including standards of mass, capacity, length, and precision balances. The mass and capacity standards have been received and placed under examination and test.

In response to an official request from the United Nations, a member of the staff was sent to survey the weights and measures situation in Central America and to advise as to the establishment of a modern system of standards and weights and measures supervision.



This set of weights and measures (including standards of length, mass, and capacity) was presented to the new State of Hawaii at the 45th National Conference on Weights and Measures (page 144).

Studies were continued and recommendations were made to the States in the area of control of prepackaged commodities. The Department of Agriculture now estimates that at least three-quarters of each retail food dollar is spent for packaged food. In addition, many other commodities are offered at retail in package form. With the tremendous increase in packaging, more and more weights and measures effort must be devoted to package control. Studies have continued in this field, and much effort has been devoted to the training of State and local officials in the control-by-sampling technique.

In a ceremony held at the auditorium of the Department of Commerce during June, a set of weights and measures comprising standards of length, mass, and capacity was presented to the new State of Hawaii by Secretary of Commerce Frederick H. Mueller. These standards are providing a firm basis for an accurate, uniform measurement system in the new State, so vital to the growth of commerce and industry.

Traditionally, the National Conference on Weights and Measures has been one of the principal means of promoting uniformity and raising performance standards in weights and measures administration in the United States. Sponsored by the Bureau, the 45th Annual Conference was held in Washington, D.C., during the year. Thirty-six States and the District of Columbia were officially represented at this 5-day meeting. The total registered attendance was 391.

3. APPENDIXES

3.1. ORGANIZATION OF THE NATIONAL BUREAU OF STANDARDS*

DIRECTOR	Allen V. Astin
DEPUTY DIRECTOR	Robert D. Huntoon
Assistants to the Director	C. N. Coates
	U. Fano
	W. A. Wildhack
Consultants to the Director	L. F. Curtiss
	K. E. Shuler
Associate Director for Physics	Robert D. Huntoon
Associate Director for Engineering	Archibald T. McPherson
Associate Director for Chemistry	Edward Wichers
Consultants	W. Souder
	M. B. Wallenstein
Associate Director for Planning	Irl C. Schoonover
NBS Reactor Program	C. O. Muehlhause
Associate Director for Administration	R. S. Walleigh
Financial Management Officer	N. L. Christeller
Legal Advisor	H. J. Johnson
Patent Advisor	D. Robbins
Director for the Boulder Laboratories	F. W. Brown
Director Emeritus	Lyman J. Briggs

NBS WASHINGTON

SCIENTIFIC AND TECHNICAL DIVISIONS AND SECTIONS

ELECTRICITY	
Chief	C. H. Page
Resistance and Reactance	J. L. Thomas
Electrochemistry	W. J. Hamer
Electrical Instruments	F. M. Defandorf
Magnetic Measurements	I. L. Cooter
Dielectrics	J. D. Hoffman
METROLOGY	
Chief	A. G. McNish
Assistant Chief	D. B. Judd
Photometry and Colorimetry	L. E. Barbrow
Refractometry	F. E. Washer
Photographic Research	C. S. McCamy
Length	B. L. Page
Engineering Metrology	I. H. Fullmer
Mass and Scale	H. S. Peiser
Volumetry and Densimetry	C. T. Collett, *Acting*

*As of September 1, 1960.

HEAT	
Chief	C. M. Herzfeld
Assistant Chief for Thermodynamics	C. W. Beckett
Temperature Physics	J. F. Swindells
Heat Measurements	D. C. Ginnings
Cryogenic Physics	R. P. Hudson
Rheology	R. S. Marvin
Molecular Kinetics	F. L. Howard
Equation of State	J. Hilsenrath
Statistical Physics	M. S. Green
Molecular Spectroscopy	D. E. Mann
RADIATION PHYSICS	
Chief	L. S. Taylor
X-ray	H. O. Wyckoff
Radioactivity	W. B. Mann
Radiation Theory	L. V. Spencer, *Acting*
High Energy Radiation	H. W. Koch
Radiological Equipment	S. W. Smith
Nucleonic Instrumentation	L. Costrell
Neutron Physics	R. S. Caswell
CHEMISTRY	
Acting Chief	Edward Wichers
Acting Assistant Chief	R. G. Bates
Surface Chemistry	*Vacant*
Organic Chemistry	H. S. Isbell
Analytical Chemistry	J. L. Hague, *Acting*
Inorganic Chemistry	R. Gilchrist
Electrodeposition	A. Brenner
Molecular Structure and Properties of Gases	F. Buckley
Physical Chemistry	R. G. Bates
Thermochemistry	E. J. Prosen
Spectrochemistry	B. F. Scribner
Pure Substances	C. P. Saylor
MECHANICS	
Chief	B. L. Wilson
Consultants	W. G. Brombacher
	J. M. Frankland
	E. C. Lloyd
Sound	R. K. Cook
Pressure and Vacuum	D. P. Johnson
Fluid Mechanics	G. B. Schubauer
Engineering Mechanics	L. K. Irwin
Combustion Controls	F. R. Caldwell
ORGANIC AND FIBROUS MATERIALS	
Chief	G. M. Kline
Rubber	L. A. Wood
Textiles	H. F. Schiefer
Paper	R. B. Hobbs
Leather	J. R. Kanagy
Testing and Specifications	R. D. Stiehler
Polymer Structure	N. P. Bekkedahl
Plastics	F. W. Reinhart
Dental Research	W. T. Sweeney
METALLURGY	
Chief	J. I. Hoffman
Assistant Chief	T. G. Digges
Thermal Metallurgy	T. G. Digges
Chemical Metallurgy	L. L. Wyman
Mechanical Metallurgy	J. A. Bennett
Corrosion	G. A. Ellinger
Metal Physics	L. M. Kushner

MINERAL PRODUCTS	
Chief	A. D. Franklin
Assistant Chief	C. H. Hahner
Consultants	R. F. Geller
	E. R. Lippincott
Engineering Ceramics	M. D. Burdick
Glass	C. H. Hahner
Refractories	*Vacant*
Enameled Metals	W. N. Harrison
Constitution and Microstructure	H. F. McMurdie
BUILDING RESEARCH	
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Consultant	W. F. Roeser
Structural Engineering	D. Watstein
Fire Research	A. F. Robertson
Mechanical Systems	P. R. Achenbach
Organic Building Materials	W. W. Walton
Codes and Safety Standards	R. L. Lloyd, *Acting*
Heat Transfer	H. E. Robinson
Inorganic Building Materials	R. L. Blaine
APPLIED MATHEMATICS	
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Assistant Chief	F. L. Alt
Consultant	W. J. Youden
Numerical Analysis	P. Davis
Computation	D. I. Mittleman
Statistical Engineering	C. Eisenhart
Mathematical Physics	W. H. Pell
DATA PROCESSING SYSTEMS	
Chief	S. N. Alexander
Assistant Chief for Systems	H. K. Skramstad
SEAC Engineering Group	J. F. Rafferty
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Digital Circuitry	S. Greenwald
Digital Systems	W. A. Notz, *Acting*
Analog Systems	H. Skramstad
Applications Engineering	E. Glaser, *Acting*
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Consultant	F. L. Mohler
Spectroscopy	K. G. Kessler
Radiometry	E. K. Plyler
Mass Spectrometry	V. H. Dibeler
Solid State Physics	H. P. R. Frederikse
Electron Physics	L. Marton
Atomic Physics	S. J. Smith
INSTRUMENTATION	
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Engineering Electronics	G. Shapiro
Electron Devices	C. P. Marsden
Electronic Instrumentation	G. F. Montgomery, *Acting*
Mechanical Instruments	A. Wexler
Basic Instrumentation	J. Stern
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Chief	W. S. Bussey
Assistant Chief	M. W. Jensen
Consultant	R. W. Smith
OFFICE OF TECHNICAL INFORMATION	
Chief	W. R. Tilley
Assistant Chief	W. K. Gautier

ADMINISTRATIVE DIVISIONS

ACCOUNTING	J. P. Menzer
PERSONNEL	G. R. Porter
ADMINISTRATIVE SERVICES	H. P. Dalzell
SHOPS	F. P. Brown
SUPPLY	G. B. Kefover
MANAGEMENT PLANNING	I. Asay
BUDGET	J. E. Skillington
INTERNAL AUDIT	J. P. Menzer, *Acting*
PLANT	H. Graham

BOULDER DIVISIONS

DIRECTOR FOR THE BOULDER LABORATORIES	F. W. Brown
Consultants	
Mathematics	J. J. Sopka
Math Physics	E. H. Brown
Statistics	E. L. Crow
Astrophysics	R. N. Thomas
Radio Wave Propagation	J. R. Wait
Communications Liaison Officer	Allen Barnabei
CRPL Liaison and Program Development	A. H. Shapley
Executive Officer and Chief of Administrative Division	S. W. J. Welch
Technical Information Officer	J. R. Craddock
CRYOGENIC ENGINEERING	
Chief	R. B. Scott
Assistant Chief	B. W. Birmingham
Cryogenic Equipment	R. B. Jacobs
Cryogenic Processes	B. W. Birmingham
Properties of Materials	R. J. Corruccini
Gas Liquefaction	V. J. Johnson
*IONOSPHERE RESEARCH AND PROPAGATION	
Chief	E. K. Smith, Jr.
Assistant Chief	T. N. Gautier
Consultant	D. K. Bailey
Low Frequency and Very Low Frequency Research	A. G. Jean
Ionosphere Research	K. Davies
Prediction Services	W. B. Chadwick
Sun-Earth Relationships	R. W. Knecht
Field Engineering	H. G. Sellery
Radio Warning Services	J. V. Lincoln
*RADIO PROPAGATION ENGINEERING	
Chief	K. A. Norton
Assistant Chief for Research and Development	J. W. Herbstreit
Consultant	E. F. Florman
Data Reduction Instrumentation	W. E. Johnson
Radio Noise	W. Q. Crichlow
Tropospheric Measurements	*Vacant*
Tropospheric Analysis	P. L. Rice
Propagation-Terrain Effects	R. S. Kirby
Radio Meteorology	B. R. Bean
Lower Atmosphere Physics	M. C. Thompson, Jr.
RADIO STANDARDS	
Chief	J. M. Richardson
Assistant Chief for Radio Frequencies	W. D. George
Assistant Chief for Microwave Frequencies	D. M. Kerns
Assistant Chief for Technical Planning and Coordination	E. C. Wolzien
Consultants	W. W. Brown
	P. F. Wacker

*These divisions comprise the Central Radio Propagation Laboratory.

High-Frequency Electrical Standards	M. C. Selby
Radio Broadcast Service	A. H. Morgan
Radio and Microwave Materials	J. L. Dalke
Atomic Frequency and Time Standards	R. C. Mockler
Electronic Calibration Center	H. W. Lance
Millimeter-Wave Research	W. Culshaw
Microwave Circuit Standards	R. W. Beatty

*RADIO SYSTEMS

Chief	R. C. Kirby
Assistant Chief	D. W. Patterson
Consultant	G. W. Haydon
High Frequency and Very High Frequency Research	R. Silberstein
Modulation Research	J. W. Koch
Antenna Research	H. V. Cottony
Navigation Systems	G. Hefley
Space Telecommunications	W. C. Coombs

*UPPER ATMOSPHERE AND SPACE PHYSICS

Chief	C. G. Little
Assistant Chief	D. M. Gates
Consultants	R. J. Slutz
	D. K. Bailey
Upper Atmosphere and Plasma Physics	R. M. Gallet
Ionosphere and Exosphere Scatter	K. L. Bowles
Airglow and Aurora	F. E. Roach
Ionospheric Radio Astronomy	R. S. Lawrence

FIELD ESTABLISHMENTS

Lamp Inspector	Brookline, Mass.
Visual Landing Aids Field Laboratory	Arcata, Calif.
Master Railway Track Scale Depot	Clearing, Ill.

Materials Testing Laboratories:

CALIFORNIA	COLORADO	PENNSYLVANIA	WASHINGTON
San Francisco	Denver	Allentown	Seattle

Radio Transmitting Station WWV	Beltsville, Md.
Radio Transmitting Station WWVL	Boulder, Colo.

Central Radio Propagation Laboratory Field Stations:

ALASKA
Anchorage
Barrow
Kenai

ARIZONA
Bowie**

COLORADO
Beulah
Brighton
Cheyenne Mtn.
Erie
Fritz Peak
Gunbarrel Hill
Haswell
Hygiene
Karval
Kendrick
Kolb
Lafayette
Marble
Marshall
Table Mesa
Sunset

HAWAII
Maui (WWVH)
Kekaha

ILLINOIS
Long Branch

KANSAS
Garden City

NEBRASKA
Shickley

NORTH DAKOTA
Cavalier**
Fargo**

OKLAHOMA
Norman**

UTAH
Salt Lake City**

VIRGINIA
Fort Belvoir
Front Royal
Sterling

WYOMING
Bill

ANTARCTICA
Marie Byrd Base**
Pole Station**

AUSTRALIA
Cook**

BRAZIL, S.A.
San Jose des Campa**

CANADA
Fort Churchill
Manitoba**

GREENLAND
Thule**

ICELAND
Keflavik**

INDIA
New Delhi**

JAPAN
Ohira**

MALAYA
Singapore**

MOROCCO
Rabat**

NIGERIA
Ibbidan**

NORWAY
Andenes**

OKINAWA
Onna**
Okmma**

PANAMA CANAL ZONE
Balboa**

PERU
Lima**

PHILIPPINE ISLANDS
Poro Point**

PUERTO RICO
San Juan

SOUTH AFRICA
Pretoria**

SWEDEN
Enkoping**

**Contract or Mutual Cooperation.

3.2. STATEMENT OF THE NBS MISSION

The Enabling Act (15 USC 271–278c) determines the scientific areas in which the Bureau is authorized to function. Within those areas, the Bureau is given broad authority to formulate and carry out technical programs suited to changing national needs. The Act is broad and permissive, allowing for the selection of programs to be emphasized at any one time and not requiring activity simultaneously in all fields authorized. The most effective use of the funds and facilities which are available to the Bureau requires the continuing exercise of selective judgment.

To make optimum and orderly progress within the administrative latitude given to the Bureau, it is desirable to establish objectives which provide a basis for selection and emphasis among the variety of activities authorized by statute. These objectives (or goals), should provide a statement of Bureau mission which is more directed than the permissive authorization provided by the Enabling Act.

A mission statement should provide purpose, focus, and urgency to the Bureau's operations. It should highlight those characteristics which make the Bureau a unique institution. It should encourage imaginative and exploratory work at the frontiers of science and technology. It should permit reasonable flexibility for initiating new programs and services.

As national requirements change, the relative emphasis in Bureau programs should likewise change, while remaining within the areas authorized by legislation. There will always be, however, a central, continuing activity which it is the unique responsibility of the Bureau to prosecute at all times with an appropriate level of effort.

The mission statement which follows provides primarily a description of this central, continuing responsibility. It does not directly embrace the somewhat independent, special responsibilities which have been assigned to the Bureau, such as the Central Radio Propagation Laboratory, the National Hydraulics Laboratory, the data processing systems program, the cryogenic engineering program, the building technology program, and the fire research program. Such areas of specially assigned responsibility will be dealt with in later separate statements.

It should be further emphasized that even with allowance for the foregoing exclusions the mission statement does not encompass all of the activities of the Bureau. Such is not its purpose. It provides a focus for the overall effort recognizing that from time to time specific and important tasks, outside of the central mission, may be specially authorized.

THE CENTRAL, CONTINUING MISSION OF THE NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards must provide national leadership in the development and use of accurate and uniform techniques of physical measurement. The provision of effective standards for physical measurement demands measurement competence of the highest order since the accuracy with which measurement data may be exchanged is limited by the accuracy with which the standards can be utilized. This requirement for the highest order of measurement competence is especially important in the provision of standards and measurement techniques for use at the frontiers of science and technology. Attainment of such competence is an important aspect of fulfilling the Bureau's mission. Furthermore, consistent with the Bureau's responsibility for measurement leadership, there should be a sustained effort to seek out and take advantage of measurement excellence wherever it may exist, and not to try to do everything within the Bureau. The Bureau will then be better able to concentrate on problems where adequate measurement capability does not exist.

The Bureau, in its measurement leadership responsibility, must strive to stay ahead of the measurement requirements of science and technology. It must anticipate tomorrow's measurement problems and lead in their solution particularly in assuring that adequate standards and measurement techniques are available. It is the Bureau's responsibility to insure that measurement inadequacies do not retard scientific and technological progress.

With the goal of leadership in physical measurement as the focus of the Bureau's activities, the mission of NBS has three major components:

1. PROVISION OF THE CENTRAL BASIS WITHIN THE UNITED STATES OF A COMPLETE AND CONSISTENT SYSTEM OF PHYSICAL MEASUREMENT, AND COORDINATION OF THAT SYSTEM WITH THE MEASUREMENT SYSTEMS OF OTHER NATIONS.

Providing the central basis for the national measurement system constitutes the most unique aspect of the Bureau's mission. It includes the development and maintenance of the national standards for physical measurement, fundamental studies to improve or create new standards to meet existing or anticipated needs, research on the interaction of basic measuring processes on the properties of matter and physical and chemical processes, determination of the important physical constants which may serve as reference standards, analysis of the self-consistencies of measured values of the important physical constants, and international correlation of the national standards and definitions of the units of measurement.

2. PROVISION OF ESSENTIAL SERVICES LEADING TO ACCURATE AND UNIFORM PHYSICAL MEASUREMENT THROUGHOUT THE NATION'S SCIENCE, INDUSTRY, AND COMMERCE, AND CONSONANT WITH THEIR ADVANCING REQUIREMENTS.

The furnishing of essential services to promote accuracy and uniformity of physical measurements, includes (but is not limited to) the calibration of instruments in terms of the national standards, the development of appropriate multiples and submultiples of prototype standards, development of transfer standards and standard instruments, the broadcasting of radio signals of standard frequency, general research and development on measuring processes and instrumentation, development and dissemination of standard samples, encouragement of calibration and standards laboratories in other government agencies and private organizations and correlation of their standards with the national standards, cooperation with the states in securing uniform weights and measures inspection and enforcement, and cooperation with other organizations in the development of standard codes and specifications.

3. PROVISION OF DATA ON THE PROPERTIES OF MATTER AND MATERIALS WHICH ARE OF IMPORTANCE TO SCIENCE, INDUSTRY, AND COMMERCE, AND WHICH ARE NOT AVAILABLE OF SUFFICIENT ACCURACY ELSEWHERE.

The accurate determination of the properties of matter and materials affords a major opportunity to apply the measurement competence essential to the development and maintenance of adequate measurement standards. Here the effort is focused on data that are of great importance to science and industry and not available of sufficient accuracy elsewhere and on the measurement techniques essential to obtaining such data. The effective achievement of this objective demands a broad, systematic program of surveying what data are available or becoming available elsewhere, what data and measurement problems are important, and a coordinated effort to fill the gaps. A vigorous experimental and theoretical research program in the major areas of materials science and measurement science is also essential.

In addition to the focus given above, priority is given to precision, standard-type data on substances that are susceptible to accurate scientific characterization. Furthermore, as measurement techniques become well standardized and measurement competence becomes widely available, the Bureau will tend to encourage others to compile data in such areas, thus permitting the Bureau to redirect its resources to those areas where the need for increased measurement competence is most urgent.

These three components provide a description of the fundamental measurement-standards mission of the NBS. It is recognized that work in these areas requires the provision of specialized scientific and technical services which are essentially of a supporting nature, such as those in applied mathematics, and instrumentation reference. It is recognized that such supporting activities must, *per se*, have continuing research programs in order to retain high-level personnel and to provide effective technical contributions to the Bureau's mission-oriented projects.

3.3. Fiscal Data on NBS Program

Program and Source of Financing	Obligations Incurred (in thousands of dollars)		
Supported by NBS Appropriations:			
Operating Programs:			
Research & Technical Services		$17,138	
Construction and Facilities Program:			
Plant and Facilities	$550		
Construction of Facilities	198		
		748	
Total NBS Appropriation			$17,886
Supported by Other Funds:			
Research and Development Programs:			
Other Federal Agencies	14,491		
Nongovernmental Sources	237		
		14,728	
Calibrations, Testing, and Standard Samples		3,373	
Reimbursable Administrative Services		1,100	
Total Supported by Other Funds			19,201
Total Program			$37,087

3.4. ADVISORY COMMITTEES

STATUTORY VISITING COMMITTEE

[Reports annually to Secretary of Commerce on NBS activities (Dates indicate expiration of appointment)]

Dr. M. J. Kelly, Former President and Chairman of the Board, Bell Telephone Laboratories, Inc. (1962), Chairman
Dr. Detlev W. Bronk, President, National Academy of Sciences (1960)
Professor F. Seitz, University of Illinois (1961)
Dr. Lloyd V. Berkner, President, Associated Universities Inc. (1963)
Dr. Crawford H. Greenewalt, President, E. I. du Pont de Nemours & Co. (1964)

Technical Advisory Panels

[Appointed by the National Academy of Sciences-National Research Council in cooperation with the leading scientific and technical societies to advise NBS Director in specific technical areas. Cooperating societies are: American Ceramic Society (ACerS); American Chemical Society (ACS); American Institute of Chemical Engineers (AIChE); American Institute of Electrical Engineers (AIEE); American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME); American Institute of Physics (AIP); American Society of Civil Engineers (ASCE); American Society of Mechanical Engineers (ASME); Building Research Advisory Board (BRAB); Conference Organization for Mathematical Sciences (COMS); and Institute of Radio Engineers (IRE). Members listed served during fiscal year 1960]

Dean R. B. Lindsay, Brown University, Chairman, Committee of Panel Chairmen
Dr. O. F. Schuette, National Research Council, Executive Secretary

ADVISORY PANEL TO ELECTRICITY AND ELECTRONICS DIVISION

Prof. W. A. Lewis, Illinois Institute of Technology, Chairman (AIEE)
Prof. Norman I. Adams, Jr., Yale University (AIP)
Dr. John G. Brainerd, University of Pennsylvania (IRE)
Mr. H. P. Corwith, Western Union Telegraph Company (AIEE)
Mr. Robert W. Larson, General Electric Research Laboratories (AIEE)
Prof. Henry B. Linford, Columbia University (ACS)
Mr. Leon Podolsky, Sprague Electric Company (IRE)

ADVISORY PANEL TO OPTICS AND METROLOGY DIVISION

Prof. John Strong, Johns Hopkins University, Chairman (AIP)
Prof. Clarence E. Bennett, University of Maine (AIP)
Mr. Floyd W. Hough, Arlington, Virginia (ASCE)
Mr. Paul V. Miller, Taft Pierce Manufacturing Company (ASME)
Dr. Brian O'Brien, Pomfret, Conn. (AIP)

ADVISORY PANEL TO HEAT DIVISION

Prof. Mark W. Zemansky, City College of New York, Chairman (AIP)
Prof. C. Harold Berry, Belmont, Mass. (ASME)
Prof. Henry A. Fairbank, Yale University (AIP)
Dean Henry Eyring, University of Utah (ACS)
Prof. Joseph Kestin, Brown University (ASME)
Dean R. B. Lindsay, Brown University (AIP)
Prof. J. E. Mayer, University of Chicago (ACS)
Prof. Glen C. Williams, Massachusetts Institute of Technology (AIChE)

ADVISORY PANEL TO ATOMIC AND RADIATION PHYSICS DIVISION

Prof. A. O. C. Nier, University of Minnesota, Chairman (AIP)
Prof. John Bardeen, University of Illinois (AIP)
Prof. J. W. M. DuMond, California Institute of Technology (AIP)
Dr. William A. Higinbotham, Brookhaven National Laboratory (IRE)
Prof. Polykarp Kusch, Columbia University (AIP)
Prof. Harold A. Lamonds, North Carolina State College (AIEE)
Dr. Otto Oldenberg, Harvard University (AIP)
Dr. H. M. Parker, General Electric Co. (AIP)

ADVISORY PANEL TO CHEMISTRY DIVISION

Prof. F. Daniels, University of Wisconsin, Chairman (ACS)
Prof. N. Howell Furman, Princeton University (ACS)
Prof. Hans H. Jaffe, University of Cincinnati (ACS)
Dr. J. R. Ruhoff, Malinckrodt Chemical Company (ACS)
Dr. Norman A. Shepard, Stamford, Conn. (ACS)

ADVISORY PANEL TO MECHANICS DIVISION

Dean Dana Young, Yale University, Chairman (ASME)
Prof. Lynn S. Beedle, Lehigh University (ASCE)
Prof. S. R. Beitler, Ohio State University (ASME)
Prof. A. T. Ippen, Massachusetts Institute of Technology (ASCE)
Dr. H. F. Olson, Radio Corporation of America (AIP)
Prof. Jesse Ormondroyd, University of Michigan (ASME)
Dr. Milton Plesset, California Institute of Technology (AIP)

ADVISORY PANEL TO ORGANIC AND FIBROUS MATERIALS DIVISION

Dr. Norman A. Shepard, Stamford, Conn., Chairman (ACS)
Dr. J. H. Dillon, Textile Research Institute (AIP)
Dr. Milton Harris, Harris Research Laboratory (ACS)
Prof. Herman F. Mark, Polytechnic Institute of Brooklyn (AIP)
Prof. C. S. Marvel, University of Illinois (ACS)
Dr. C. G. Overberger, Polytechnic Institute of Brooklyn (ACS)
Dr. J. F. Downie Smith, Carrier Corporation (ASME)

ADVISORY PANEL TO METALLURGY DIVISION

Dr. E. C. Smith, Republic Steel Corporation, Chairman (AIME)
Dr. D. J. Dienes, Brookhaven National Laboratory (AIP)
Mr. John Freeman, Jr., American Brass Company (AIME)
Dr. Francis L. LaQue, International Nickel Company (ACS)
Mr. Arthur R. Lytle, Linde Company (AIME)
Dean Elburt Osborn, Pennsylvania State University (ACerS)
Dr. Joseph A. Pask, University of California (ACerS)
Dr. Albert J. Phillips, American Smelting and Refining Co. (AIME)
Mr. D. B. Rossheim, M. W. Kellog Corporation (ASME)
Dr. Cyril S. Smith, University of Chicago (AIME)

ADVISORY PANEL TO MINERAL PRODUCTS DIVISION

Dean Elburt Osborn, Pennsylvania State University, Chairman (ACerS)
Mr. Herbert Insley, Washington, D.C. (ACerS)
Dr. Norbert J. Kreidl, Bausch and Lomb Optical Company (ACerS)
Mr. John T. Roberts, Ingersoll-Humphreys Division, Borg-Warner (ACerS)
Prof. Pierce Selwood, Northwestern University (ACS)
Mr. Karl Schwartzwalder, A. C. Spark Plug Div., General Motors Corporation (ACerS)
Dr. Robert B. Sosman, Rutgers, The State University (ACerS)
Prof. Bertram E. Warren, Massachusetts Institute of Technology (AIP)
Dr. Clarence Zener, Westinghouse Electric Corporation (AIME)

ADVISORY PANEL TO BUILDING TECHNOLOGY DIVISION

Dr. G. H. Hickox, Fort Belvoir, Va., Chairman (ASCE)
Mr. G. M. Dusinberre, Pennsylvania State University (ASME)
Dr. James F. Eversole, Union Carbide Development Corporation (ACS)
Mr. W. C. Hansen, Universal Atlas Cement Company (ASCE)
Prof. Robert A. Hechtman, The George Washington University (ASCE)
Mr. Paul V. Johnson, Structural Clay Products Research Foundation (ACerS)
Prof. James T. Lendrum, University of Florida (BRAB)
Dean W. L. McCabe, Polytechnic Institute of Brooklyn (AIChE)
Dr. John S. Parkinson, Johns-Manville Products Corporation (AIP)
Mr. Raymond C. Reese, Toledo, Ohio (ASCE)

ADVISORY PANEL TO APPLIED MATHEMATICS DIVISION

Prof. A. H. Taub, University of Illinois, Chairman (COMS)
Prof. David Blackwell, University of California (COMS)
Dr. Alston S. Householder, Oak Ridge National Laboratory (COMS)
Prof. Mark Kac, Cornell University (COMS)
Prof. Philip M. Morse, Massachusetts Institute of Technology (COMS)
Prof. J. Walsh, Harvard University (COMS)

ADVISORY PANEL TO DATA PROCESSING SYSTEMS DIVISION

Dr. Alston S. Householder, Oak Ridge National Laboratory, Chairman (COMS)
Mr. John C. McPherson, International Business Machines Corporation (IRE)
Prof. Charles L. Miller, Massachusetts Institute of Technology (ASCE)
Prof. Raymond Pepinsky, Pennsylvania State University (AIP)
Prof. William H. Radford, Massachusetts Institute of Technology (IRE)
Mr. Morris Rubinoff, Philco Corporation (AIEE)

ADVISORY PANEL TO CRYOGENIC ENGINEERING DIVISION

Prof. Charles Squire, The Rice Institute (AIP)
Prof. S. C. Collins, Massachusetts Institute of Technology (ASME)
Mr. A. Latham, Jr., Arthur D. Little Company (AIChE)
Dr. Clyde McKinley, Air Products Incorporated (AIChE)

ADVISORY PANEL TO CENTRAL RADIO PROPAGATION LABORATORY

Prof. Henry G. Booker, Cornell University, Chairman (IRE)
Mr. Stuart L. Bailey, Washington, D.C. (IRE)
Mr. A. B. Crawford, Bell Telephone Laboratories
Dr. S. W. Herwald, Westinghouse Electric Corporation (AIEE)
Dr. John S. Smyth, Smyth Research Associates (AIP)
Dean George Town, Iowa State University (AIEE)
Prof. A. H. Waynick, National Science Foundation (IRE)
Dr. H. W. Wells, Carnegie Institution of Washington (IRE)
Prof. J. B. Wiesner, Massachusetts Institute of Technology (IRE)

ADVISORY PANEL TO RADIO STANDARDS DIVISION

Prof. E. C. Jordan, University of Illinois, Chairman (IRE)
Prof. Walter Gordy, Duke University (AIP)
Prof. W. A. Lewis, Illinois Institute of Technology (AIEE)
Prof. Arthur A. Oliner, Polytechnic Institute of Brooklyn (IRE)
Dr. John C. Simons, National Research Corporation (IRE)
Mr. Robert C. Sprague, Sprague Electric Company (AIEE)

WEIGHTS AND MEASURES ADVISORY COMMITTEE

[Members are nominated by the National Conference on Weights and Measures]

Dr. A. T. McPherson, National Bureau of Standards, Chairman
Prof. L. J. Gordon, Weights and Measures Research Center, Denison University
Mr. Rollin E. Meek, State Board of Health, Indiana
Commissioner P. C. Brinkley, State Department of Agriculture and Markets, Virginia
Mr. L. T. Gustafson, Creamery Package Manufacturing Company
Mr. J. E. Moss, American Petroleum Institute
Mr. E. C. Westwood, City Sealer of Weights and Measures, Salt Lake City, Utah

ASA-ASTM ADVISORY COMMITTEES

For many years the National Bureau of Standards has worked in close cooperation with the American Standards Association and the American Society for Testing Materials. The committees designated by these organizations to advise the Director of the Bureau in areas of mutual interest currently are being reorganized.

3.5. AWARDS AND HONORS

Recognition of the Bureau's contributions to science and technology often takes the form of awards and honors from government, academic, professional, and industrial groups. The following list reflects such recognition bestowed on Bureau staff members during fiscal year 1960.

RECIPIENT	AWARD
Appel, William D.	Honorary degree of Doctor of Science from North Carolina State College
Astin, Allen V.	Honorary degree of Doctor of Science from New York University
Astin, Allen V.	National Civil Service League Career Service Award
Astin, Allen V.	Eli Whitney Memorial Award from the American Society of Tool Engineers
Astin, Allen V.	Elected to the National Academy of Sciences
Bright, Harry A.	Anachem Award of the Detroit Section of the American Chemical Society
Bussey, William S.	Elected a Vice President of the British Institute of Weights and Measures Administration
Cunningham, James A.	Certificate of Merit from the D.C. Council of Engineering and Architectural Societies
Davis, Marion M.	Elected President of the D.C. Chapter of Sigma Xi
Dellinger, J. H. (retired)	Annual Pioneer Award from the Institute of Radio Engineers
Foster, Bruce E.	Elected Director of the American Concrete Institute
Fullmer, Irvin H.	Cited for leadership by the Board of Codes of the American Society of Mechanical Engineers
Gardner, Irvine C.	Elected a Fellow in the Optical Society of America
Gibson, Kasson S.	Elected a Fellow in the Optical Society of America
Harrison, William N.	Award of Merit of the American Society for Testing Materials
Hudson, Ralph P.	Fellowship from the John Simon Guggenheim Memorial Foundation
Judd, Deane B.	Elected a Fellow in the Optical Society of America
Keegan, Harry J.	Elected a Fellow in the Optical Society of America
Kiess, Carl C.	Elected a Fellow in the Optical Society of America
Mason, Henry L.	Elected a Fellow in the American Society of Mechanical Engineers
McPherson, Archibald T.	Honor Award by the American Institute of Chemists
Mebs, Russell W.	Burgess Memorial Award by American Society for Metals
Mohler, Fred L.	Elected a Fellow in the Optical Society of America
Norton, Kenneth A.	Harry Diamond Memorial Award for 1960 of the Institute of Radio Engineers
Parsons, Douglas E.	Honorary membership in the American Society for Testing Materials
Plyler, Earle K.	Elected a Fellow in the Optical Society of America
Richardson, John M.	RESA Boulder Scientist Award
Rosenberg, Samuel J.	Elected to Alpha Sigma Mu
Scribner, Bourdon F.	Elected a Fellow in the Optical Society of America
Sitterly, Charlotte M.	Elected a Fellow in the Optical Society of America
Skramstad, Harold K.	Best Presentation of a Technical Paper by the Eastern Joint Computer Conference
Spencer, Lewis V.	Distinguished Service Award from the Office of Civil and Defense Mobilization
Stromberg, Robert R.	Elected President of the Washington-Baltimore Chapter of the Society of Plastic Engineers
Sweeney, William T.	Wilmer Souder Award of the International Association for Dental Research
Taylor, Lauriston S.	Honorary degree of Doctor of Science from the University of Pennsylvania
Teele, Ray P.	Elected a Fellow in the Optical Society of America
Tipson, Robert S.	Elected Member-at-Large of the Council of the Gordon Research Conferences
Wildhack, William A.	Elected a Fellow in the Instrument Society of America
Wood, Lawrence A.	Elected president of the Washington Academy of Sciences
Joint Award: Block, Stanley; Levin, Ernest M.	S. B. Meyer, Jr., Award of the American Ceramic Society

DEPARTMENT OF COMMERCE MERITORIOUS SERVICE AWARDS

RECIPIENT	TECHNICAL AREA
Achhammer, Bernard	Chemical structure and stability relationships of plastics and polymers
Burdick, Milton	Engineering properties of materials at high temperatures
Cassel, James	Chemistry and structure of collagen
Deming, Lola	Mathematical and statistical analyses
Irish, Carolyn	Physical metallurgy
Kerns, David	Microwave standards and measurement techniques
Levin, Ernest	Phase studies in nonmetallic minerals
Logan, Hugh	Stress corrosion cracking of metals

Mann, Lytle	Instrumentation for the electron physics program
Page, Benjamin	Intercomparison and calibration of line standards of length
Selby, Myron	Radio standards and radio measurement techniques
Smith, Patia	Administrative duties
Stober, Alfred	Free radicals research program
Taylor, John	Electrochemical methods of analysis
Wachtman, John, Jr.	Mechanical properties of ceramic materials
Whitney, Virginia	Extensive and specialized reference and bibliographic assistance

DEPARTMENT OF COMMERCE EXCEPTIONAL SERVICE AWARDS

RECIPIENT	TECHNICAL AREA
Keulegan, Garbis	Hydrodynamics
McNish, Alvin G.	Geomagnetism, ionospheric physics, metrology and standardization
Page, Chester H.	Electronics, ordnance, physical research and measurement
Sitterly, Charlotte	Spectroscopy and astrophysics and interpretations of the solar spectrum
Testa, Leonardo	Contributions as a creative glassblower to scientific programs
Wyckoff, Harold	Radiation shielding and measurements
Joint Award:	
Bass, Arnold Broida, Herbert	Free radicals research program

3.6. EDUCATION AND TRAINING PROGRAM

The Bureau sponsors a broad Employee Development Program oriented to the education and training needs of all staff members. Primary program objectives are increasing efficiency in the conduct of official, assigned duties, and systematic preparation for increased responsibilities. This program is implemented through two major educational media: The NBS Graduate School, and training through non-Government facilities. The program covers educational levels up through postdoctoral research and includes general staff development courses.

The curriculum of the Bureau's Graduate School, with an average of 40 courses a year, includes graduate and undergraduate courses in the physical sciences, mathematics, and certain branches of engineering; and a series of scientific colloquia and seminars led by research leaders from the Bureau staff and from other research centers in this country and abroad. Educational counseling and a program of thesis accreditation are also provided. A series of general staff development courses is also offered through the Graduate School. Typical examples in this category are mechanical drawing, scientific Russian, and preparation of technical papers and reports.

The Graduate School curriculum is divided into courses classed as NBS out-of-hours, NBS in-hours, and NBS university-sponsored out-of-hours. Course offerings, based on periodic need surveys, are determined by the NBS Educational Committee. The program is flexible to meet the varied and changing needs of the staff. For example, a Technician Career Program was established in 1960 to increase job efficiency and to offer broader educational opportunities for subprofessional laboratory personnel. Since the establishment of the Graduate School in 1908, more than 15,500 registrations have been recorded, and more than 270 graduate degrees have been awarded by 40 different universities, partly on the basis of credits obtained, or thesis work carried on, through the Graduate School. During the past year, there were 1,322 registrations in 72 courses offered at the Washington

and Boulder Laboratories. Approximately 500 of these registrations were from the Army's Diamond Ordnance Fuze Laboratories and other government agencies in the Washington area.

The Bureau sponsors three major training programs through non-government facilities under authority of the Government Employees' Training Act of 1958. These are:

1. Full-time (3 to 12 months) postdoctoral study and research assignments at universities and research centers, both in this country and abroad.
2. Full-time (less than 3 months) attendance at institutes, seminars, short concentrated courses, workshops, etc. Generally, these are offered through the educational facilities of major universities and industrial laboratories throughout the country.
3. Part-time, job-related, academic courses at local educational institutions, generally in early evening classes.

Approximately 240 staff members were trained through non-government facilities in 1960. Nine selected career scientists were sent on full-time research assignments to universities and research centers. Thirty-one staff members, primarily scientists and subprofessional laboratory personnel, attended short concentrated courses and training programs at universities and in industry. In addition, 200 employees, mostly from technical divisions, attended job-related courses at local educational facilities. Participants' full salaries and expenses in non-government training programs were paid by the Bureau. These included tuition, related fees, travel, and per diem, as well as transportation of family and household effects for full-time, long-term training.

An annual summer student trainee program at the Bureau is open to college students majoring in the physical sciences, mathematics, and certain branches of engineering. This activity is an integrated work-study program including lectures, tours, demonstrations, supervised laboratory assignments, and professional counseling. The program has the twofold purpose of acquainting young people with career opportunities in scientific research at NBS and preparing select students for such careers. The 1960 summer student program had an approximate enrollment of 200 students, 100 of whom were returnees from previous summers. The new group included 13 outstanding high school students who had obtained recognition through the Westinghouse Science Talent Search or other national science competition.

The 1960 student group represented 58 colleges and universities from a wide geographical area.

In collaboration with the National Research Council, the Graduate School offers postdoctoral resident research associateships to young scientific investigators of unusual ability and promise of becoming creative leaders in basic research. Associates are given an opportunity for advanced training in basic research in the various branches of the physical and mathematical sciences. While acquiring basic knowledge, they have opportunities for

developing new scientific approaches and laboratory skills, thus advancing scientific knowledge. Associateships, which are limited to 20 at any one time, are tenable at both the Washington and Boulder Laboratories.

The Bureau's educational program also includes weekly Scientific Staff Meetings which run from September through May. Of less specialized nature than colloquia and seminars offered in the Graduate School, the Scientific Staff Meetings are open to all members of the professional staff at the Bureau and are also regularly attended by scientific personnel from neighboring laboratories. Designed to keep Bureau personnel abreast of current developments in the various fields, these lectures are given by members of the staff and by scientists from universities and other laboratories in the United States and abroad. Lectures by members of the Bureau staff include a yearly report to the staff by the Director, lectures on current research of broad general interest to other members of the staff, reports by staff members on international meetings, and reports from fellowship scientists on research work at other institutions in this country and abroad. About two-thirds of the program is devoted to lectures by guest scientists.

3.7. COOPERATIVE RESEARCH WITH INDUSTRY

The Bureau's Research Associate Plan, a cooperative program with American industry, has resulted in many significant developments in science and technology. Under this plan, technical, industrial, and commercial organizations can support work at the Bureau on projects that are of special interest to them, yet are of sufficient general interest to justify use of government facilities. These projects must also be important from the standpoint of the Nation's sum total of technological knowledge. Supporting industries donate both funds and personnel for the projects. At the present time 12 groups are supporting research associates at NBS in the following areas:

Sponsor	*Field of Activity*
American Dental Association	Dental research.
American Electroplaters Society	Porosity and corrosion of electroplated surfaces.
American Society for Testing Materials	Cement reference laboratory.
American Standards Association	Codes, specifications, and standards.
Asphalt Roofing Industry Bureau	Asphalt roofing research.
Bone Char Research Project, Inc.	Studies of adsorption and adsorbents.
Calcium Chloride Association	Hydration of portland cement.
NBS-Joint Committee on Chemical Analysis by Powder Diffraction Methods: ASTM, American Crystallographic Assoc., Institute of Physics (British), National Assoc. of Corrosion Engineers.	Standard X-ray diffraction powder patterns.
National Research Council	Electron physics. Atomic physics.
Porcelain Enamel Institute	Development of standard tests.
Portland Cement Association	Basic research in physical chemistry related to portland cement.

An important and similar area of cooperation between the Bureau and industry is the program authorized in 1950 by Public Law 619 under which the Bureau is authorized to accept funds for the purpose of furthering its work. This arrangement permits individuals as well as technical, industrial, and commercial organizations to support work at the Bureau when the results are expected to be of value to the general public.

During the past year 11 projects were supported by gifts from 10 organizations as follows:

Gift-Supported Projects

Donor	*Field of Activity*
American Iron and Steel Institute	Durability of steel pilings.
American Iron and Steel Institute	Ship plate steels.
American Petroleum Institute	Metal-organic standards.
Corrosion Research Council of the Engineering Foundation.	Reactions at metal surfaces and on stress corrosion.
Edward Mallinckrodt, Jr., Foundation	Ether peroxides.
Edward Orton Jr., Ceramic Foundation	Research in clays.
Expanded Shale Clay and Slate Institute	Shale aggregate.
Illuminating Engineering Research Institute	Programing computers for calculating the chromaticity coordinates with lamps having line spectra.
National Lime Association	Hydration of lime.
Technical Association of the Pulp and Paper Industry	Air-leak smoothness testers.
UNESCO	Ionization chamber.

3.8. PUBLICATIONS AND PATENTS

Publications in the Bureau's Series*

Journal of Research. Contains full research papers, including laboratory data, experimental procedures, and theoretical and mathematical analyses. Advances in measurement standards and techniques . . . physical constants . . . properties of materials . . . instrumentation . . . radio propagation.

The Journal is published in four separate sections . . .

A. Physics and Chemistry—issued six times a year.
B. Mathematics and Mathematical Physics—issued quarterly.
C. Engineering and Instrumentation—issued quarterly.
D. Radio Propagation—issued six times a year.

The papers listed below have appeared in the four-section Journal since July 1959.

Volume 63A, July–December 1959

Description and analysis of the first spectrum of iodine, C. C. Kiess and C. H. Corliss.

CH in the solar spectrum, C. E. Moore and H. P. Broida.

Infrared studies in the 1- to 15-micron region to 30,000 atmospheres, C. E. Weir, E. R. Lippincott, A. Van Valkenburg, and E. N. Bunting.

Phosphinoborine compounds: mass spectra and pyrolysis, L. A. Wall, S. Straus, R. E. Florin, F. L. Mohler, and P. Bradt.

Experimental and theoretical study of kinetics of bulk crystallization in poly-(chlorotrifluoroethylene), J. D. Hoffman, J. J. Weeks, and W. M. Murphey.

Reflection of fast neutrons from water, M. J. Berger and J. W. Cooper.

Some vibrational-rotational bands of deuterated methanes, H. C. Allen, Jr., and E. K. Plyler.

Precise coulometric titration of acids and bases, J. K. Taylor and S. W. Smith.

*Publications in these series are available, unless otherwise indicated, from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.

Heat of formation of titanium tetraiodide, W. H. Johnson, A. A. Gilliland, and E. J. Prosen.
Reactions of pentafluorohalobenzenes, W. J. Pummer and L. A. Wall.
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Studies of beryllium chromite and other beryllia compounds with R_2O_3 oxides, C. E. Weir and A. Van Valkenburg.
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Relations between summation methods and integral transformations, W. Greub.
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Creep of cold-drawn nickel, W. D. Jenkins and C. R. Johnson.
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Apparatus for the measurement of the normal spectral emissivity in the infrared, A. G. Maki, R. Stair, and R. G. Johnston.
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Radiation field from a rectangular source, J. H. Hubbell, R. L. Bach, and J. C. Lamkin.
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Ratio-recording spectroradiometer, H. K. Hammond III, W. L. Holford, and M. L. Kuder.
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Origin of [OI] 5577 in the airglow and the aurora, F. E. Roach, J. W. McCaulley, and E. Marovich.
Comparison of absolute intensities of [OI] 5577 in the auroral and sub-auroral zones, F. E. Roach, J. W. McCaulley, and C. M. Purdy.
Origin of "very-low-frequency emissions", R. M. Gallet and R. A. Helliwell.
Climatology of ground-based radio ducts, B. R. Bean.
Power requirements and choice of an optimum frequency for a worldwide standard-frequency broadcasting station, A. D. Watt and R. W. Plush.
Measurements of phase stability over a low-level tropospheric path, M. C. Thompson, Jr., and H. B. Janes.
System loss in radio wave propagation, K. A. Norton.
Mode expansion in the low-frequency range for propagation through a curved stratified atmosphere, H. Bremmer.
Transmission and reflection by a parallel wire grid. M. T. Decker.
Synoptic variation of the radio refractive index, B. R. Bean and L. P. Riggs.
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Stratification in the lower ionosphere, C. Ellyett and J. M. Watts.
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Fields in electrically short ground systems: an experimental study, A. N. Smith and T. E. Devaney.
Diffraction of electromagnetic waves by smooth obstacles for grazing angles, J. R. Wait and A. M. Conda.
Very-low-frequency radiation spectra of lightning discharges, W. L. Taylor and A. G. Jean.
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Study at 1046 megacycles per second of the reflection coefficient of irregular terrain at grazing angles, R. E. McGavin and L. J. Maloney.
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Effect of antenna size on gain, bandwidth, and efficiency, R. F. Harrington.
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Measured frequency spectra of very-low-frequency atmospherics, T. Obayashi.
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57 (PB161558) Variable capacitor calibration with an inductive voltage divider bridge, T. L. Zapf. 50 cents.
58 (PB161559) A survey and bibliography of recent research in the propagation of VLF radio waves, J. R. Wait. 75 cents.

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PATENTS

The following U.S. patents have been granted to NBS inventors; assigned (or licensed as indicated) to the United States of America, as represented by the Secretary of the department noted in parentheses:

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Beatty, Robert W., No. 2,922,963, January 26, 1960. Adjustable waveguide termination. (Commerce.)

Brauer, Gerhard M., No. 2,936,242, May 10, 1960. Cements from metal oxides and chelating agents. (Commerce.)

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Cooke, Finley L., No. 2,929,027, March 15, 1960. Amplifier including hum elimination control means. (Navy.)

Cordero, Fidel, No. 2,913,008, November 17, 1959. Nonlinear sensitive diaphragm. (Commerce.)

Cunningham, James A., and Holt, Arthur W., No. 2,913,600, November 17, 1959. Diode amplifier and computer circuitry. (Commerce.)

Davis, Merlin, No. 2,900,861, August 25, 1959. Electronic musical instruments. (Licensed to the United States of America as represented by the Secretary of Commerce.)

deMinjer, Clara H., and Brenner, Abner, No. 2,929,742, March 22, 1960. Electroless deposition of nickel. (Commerce.)

Forman, Ralph, No. 2,935,624, May 3, 1960. Electrostatically controlled reference tube. (Commerce.)

Golden, Sidney, No. 2,924,562, February 9, 1960. Method of free radical production and stabilization. (Licensed to the United States of America as represented by the Secretary of Commerce.)

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