Annual Report 1950

National Bureau of Standards

Miscellaneous Publication 200

UNITED STATES DEPARTMENT OF COMMERCE
Charles Sawyer, *Secretary*
NATIONAL BUREAU OF STANDARDS
E. U. Condon, *Director*

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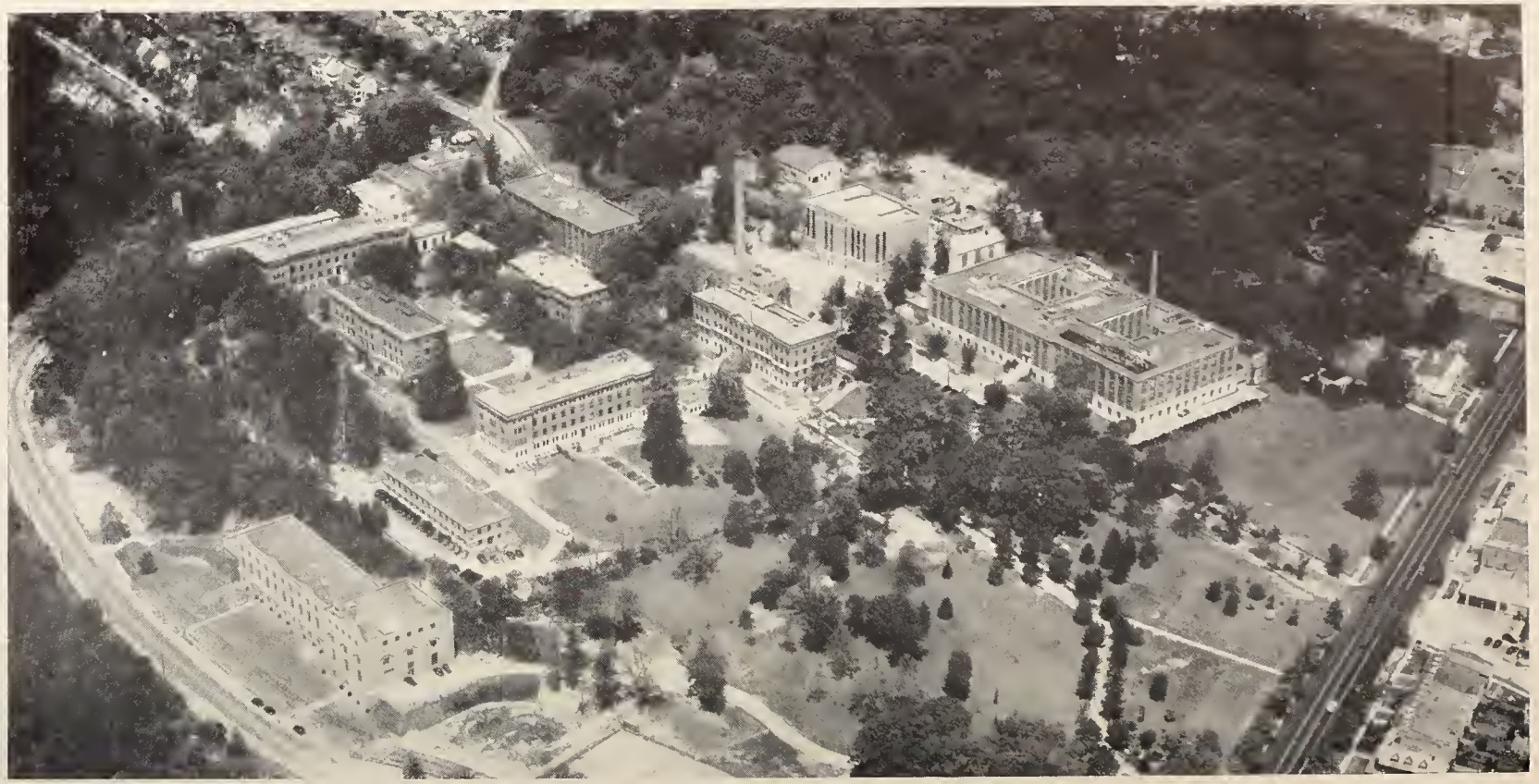

Aerial view of the National Bureau of Standards.

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1. General Review

The National Bureau of Standards is the principal agency of the Fedcral Government for basic and applied research in physics, mathematics, chemistry, and engineering. In addition to its general responsibility for basic research, the Bureau undertakes specific researeh and development programs, develops improved methods for testing materials and equipment, determines physieal constants and properties of materials, tests and calibrates standard measuring apparatus and reference standards, develops specifieations for Federal purehasing, and serves the Government and the scientifie institutions of the Nation in an advisory capacity on matters relating to the physieal seiences. The Bureau also has eustody of the national standards of physical measurement, in terms of which all working standards in research laboratories and industry are calibrated, and carries on necessary research leading to improvement in sueh standards and measurement methods.

Most of the Bureau's work was conducted at its laboratorics in Washington. Four materials testing stations, chiefly conecrned with cement analysis, were maintained in Allentown, Pa.; Seattle, Wash.; Denver, Colo.; and San Franeisco, Calif. Two proving grounds were in usc during the year (one in Maryland, the other in New Jersey). A railway-scale test-car station was maintained in Clearing, Ill., and a lamp-inspecting station in Brookline, Mass. Research in certain fields of applied mathematics was conducted at the Bureau's Institute for Numerical Analysis, Los Angeles, California. Radio propagation activities involved the maintenance of field stations at Sterling and Fort Belvoir, Va.; Puunene, Territory of Hawaii; Puerto Rico; Greenland; Guam; Trinidad, British West Indies; White Sands Proving Ground, Las Cruces, N. Mex.; Cheyenne Mountain, Colo.; and Anchorage and Point Barrow, Alaska. Eleven other radio propagation field stations were under contract to the Bureau. In addition, two transmitting stations were operated: WWV at Beltsville, Md., and WWVH in Hawaii.

Research and Development

A significant accomplishment of the year was the completion and successful operation of SEAC—the National Bureau of Standards Eastern Automatic Computer. SEAC is the fastest general-purpose, automatically sequenced electronic computer now in operation. It was developed and constructed, in a period of 20 months, by the staff of the National Bureau

of Standards under the sponsorship of the Department of the Air Force to provide a high-speed computing service for Air Force Project SCOOP (Scientific Computation of Optimum Programs), a pioneering effort in the application of scientific principles to the large-scale problems of military management and administration. SEAC will also be available for solving other important problems in such fields as atomic physics, ballistics, and aerodynamics. In addition, SEAC is expected to aid in further development of computing machines at the Bureau and to provide important training and operational experience for personnel of those Federal agencies that plan to operate other electronic computers as soon as they are completed.

SEAC automatically performs all of the logical and arithmetical operations required to solve a particular problem once it is supplied with coded instructions and numerical data. Its high speed permits the use of many simple steps that can be combined into a complex and powerful sequence for the solution of difficult problems. This makes it possible to solve important mathematical, computational, and statistical problems which would otherwise be impossible of solution in any reasonable period of time, or which would be prohibitive in cost if attempted by conventional methods.

The design and construction of SEAC was part of an extensive program on electronic computers undertaken by the National Bureau of Standards in cooperation with the Office of Naval Research, the Bureau of the Census, the Department of the Army, and the Department of the Air Force. This program involves the research, design, and development work necessary to produce faster, simpler, and more versatile electronic computers and to make more effective use of the machines already in existence. In addition to constructing machines for its own use, the Bureau is acting as the technical coordinating ageny for the construction by industry of five large-scale computers for other Government agencies.

At the close of the fiscal year, a second high-speed, general-purpose electronic computer was nearing completion at the Bureau's Institute for Numerical Analysis in Los Angeles. This machine will be known as SWAC—the National Bureau of Standards Western Automatic Computer. Sponsored by the Office of Air Research of the Air Force, it will be operated by the National Bureau of Standards to provide a fast and powerful computational tool for three large types of problems: (1) problems of the Office of Air Research of the Air Force and aircraft problems originating with contractors of the Air Force (in particular, the aircraft industry of the West Coast); (2) problems in engineering, physics, and mathematics originating in the laboratories of the Bureau and other Government agencies; and (3) problems in research in numerical analysis and those arising in connection with the development of the art of machine computation.

Another electronic development, the NBS Electronic Currency Counter, is expected to save the Government about a quarter of a million dollars annually. This device, designed and constructed under the sponsorship of the Treasury Department, automatically counts old paper bills at the rate

An extremely sensitive method was developed for testing the planeness of optical surfaces (p. 19). Additional fringes are interpolated between the half-wavelength fringes of the usual interferometer pattern. Above: interference pattern of an optical flat; contour interval, one-half wavelength, or 0.00001 inch. Below: portion of same surface greatly magnified; contour interval one-thirtieth wavelength, or 0.0000006 inch. (Photographs awarded second prize in the Fourth Annual Photography-in-Science Salon of the American Association for the Advancement of Science.)

of 30,000 per hour. Although new paper money has been machine-counted for many years, the mechanical handling of worn-out notes has until now been a difficult problem. Old money is limp, wrinkled, and difficult to work with. Single, torn notes are occasionally taped together. These and similar problems have meant that the condition of returned notes is variable, and tedious counting by hand has been necessary.

Money returned to the Treasury is in the form of stacks of 100 notes, cut in half lengthwise. The NBS Electronic Currency Counter counts the half-notes in these packets and automatically rejects those with more or less than 100. Counting is achieved by means of an electronic sensing device consisting of a beam of light and a photoelectric system. As the notes are unfurled, interrupting the beam of light, the photoelectric tube counts them by sensing the interruptions of the beam. Impulses from the electric eye go into an electronic arithmetic unit, which tallies the individual impulses. In this way, rapid counting combined with accuracy, the principal objective of the development program, has been achieved.

Research and study in atomic physics at the Bureau extends back to 1913, when a radium laboratory was established. At that time the primary standard of radium, prepared by Madame Curie, entered the custody of the Bureau, and commercial preparations of radium were measured in terms of this standard. As a result of recent scientific advances, atomic and radiation physics is now clearly recognized as a large and increasingly important branch of physics, and an expanded interest on the part of the Federal Government in this field is now required to establish standards of measurement for new industries in such fields as radioactivity and high-voltage X-rays, to provide for the proper protection of workers and consumers, and to protect its own investments as a consumer of new products. In addition to fundamental research, studies necessary for the extension of measurement and standardization are conducted.

During the past year, the program for the calibration of standard samples of artificially produced radioactive isotopes continued to grow as the demand for such standards increased in medicine, science, and industry. Efforts were directed toward more precise calibration and toward the development of uniform standards for isotope measurement. Thus, a new system of calibration was developed for laboratories using radioactive phosphorus and iodine which materially increased the consistency of their results. Similar work is under way on other radioactive isotopes.

The increased availability of large quantities of radioactive materials and the greater diversity of machines for generating radiation have caused problems of radiation measurement and protection to grow steadily more complex. Investigation of two general problems of instrumentation in this field was initiated during the year: (1) the development of instruments for measuring the properties of beta-rays, and (2) the development of instruments for measuring dosages of high-intensity, low-voltage X-rays. These investigations will be of particular value in new methods of therapy

NBS laboratory in which ammeters, voltmeters, and other electrical indicating instruments are calibrated in terms of the national standards of resistance and voltage.

now being utilized by the medical profession, for various kinds of research being performed by the Atomic Energy Commission, and to answer the demands of research laboratories and industry, where use of such radiations is increasing.

With the installation of a new 50-million volt betatron, work in radiation physics was also extended into the region of extremely high energies. This new program in high-energy radiation has four main aspects: the investigation of shielding and protection against high-energy X-rays, the medical applications of these radiations, their industrial applications, and their basic physical properties.

X-rays with energies between 10 and 70 million volts are now widely used in the medical treatment of deep-seated tumors. These high-energy radiations can be directed to burn out a pinpoint of afflicted tissue deep within the human body without damaging the surrounding area, but proper protective precautions are of the greatest importance—both to the patient and to the radiologist administering the treatment. The Bureau has already established standards for protection against low-energy X-rays, and the new betatron research program will fill the need for standards of protection in the higher regions now available to medicine. The much deeper penetration of high-energy X-rays requires entirely new scientific standards for full exploitation of these sources of radiation while maintaining adequate protection.

Standards for protection against radiation have not only a safety aspect but an economic one. Today, the exact wall thicknesses and best struc-

tural materials are not known for high-energy X-rays. In order to be on the safe side, high-energy installations are over-protected, with excessively thick walls and barriers which add greatly to the cost. In many installations the cost of protective walls and barriers exceeds that of the X-ray or betatron equipment itself. Accurate recommendations for barrier thicknesses in the high-energy field, similar to those previously developed by the Bureau for lower energies, will result in large savings.

In connection with the work in atomic physics, a new instrument, the *omegatron,* was developed to discriminate between atomic particles of different masses. The omegatron is basically a miniature cyclotron, operating on the same fundamental principle as a large cyclotron, but the heart of the instrument is little larger than a package of cigarettes. Its successful development makes possible the determination of the values of several important atomic constants with exceedingly high precision. For example, the faraday—a constant of basic interest to both physicists and chemists—is now being evaluated for the first time directly by physical methods; all previous measurements of the faraday have been electrochemical. Since the faraday was defined as a unit of quantity of electricity, many attempts have been made, over a period of 100 years, to determine its precise value. The present discrepancy between the two best determinations thus far—with the iodine voltameter and with the silver voltameter—has been distressing to scientists engaged in revising the tables of atomic constants since the faraday is a key component of these tables. The work now under way at the Bureau provides an independent check on the electrochemical method, and preliminary results indicate that use of the omegatron will give increased accuracy. Development of the omegatron has also made possible the very precise determination of the magnetic moment of the hydrogen nucleus, or proton, so that the ratio of the mass of the proton to the mass of the electron can now be known with greater precision than ever before.

In addition to absolute measurements of mass, the omegatron has many other possible uses. For example, its high resolution and extreme sensitivity make it ideal for analysis of gases and vapors and for the measurement of nuclear packing fractions (the excess of actual mass value over mass number for any isotope), which are very important in atomic physics.

In another project, the electron-optical shadow method, recently developed at the Bureau for photographing and studying minute electric and magnetic fields, was further extended. Modification of the method resulted in an accurate, sensitive technique for experimentally determining the electric-field distribution and space-charge density within a magnetron, a vacuum tube widely used for generating power at microwave frequencies.

The high space-charge density within a magnetron is known to have an important bearing on performance, but very little is actually known concerning the electric-field distribution and space-charge configuration within the tube. Although the problem has been investigated theoretically by many workers, the formidable mathematics involved have not permitted

Calibration of a Mueller bridge in the Bureau's resistance measurements laboratory. If the instrument is frequently calibrated, it can measure resistance with an accuracy of a few parts in a million.

an exact solution, and the various simplifications of the theory that have been suggested have led to widely divergent results. Attempts at direct measurement have also proved unsuccessful because the very critical symmetry of the field under study was disturbed. A promising approach to the problem has now been provided by the method developed at the Bureau. Further application of the method should lead to a much better understanding of magnetron operation and should yield information of considerable value to the engineer who is interested in designing improved types of magnetrons or in predicting the performance of existing types.

In a continuing program of research on the properties of matter at extremely low temperatures, significant discoveries were made concerning superconductivity and the properties of liquid helium II. At the temperature of liquid helium, metals such as lead and tin, ordinarily poor conductors of electricity, become superconductors with a complete loss of electrical resistance. The Bureau is now making studies seeking a more complete explanation of this and other low-temperature phenomena. Included in the program is an investigation of the extraordinary properties of liquid helium near absolute zero, which seem to constitute a fourth state of matter.

In liquid helium II, a form of helium exising at very low temperatures, heat is transmitted as a kind of wave motion analogous to sound and known as "second sound." During the year, the Bureau succeeded in measuring for the first time the velocity of second sound at temperatures well within one Centigrade degree of absolute zero. The results obtained, in addi-

tion to settling a point of long-standing disgareement among low-temperature physicists, provide a useful oricntation for mapping future research efforts in this field and should eventually lead to a better understanding of the nature of matter.

The two-fluid theory of liquid helium II states that, in the presence of a heat current, two kinds of atoms which make up helium II flow in opposite directions to produce second sound. A striking demonstration of the validity of this theory was provided by the devclopment of a very simple yet highly accurate mechanical technique, known as the Thermal Rayleigh Disk Method, for investigating second sound. The method constitutes the first mechanical means for detection of this phenomenon. By its use, it has been possible to study the relative amounts and properties of the two fluid components, and the rcsults fully confirm theoretical expectations.

In superconductivity, a new and wholly unexpected rclationship was discovered betwecn loss of electrical resistance at very low temperatures and the constitution of the atomic nucleus. Until now it has been generally supposed that superconductivity is concerned cxclusively with the properties of the atomic configuration outside the nucleus. However, the results obtained at the Bureau, in combination with an independent and almost simultaneous discovery of the same phenomenon at Rutgers University, establish the validity of the nuclear effect beyond question.

As in previous years, much work was done in the general field of aeronautics. For cxample, methods wcre devised for determining the stiffness of typical aircraft wing structures with discontinuities such as bulkheads and cut-outs and with varying amounts of swecpback. To aid the Department of the Navy in the flight-testing of aircraft, an instrument was designed and constructed which automatically indicates the force applied by the pilot to the control stick of an airplane. Another instrument was developed for dctecting gasoline vapors or other combustible gases in airplane cabins or cargo holds. The devclopment of improved equipment and methods for testing aircraft accessories was continued, with particular emphasis on the components of the fuel and electrical systems. As part of a comprehensive program on the properties of laminated plastics for aircraft use, projects were completcd dcaling with the effect of simulated service conditions, fuel immersion, and extreme temperatures on these materials. An improved photogrid technique for determining elongation of aircraft sheet metal was developcd. The effect of chromium plating on the fatigue characteristics of steels uscd in aircraft was investigated, and study of the corrosion of aluminum, magnesium, and stainless steel sheet metal for aircraft was continued.

The field of jet engines and fuels received justified emphasis during the year. Although jet engines are being increasingly utilized for high-speed flight, much research and development remains to be done in order to attain the desired reliability, economy, performance, and safety. Through continuing projects, sponsored by the military services, the Bureau is aiding

Calibrated chromatic reflectance standards (foreground), covering 10 important commercial colors, are now available from the Bureau for use with photoelectric reflectometers.

in the solution of these problems. Thus, operation of the combustion chamber at high altitudes has been the subject of much investigation. In the field of basic combustion studies, an extensive program was undertaken which seeks to measure true burning velocities and flame temperatures by a spectral line-reversal method. Further development of temperature-sensing devices for indicating performance and controlling operation is also urgently needed. Work in this field included the development and evaluation of reliable pneumatic temperature-sensing devices and the development of a new type of thermocouple capable of withstanding the mechanical stress to which thermocouples installed in turbo-jet engines are subjected. Another area in whch important technical improvements were made was the development of high-temperature coatings to protect metals and alloys used in jet engines against rapid deterioration from the effects of hot gases.

In automotive research, studies were directed toward the improvement of engines, fuels, tires, and accessories and the development of better methods for their evaluation. The Bureau has been active in this field since World War I, when a need for research on automotive problems first arose, and has contributed materially to the design and development of the test engines, equipment, and instrumentation now used to rate motor, aviation, and Diesel fuels. Since the development of standardized engine tests in 1932, the Bureau has served as the agency for the calibration of

reference fuels, such as normal heptane and isooctane, used throughout the country for the knock rating of gasolines. These reference fuels are now available at a purity of 99.99 percent as a result of improvements in the Bureau's purification process.

To learn more about the knocking characteristics of the individual hydrocarbons found in gasoline, an apparatus for investigating the burning mechanism of fuels was constructed. As this equipment can give more detailed information concerning the entire combustion process, it is expected to lead to a better understanding of engine knock and to point the way to improvement of engines and fuels. Other important studies completed or in progress included the effect of gasoline additives on valve deposits, the effect of oil additives on piston and piston-ring deposits, and a rather broad investigation of the behavior of tires under a variety of conditions which is expected to provide a means for predicting the expected normal service life of a tire.

A large part of the Bureau's research and development work is performed for other agencies of the Government, in particular the National Military Establishment, the Atomic Energy Commission, and the National Advisory Committee for Aeronautics. Typical projects are concerned with ordnance electronics, guided missiles, and atomic energy. Significant broad values are obtained for the Nation as a whole through the general research and development programs in these areas.

The projects discussed briefly above are indicative of the over-all achievements during the year. More detailed information on typical projects will be found in the sections of this report which treat separately the work of the scientific and technical divisions.

Testing, Calibration, and Standard Samples

The Bureau's testing and calibration activities stem from its custody of the Nation's basic physical standards. In many cases, master standards used in industry must be checked periodically against these national standards. The Bureau is also responsible for testing many of the materials purchased by the Bureau of Federal Supply, the Treasury, and other Federal agencies. In the course of this test, calibration, and standard samples work, new methods of measurement and new instruments are devised, and new technical data on the properties of materials are obtained.

Over 250,000 tests and calibrations were performed for other Government agencies and the public. This work provides the basis for accurate measurement in industry, laboratories, and institutions throughout the Nation. In addition, about 19,000 standard samples were prepared and distributed by the Bureau. Typical services of this kind included the sample-testing of about 9,000,000 barrels of cement, the testing and certification of over 2,000 radium preparations sold in this country, distribution of about 1,100 standards of radioactive materials, about 900 measurements of radon in breath samples from radium dial painters or in the workroom air, the

life-testing of more than 5,000 light bulbs (a sampling of over 4,000,000 purchased by the Government this year), the testing of 2,500 samples of microfilm for hypo content, and the sample-testing of about 74,000 clinical thermometers.

Codes and Specifications

The results of a large part of the research and testing have a direct bearing on the development of technical requirements designed to assure safe working and living conditions. The Bureau thus provides a central source of information to which Federal, State, and municipal authorities, as well as industrial and trade associations, can turn when dealing with problems of safety or with building and plumbing codes. During the year, representatives of the Bureau took an active part in work on revision of the National Electrical Code, the National Electrical Safety Code, the Code for Protection Against Lightning, the American Standard Elevator Safety Code, and other codes in the safety field. Other work in process was concerned with codes for mechanical refrigeration, electrical equipment in coal mines, electrical raceways, wood poles and crossarms, and plumbing systems.

Assistance was rendered to industry in the development of voluntary programs for the elimination of waste, and the Bureau also cooperated with organizations of manufacturers, distributors, and consumers in the development of qualitative and quantitative voluntary standards.

Cooperative and Consulting Services

One of the important factors in the successful prosecution of the diversified programs at the National Bureau of Standards is the availability of experts in nearly every special field of physics, applied mathematics, chemistry, and engineering. This combination of experts means that almost any problem in the physical sciences can be undertaken within the Bureau. At the same time, the results of investigation and the knowledge of its experts are available for additional uses. Thus, the Bureau serves every agency of the Federal Government and many State and municipal governments by rendering advisory and technical services. An important role of this type is played in the development and establishment of Federal specifications, which are necessary for economy in Federal purchasing. The Bureau also cooperates extensively with scientific and technical associations both in this country and abroad, on problems of concern to the Government and the Nation.

During the year, services of an advisory or consulting nature were rendered to almost every agency of the Federal Government. Typical services included consultative assistance to the Veterans' Administration in the preparation of specifications for medical X-ray equipment; aid to the State Department in the design of language record reproducing systems; determination of the causes of aircraft failures for the Civil Aeronautics Board; assistance to the Los Alamos Scientific Laboratory in planning improve-

ment of its timing equipment; development of methods for the modification of diathermy equipment for the Office of the Surgeon General, U. S. Army; technical advice and testing in connection with the relighting of the Senate and House Chambers; work on the preservation of the Constitution and the Declaration of Independence for the Library of Congress; and study of static electricity hazards in Government hospitals.

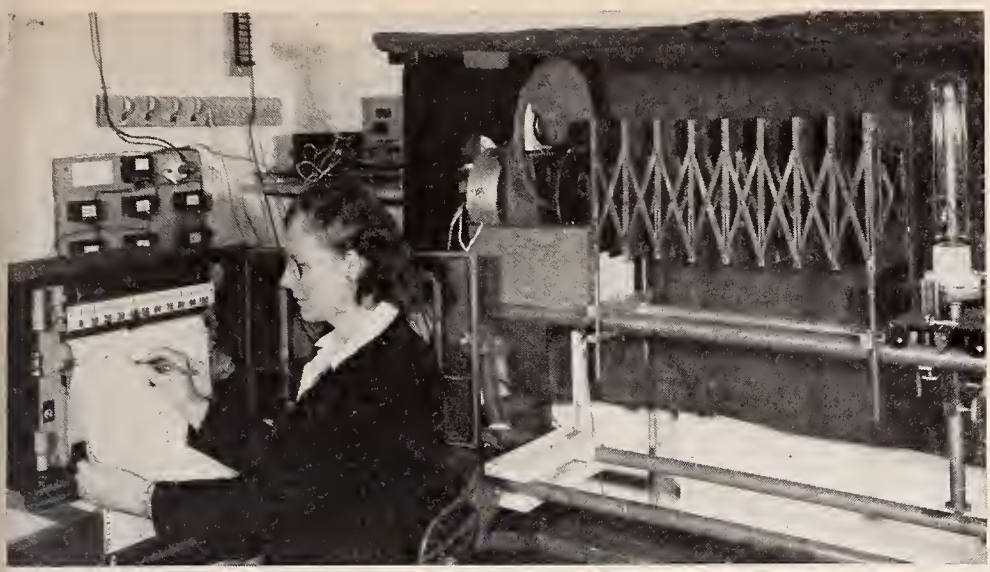
The Bureau also participated in the work of hundreds of technical committees, societies, associations, and commissions organized to bring new advances of science into the technology of industry, to standardize materials and products for greater economy and improved quality, and to establish uniform scientific standards throughout the world. Bureau staff members now hold approximately 1,600 positions on such national and international groups. An example is the Bureau's participation in the American Society for Testing Materials, in which the Bureau is represented by 434 committee memberships. The Bureau also holds about 250 memberships on committees of the American Standards Association and is the managing agency for several ASA projects.

Work in Progress

Several major programs, each encompassing a large number of specific projects, were in progress during the year. The continuing programs in electronic computers, atomic and radiation physics, low-temperature physics, aeronautics, jet engines and fuels, and automotive research have already been discussed. Other current programs important to science, industry, and the Nation deal with high polymers, building technology, radio propagation, electronics, applied mathematics, metallurgy, corrosion, optical instruments and optical glass, and dental materials.

Many new mathematical methods and experimental techniques are being employed at the Bureau in an integrated approach to the study of high polymers. Recent developments in this branch of chemistry have created synthetic plastics, rubbers, and textiles. The Bureau's program seeks not only to improve present knowledge of high polymers but to develop new materials of this type and to provide for their practical application. During the year, for example, fundamental research on the water-vapor relations of leather and collagen was extended to a practical study of the permeability of leather to water vapor, an important factor in determining the comfort of shoes. An important phase of the rubber program is the work on the standardization of Government synthetic rubbers, which involves the development of methods both for chemical analysis and physical testing.

Another major continuing program at the Bureau involves a unified approach to the problems of the construction industry. The work is so organized that groups are simultaneously engaged in investigations of properties of materials; structural strength; fire resistance; acoustics and sound insulation; heating, ventilating, and air conditioning; durability; exclusion of moisture; building and electrical equipment; and other related projects. Attention is focused on methods of saving materials, on the use of less ex-



The luminous intensity of a mercury-vapor lamp (extreme right) is measured. During the year new luminous flux values were derived for mercury vapor lamps (p. 21).

pensive and more readily available materials wherever feasible, and on the development of more economical designs based on information concerning the properties of materials which was not known a decade ago. Engineering principles are being applied to the design of houses, providing a complete and logical method for determining allowable loads for walls, floors, and roofs. This, in turn, makes it practicable to develop structural designs and to make use of nonconventional building materials that provide sufficient strength but require a minimum amount of material and labor.

An intensive program is under way in radio propagation. All uses of radio, particularly over long distances, require a radio prediction service analogous to the weather service. This service is provided by the Bureau on the basis of its own ionospheric observations and research. To further the work in radio propagation, comprehensive programs are being carried on in radio physics and related geophysical phenomena of the upper atmosphere and troposphere. In addition, primary standards and measurement methods are under development for electrical quantities at all radio frequencies. Important problems in this field still remain unsolved; and, as a result of the tremendous postwar extension of the available frequency range, new problems are constantly arising in measurement, instrumentation, standards, and calibration services. Microwave standards of frequency, power, attenuation, dielectric, and other electric quantities for frequencies up to 100,000 cycles or more have been intensely developed since the war. In connection with this work, an atomic clock, invariant with age and independent of astronomical observations, has recently been developed which promises to provide an atomic standard of frequency and time. During the past year, work was in progress on a new type of clock or frequency standard utilizing atomic-beam techniques; it is expected that this clock

will have unprecedented accuracy, with a variation of not more than one second in 300 years. Studies are also under way on microwave propagation, and measurements of cosmic and solar radio noise at very high frequencies are being carried forward.

Also important both to the Nation's peacetime economy and to the armed forces is the Bureau's program in electronics. The NBS Electronic Currency Counter has already been mentioned. Other new and highly specialized types of electronic circuits and devices are being developed to meet the particular requirements of industry and national defense. Much of the work is classified and involves the development of new ordnance devices for the National Military Establishment; a large part of the remainder consists of projects in basic and applied electronics conducted primarily for other Government agencies. One of the projects in this field is concerned with printed electronic circuits, in which printed wiring, resistors, and coils replace the conventional wires and independent elements common in electronic equipment. Work on the development and application of printed circuit techniques is continuing as part of a general program of electronic miniaturization. Other important phases of the electronics program include the development of rugged electron tubes for civilian and military use under conditions of vibration, shock, or acceleration; investigations of the fundamental behavior of cathodes and gases in electron tubes; development of electron tubes for special purposes; design and development of components for electronic digital computing machines; and design and development of electronic instrumentation for remote indication of steam turbine clearances and temperatures and for measurement of air temperature in wind tunnels.

The basic function of applied mathematics is to provide more economical and efficient methods for conducting scientific research and development. The Bureau's mathematics division engages in basic mathematical research and in addition acts as a service organization, particularly in the fields of engineering statistics and quality control, for the Bureau, the armed services, other governmental agencies, and industry. Assistance is given to other agencies in planning experiments in engineering and physics, and commercial sampling plans are prepared for inclusion in Federal specifications and commodity standards. The computation laboratory solves a variety of mathematical problems which arise in the work of other agencies and computes mathematical tables needed in many scientific and technical fields by the Navy, the Army, and other Federal agencies.

For many years the Bureau has carried on an extensive program of service work on metallurgy. This has included studies of failures of airplanes, automotive parts, and welded ships. An extended investigation of the flow, fracture, and ductility of metals and alloys is now in progress, involving measurements at high, low, and room temperatures. Attempts are also being made to determine why metals fail in fatigue and how incipient damage can be detected and corrected. A new instrument for

the measurement of X-ray diffraction patterns has been developed to aid in this work.

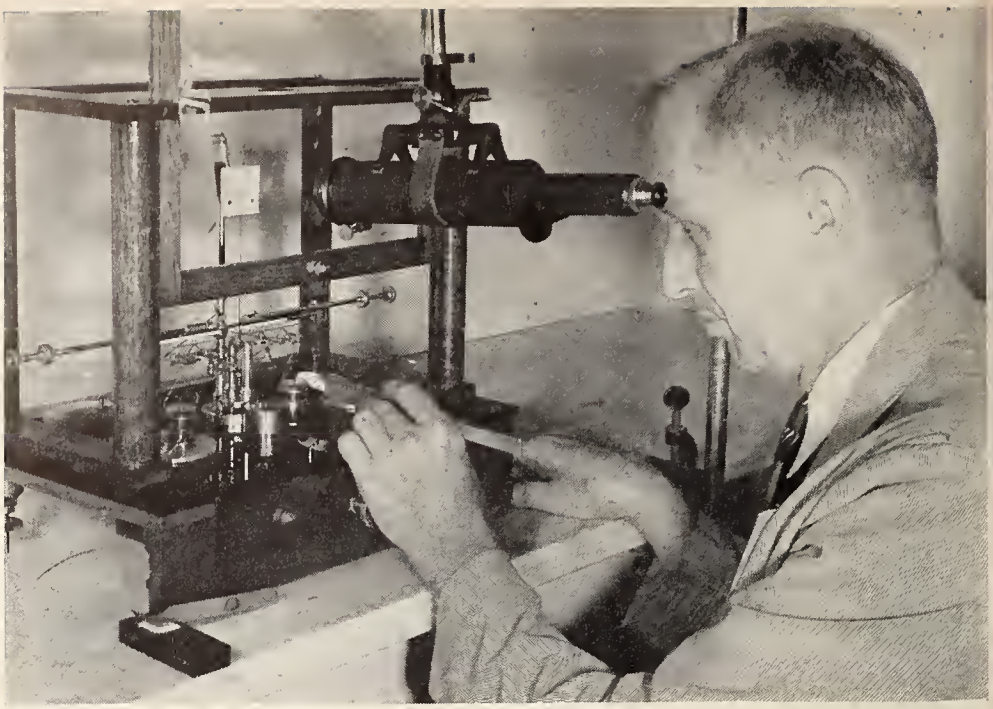
The work on corrosion of aluminum alloys in marine atmosphere, sponsored by the Navy Bureau of Aeronautics, the Air Force, and the National Advisory Committee for Aeronautics, has been instrumental in the development of modern high-strength, corrosion-resistant, lightweight alloys for aircraft use. The knowledge thus gained of corrosion problems of light metals has recently been found of value in housing applications. In this connection, the Bureau was able to establish the suitability of certain alloys for housing and to determine the precautions to be observed in installation.

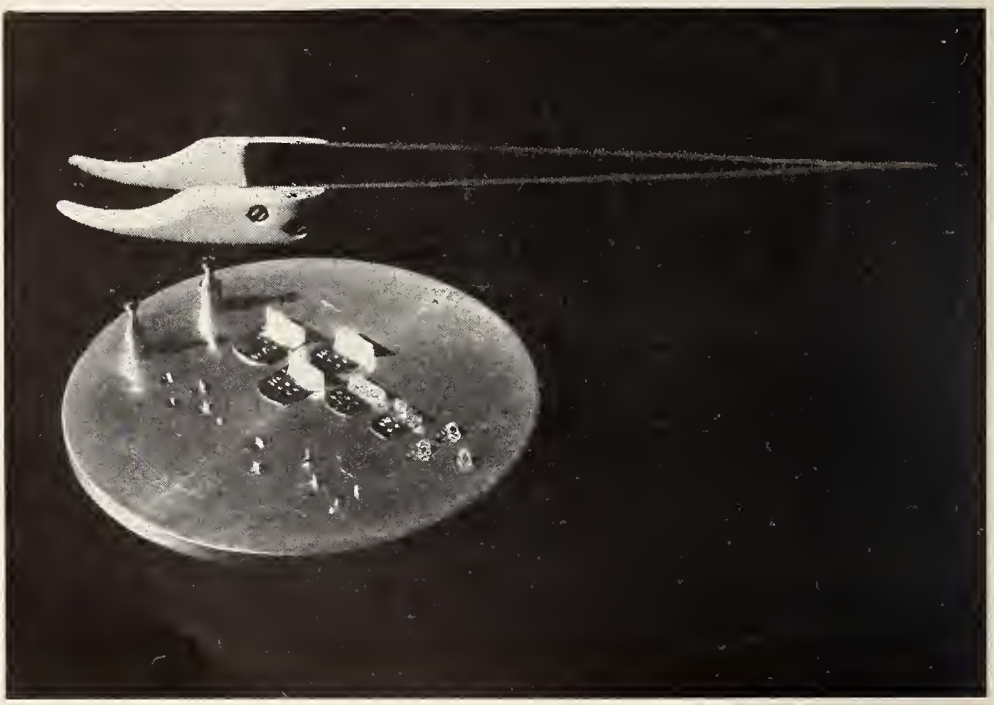
The problem of national research in optical instruments and optical glass is an important one. The peacetime requirements for precision optical instruments are almost negligible in comparison with the need for military optical instruments in wartime. Moreover, the demands made on industry for the production of nonmilitary optical instruments are relatively stable, for the required characteristics of the various instruments do not change greatly within short periods of time. In military optical work the reverse is true, and the necessity for specialized laboratory research is correspondingly increased.

In view of this need for a continuing, integrated program of research and development in optical science, the Bureau, with the cooperation of the Army and Navy, has conducted for many years a coordinated series of projects basic to the production of all types of optical instruments, with special emphasis on military fire-control devices. The Bureau is the only scientific institution in the world which has complete facilities for making an optical instrument beginning with the raw materials and producing, in turn, the glass, the optical design, lenses and prisms, mechanical parts, and finally the finished instrument.

Of the $864,000,000 spent for dentistry by this country in 1948, over $100,000,000 was for dental materials. Yet for many years the only information available to the practicing dentist on the properties of these products came from the limited amount of research, mostly clinical, that was done in a few dental schools and from the research that could be financed by manufacturers of dental products. This information was very often incomplete, conflicting, and in many instances completely erroneous.

To meet the needs of the dental profession, the Bureau therefore established a broad program of research on dental materials, which over the past 30 years has aided in the solution of many of the problems encountered in dentistry. This program—sponsored by the American Dental Association, the Veterans' Administration, and the dental services of the Army, Navy, and Air Force—includes investigations of the fundamental physical, chemical, and engineering properties of dental products, the development of special equipment and methods for evaluating these properties, and the clinical application of the findings. In addition, specifications for dental materials are developed, and dental materials are tested and certified for





High-precision methods were developed for calibrating small weights as standards for modern microbalances (p. 23). Above: standard weights for microbalances are compared with the standards of mass (below) which the Bureau maintains for calibration of these weights. Values of the NBS standards range from 1 gram down to 0.05 milligram.

conformance to specifications. During the past year, for example, an investigation of the causes of the cracking of artificial dentures was extended; progress was made toward a better understanding of the curing mechanism in denture resins; the effect of the use of mechanical condensers on the properties of dental amalgam was investigated; and data were obtained on the instability of dental impression materials, providing an explanation for the difficulty encountered by the armed services in the use of these materials in tropical areas.

In order to develop satisfactory methods for preventing tooth decay, there must be some adequate explanation of the processes which occur in the decalcification of teeth. Great differences exist in the resistance of different teeth to decalcification, and these differences are thought to be associated in some way with the manner in which the hard, calcified tooth structures are deposited. To learn more about the problem, the Bureau, in cooperation with the American Dental Association, has begun an investigation of the structure of teeth. This program has included work on determination of the hardness of enamel and dentin and studies of the abrasion and decalcification of tooth structures due to the chemical and mechanical action of certain toothpaste ingredients. In the course of an investigation of the possibility of remineralization of teeth through the use of fluorides and calcium salts, some of the first electron-microscope studies of the structure of enamel were made. The present program includes an investigation of the chemistry of the basic calcium phosphates, the major inorganic constituents of teeth.

The remainder of this report attempts to suggest the nature and scope of the Bureau's work through examples of typical projects.

2. Electricity and Optics

The work in electricity and optics is for the most part closely connected with problems of measurement in these fields and relates to the establishment of units of measurement, the development of improved or new methods of measurement, the design of improved or new standard apparatus, the development of standards for issuance, and studies of the properties of materials.

The electrical work includes the establishment and maintenance of the units of resistance and voltage; their application in the development of standard apparatus for measuring inductance, capacitance, electric current, power, energy, magnetizing force, and magnetic induction; and the dissemination throughout the Nation of standard values of these quantities. The work in optical standards and measurements includes problems of luminous intensity and flux; spectrophotometry, color, transmittance, reflectance, opacity and gloss; refractive index, focal length and resolution of lenses, cameras, and other optical systems; and sensitivity and contrast of photographic emulsions.

Precise Electrical Measurements

The Bureau's development of standard equipment for testing a-c ammeters and voltmeters at frequencies ranging up to 20,000 cycles per second has been extended to cover currents up to 50 amperes and voltages to 400 volts with an accuracy approaching 0.01 percent. The use of large electrical powers at these frequencies is rapidly increasing in the fields of aeronautics, metallurgy, and woodworking machinery.

Static Electricity Hazards

Static charges are built up in a great variety of industrial operations and often cause sparks which create serious fire or explosion hazards. This is especially true in the operating rooms of hospitals, where explosive mixtures of anesthetic gases and air may be ignited by the static charges that are built up by the movement of personnel or equipment over the floor.

An interdepartmental committee, initiated by the Public Buildings Administration, requested the Bureau's assistance in formulating specifications for a flooring construction which would provide sufficient electrical conduction between persons and objects resting on it to assure the harmless dissipation of electric charges as fast as they tend to develop. It was found that a terrazzo floor with a cement matrix containing a small percentage of acetylene carbon black is satisfactory over a wide range of atmospheric humidities. Such flooring will be specified in the future for Government hospital construction.

Application of High-Speed Computers to Lens Design

Modern photography, microscopy, and astronomy are demanding optical instruments of greater precision than ever before. Progress in optical theory has kept pace with the demand, but the mathematical computations are, in many cases, so involved that ordinary methods employing desk calculators become too lengthy and expensive.

To remove this restriction, a new system of equations for tracing skew rays through an optical system was developed, making possible the application of SEAC (National Bureau of Standards Eastern Automatic Computer) to the problem. An advantage of the new system of equations is that the same formulas can be applied for the different combinations of spherical and plane surfaces; this greatly facilitates the programming of these equations for automatically sequenced electronic computers.

SEAC, in solving a skew-ray problem, traced a total of 32 light rays through 11 optical surfaces. About 10 seconds were required for each ray. In a similar manner, the machine can compute an unlimited number of light-ray paths through as many as 100 or more lens surfaces. This means that for the more complicated systems SEAC can solve as many problems in one hour as an experienced operator can solve in 15 weeks using the best desk calculator, or in about six years without mechanical aids.

Planeness of Optical Surfaces

An extremely sensitive method was developed for testing interferometrically the planeness of optical surfaces up to 10 or 12 inches in diameter. By means of a new photographic technique, a complete contour map of the optical surface is produced having contour intervals from $\frac{1}{30}$ to $\frac{1}{50}$ of a wavelength of light, rather than one-half of a wavelength as in conventional test methods. Because of the close spacing of the contours, local variations in the surface that would escape detection by the usual methods are made clearly visible.

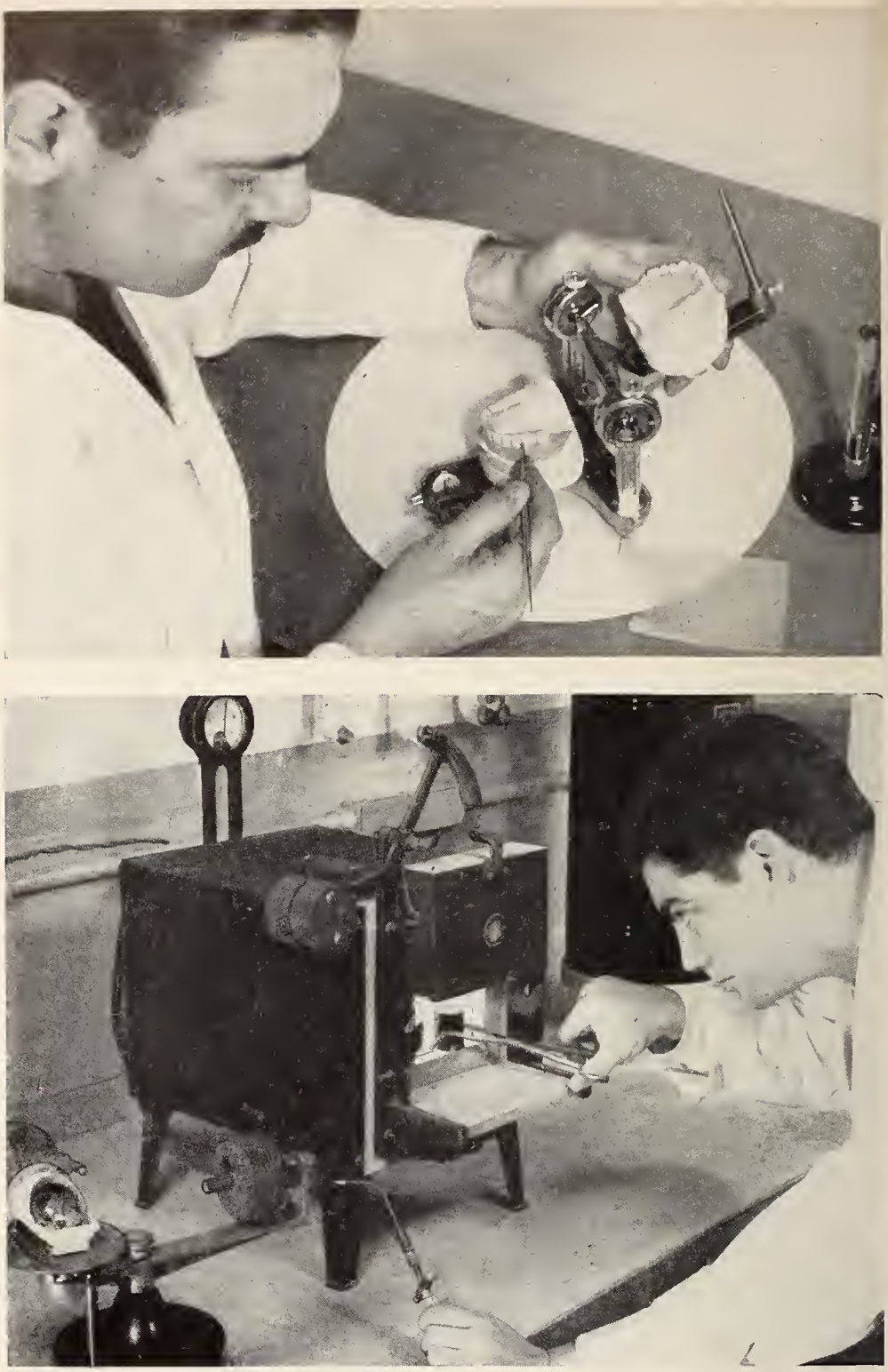
New Type of Interferometer

Preliminary tests of a new type of interferometer recently designed at the Bureau indicate the possibility of making interferometers with apertures as large as those of the largest astronomical telescope. The new instrument also promises to lessen the cost of large interferometer installations by reducing the number of transmitting elements required. The only transmitting component is the beam splitter, which need not exceed 2 inches in diameter and 0.25 inch in thickness. Thus the maximum aperture is determined not by the aperture of a transmitting element, as in the usual interferometer, but by the maximum realizable apertures of reflecting elements.

Permanent Gloss Standards

Measurement of gloss is becoming increasingly important in many industries. For example, high-gloss paper is required for good reproduction of half-tone prints, and low-gloss paper for easy reading of materials in type. Outdoor finishes, such as automotive enamels, have high gloss for permanence while matte finishes are given most war goods for low visibility. Gloss measurements are also important in defining the wear resistance of plastics and ceramics.

Measurement of gloss is essentially very simple. When a specimen is illuminated at some angle from the perpendicular, the proportion of the light reflected at angles near that of mirror reflection is defined as gloss. A critical part of the definition of gloss, however, is the amount by which the reflected beam may depart from the strict direction of mirror reflection and still be counted as contributing to gloss. With glossmeters commercially available at the present time, replacement of the lamp, for example, may introduce instrumental error unless readjustment is made. The Bureau has therefore prepared and made available new permanent gloss standards which permit a rapid check of instrument calibration at any time and give a basis for readjustment of the instrument if required. These standards, which may be used to calibrate any 60-degree specular glossmeter in the range from matte to high gloss, are made of ceramic materials for permanence, and the surfaces have been specially chosen for similarity to commercial materials whose gloss is important.



Investigations of the physical, chemical, and clinical properties of dental materials are conducted at the Bureau (p. 24). Above: experimental dentures are processed under controlled conditions to obtain clinical data on materials and techniques. Below: casting of a dental gold alloy at the Bureau for experimental study.

Revision of the Union Colorimeter Scale

A number of complicated processes are employed in the refining of petroleum to produce gasoline, kerosine, and lubricating oils and greases. Measurements of the color of the product are used to follow the progress of these processes and also as a basis for the purchase and sale of petroleum products in various stages of refinement. For the past 20 years, such measurements have been made by visually comparing the color of the oil with a series of glass color standards making up the scale of the Union colorimeter. At the request of the American Society for Testing Materials, a suggested revision of the Union colorimeter scale has now been developed. This revised scale duplicates the colors of petroleum products more closely than the original scale and has much more uniform color intervals. Glass color standards prepared in accordance with the revised scale are expected to permit more accurate color measurements to be made of petroleum products and thus to facilitate their purchase and sale.

Photometry of Mercury Vapor Lamps

Since 1936 the determination of the light output of mercury-vapor lamps in this country has been based on the values of luminous flux assigned to two groups of mercury-vapor lamp standards: a group of 250-watt lamps and a group of 400-watt lamps. These two sets of standards were originally calibrated at the Bureau by visual comparison with incandescent lamp standards viewed through color-matching filters. In spite of the resulting approximate color match, major differences in spectral energy distribution persisted. Because of these differences, the visual measurements were made only with great difficulty and resulted in considerable doubt as to the reliability of the values thus assigned to the mercury-vapor standards.

Within the past year, the light output of the two groups of mercury-vapor lamp standards has been redetermined by the use of a physical photometer which embodies a thermopile and an accurate luminosity filter. This recalibration was in terms of the new photometric units which became effective on January 1, 1948.

The new values assigned to the 250-watt mercury-vapor lamps are 4.5 percent lower than those originally assigned visually while the new values assigned to the 400-watt mercury-vapor lamps are 9 percent lower than the visually assigned values. Intercomparison of the two groups of standards in a photoelectrically equipped integrating photometer indicates that the uncertainty in the new values assigned to the mercury-vapor lamp standards does not exceed 2 percent. By mutual agreement, effective August 1, 1950, all calibrations of mercury-vapor lamps are to be on the new basis.

Lighting at the Shrine in the Library of Congress

In connection with the Bureau's development of a method for the preservation of the Constitution and the Declaration of Independence, a detailed study of the lighting and viewing conditions at the Shrine in the Library of Congress was made. The new lighting units that were suggested have now been received, and a method of support has been chosen that will add no load to the arched ceiling. Suggestions for redecoration to conceal the ceiling ports have also been worked out.

Lighting of the Senate and House Chambers

During the year the relighting of the Senate and House Chambers was completed. The Bureau cooperated both in a consulting capacity and by making tests of samples of materials intended for use in refinishing the chambers. Measurements of the illumination on the desks and of the luminance of the ceilings and walls were carried out at various stages of the work.

Refractometry

Equipment was developed for extending precise measurements of the index of refraction of glasses and other optical materials into the infrared. Three different types of detectors and two types of sources were studied. With this and other equipment, extensive measurements of index of refraction were made on selected glasses over the entire spectral range transmitted. Refractive-index measurements were also made on silver chloride crystals for wavelengths ranging from 0.578 to 20.6 microns. From the data, constants were evaluated for dispersion formulas from which the indices may be computed for any wavelengths in this range with an accuracy of approximately ± 0.0001.

3. Metrology

Measurement, instrumentation, and standardization problems, involving the basic concepts of length, mass, time, capacity, and density, constituted the greater part of the work in metrology. In addition, a broad program of research on the physical and chemical properties of dental materials was continued. The Bureau extended its mass standardization service to include weights for microbalances, which are becoming increasingly important for research in atomic energy, vitamin therapy, and microchemical techniques. An instrument was developed which provides a convenient graphic record of the drift in rate of a timepiece over an interval of several days. In connection with the work on dental materials, a method was developed for mounting metallurgical samples in acrylic resin for polishing and examination, without the application of heat. A study of the instability of alginate materials for dental impressions under tropical conditions was also completed, and the precautions necessary to prevent deterioration were determined.

Standard Weights for Microbalances

To provide standards for modern microbalances, the Bureau has recently developed methods for calibrating small standard weights below 100 mg with a precision of one or two ten-millionths of a gram. This precision—perhaps the highest ever obtained with the knife-edge type of balance—will permit the weighing of samples about one-tenth as large as formerly. The resultant increase in the field of usefulness of microbalances should mean great savings to workers in such fields as atomic energy, vitamin therapy, and microchemical techniques, where minute samples must be weighed with high accuracy.

Development of methods for calibration of extremely small weights has greatly simplified the problem of calibrating quartz microbalances directly in terms of known standard weights. This, in turn, makes possible the saving of much time, equipment, and labor formerly spent in indirect methods of calibration. The quartz microbalance itself is now being intensively studied as part of a broad program which the Bureau is undertaking for the improvement of precision balances. Efforts are being made to improve the uniformity of its fabrication and to increase its capacity. The construction of the equal-arm knife-edge type of balance is also under study, with the object of attaining greater accuracy through improved design, use of new materials, and avoidance of troublesome temperature effects.

New System for Weight Calibration

In recent years, the increasing interest in scientific research in this country has brought about a corresponding increase in the number of standard weights submitted to the Bureau for calibration. The largest part of this work involves sets of weights in the following combinations of units: 5, 3, 2, 1, 1; 5, 2, 2, 1, 1; and 5, 2, 1, 1, 1. At present all computations involved in the separate calibration schemes used for each of these combinations are performed with a slide rule or a desk calculator and are then checked in detail and reviewed. Plans are under way to do a large part of this work by means of a computing machine designed to give a simultaneous solution for the values of the weights from a series of equilibrium points as observed on a balance. For this purpose, a single series of observations has been devised by means of which weights in all three of the above combinations may be calibrated. Such a scheme makes possible the construction of a machine designed for the simultaneous solution of the one series of observations and its use to compute values for sets of weights in all three combinations of units. This should largely eliminate errors of computation and result in great savings of time and effort in the Bureau's weight calibration program.

Rate Drift of Timepieces

An instrument was developed which provides a convenient graphic record of the drift in rate of a timepiece over an interval of several days.

In this device a simple relay-type servo system keeps the phase of a crystal-controlled standard frequency in step with the frequency of the timepiece. The amount by which the phase of the standard frequency must be shifted to match the unknown, varying frequency is then automatically plotted against time, providing a curve from which both the instantaneous and integrated frequency error are obtained. Although specifically designed to measure the rate drift in watches, clocks, and marine chronometers, the device can be modified to record the frequency drift in oscillators having frequencies of 10 cycles per second or less. Frequencies as low as one cycle in thirty seconds have been monitored using this device.

Dental Materials

The work on crazing of denture resins has been extended to all types of acrylic resin teeth now on the market. This investigation has demonstrated conclusively that water absorbed during the curing cycle is the factor primarily responsible for the introduction and subsequent release of strains in the surface of those artificial teeth that are subject to crazing. In order to understand why certain teeth craze more readily or bond to the denture base more satisfactorily than others, and to explain the mechanism by which crazing is produced in certain teeth, an investigation is being conducted on the fundamental physical properties of plastic teeth, denture base resins, and self-curing resins. Preliminary measurements of flow, stress-strain, relationships in compression, and the bonding of teeth have been made.

In studies of resins which cure at high temperatures, progress was made toward a better understanding of the mechanism of polymerization and the factors which affect the rate and completeness of cure of acrylic resins. Experimental work on samples of monomer containing varying amounts of catalyst, inhibitor, and water definitely established that water is an important factor in the polymerization process, probably associated with the rate of production of peroxides in the monomer. Methods were developed for detecting the presence of and removing impurities from the monomer. Quantitative data obtained on samples of highly purified monomer containing varying amounts of catalyst and water confirm previous qualitative measurements of the accelerating effect of water on the induction period of benzoyl peroxide-catalyzed methyl methacrylate. Further experiments will be made to determine the effect of water in the presence of hydroquinone inhibitor. It is believed that the data obtained from these studies will be of value in explaining some of the difficulties of processing acrylic resin for dental use and in solving some of the problems encountered in the storage of these resins.

The development and widespread use of mechanical condensers for packing amalgam have led to an investigation of the effect of mechanical condensation on the properties of amalgam. Data obtained from comparative tests on hand- and mechanically-condensed amalgam indicate that the

mechanically condensed amalgam has less expansion, less flow, and a higher early crushing strength. Additional experiments using amalgam with a high mercury-to-alloy ratio (20:5 instead of the usual 8:5) have produced an amalgam with an average crushing strength and a microstructure similar to that of amalgam having an 8:5 ratio. The dimensional change (+3 microns) is reported to be approximately that specified as a lower limit by American Dental Association specifications. Further studies concerning the effect of annealing the alloy on the resultant physical properties of amalgam are being conducted.

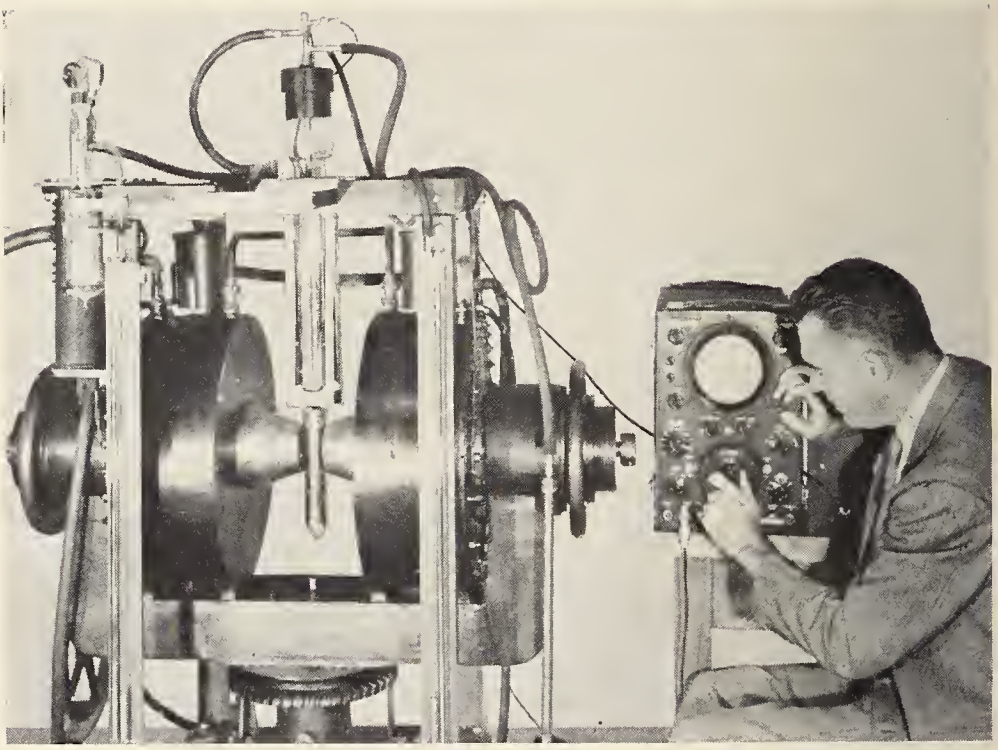
In the course of this investigation a simple, inexpensive method was developed for mounting metallurgical specimens, such as dental amalgams, at temperatures only slightly above room temperature and without the external application of heat. The technique employs a denture material of modified acrylic resin as the mounting. This material consists of a polymer and monomer which, when mixed in the proper proportions, will polymerize or set under pressure at room temperature. As the amount of heat generated by the polymerization reaction can be controlled by varying the amount of resin present, the new procedure makes it possible to mount a wide variety of specimens for polishing and microscopic study without disturbing the crystal structure.

Data were obtained on the instability of the alginates used in the preparation of many impression materials. This information offers an explanation for the difficulty encountered by the Armed Services in the use of these materials in tropical areas. A report summarizing these data and the precautions necessary to prevent deterioration of alginate impression materials under tropical conditions is being prepared.

A project for the study of the structure of tooth enamel and dentin was initiated during the year. Sections of teeth were photographed at high magnification by means of the fluorescence excited by ultraviolet light, and the spectra of the fluorescence were studied. New methods and equipment are now under investigation to overcome difficulties due to the low intensity of the fluorescence.

4. Heat and Power

To provide a fundamental basis for precise measurements of heat and power, the Bureau has established and maintains a scale of temperature from the lowest obtainable to the highest temperatures of incandescent bodies and flames. Instruments are certified for the measurement of temperatures in this range on the International and Kelvin scales. From the measurement of temperature alone, the work broadens to include the determination of quantities of heat by calorimetry in temperature regions extending over a large part of the scale. Coordinate with the calorimetry is a study of the thermodynamic properties of solids, liquids, and gases. From these basic fields of research, the work branches into engineering applications



Above: superconductivity (p. 33) is dramatically demonstrated by the floating magnet experiment. Immersed in liquid helium II, the magnet remains suspended above a superconducting tin plate. The superconducting current induced in the plate by the magnet sets up a magnetic field which repels the magnet. Below: study of the velocity of second sound near absolute zero (p. 33) settled a point of long-standing disagreement regarding the nature of liquid helium II.

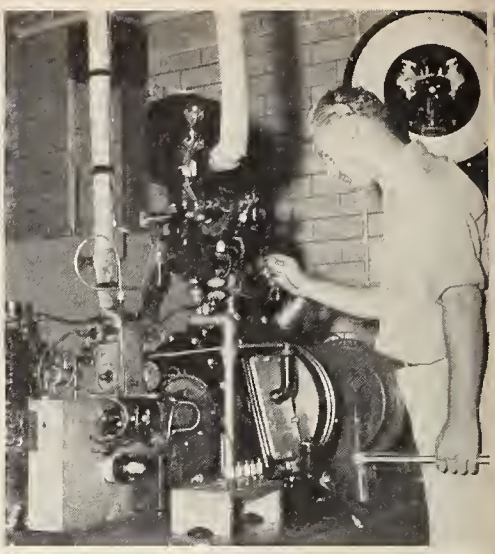
to automotive and aircraft engines. One branch extends into the fundamentals of combustion, with applications to gas turbines, jet engines, and jet propulsion. Another branch covers lubrication problems that arise not only in automotive engines but in all mechanical devices.

The Bureau is also responsible for determining and maintaining standards of viscosity and for certifying the viscosities of fluids used for calibrating viscometers. It maintains standards for the metering and carburetion of liquid fuels in internal combustion engines, and for the determination of the octane and cetane numbers of automotive, aviation, and Diesel engine fuels. Research is conducted to increase the accuracy of these standards and to develop improved measuring instruments and apparatus. Thermal properties of pure substances and commercial materials are determined, upon requests from other Government agencies, either by direct experiment or by calculation from the fundamental atomic and molecular properties of the substances; and published data on thermal properties are critically reviewed and compiled.

Temperature Measurements

As a result of the increasing need for reliable temperature measurements at both very high and very low temperatures, research to develop suitable instruments and methods of calibration has been in progress during the past year. Two sensing elements, an iridium—iridium-rhodium thermocouple probe for use at extremely high temperatures and a germanium resistance thermometer for use near absolute zero, were developed. Both of these instruments represent marked advances in the measurement of extreme temperatures.

Because of the high temperatures (up to about 3,800° F) prevailing in the primary burning zone of turbojet and ramjet combustion chambers, conventional immersion-type temperature-sensing instruments are unsuitable for use in these applications. A water-cooled thermocouple probe was therefore developed which is capable of withstanding the thermal and mechanical stresses present in combustion chamber operation. One element of this thermocouple is iridium, which has a melting point of about 4,400° F, and the other is an alloy of iridium and rhodium, which melts in the neighborhood of 3,800° F. The thermocouple is supported directly in the combustion zone by means of a water-cooled mounting. Satisfactory results have been obtained in service tests in the ram-jet installation at the Bureau and also at a number of other laboratories. In one installation the instrument was used for a total of about 15 hours at temperatures ranging from 3,000° to 3,750° F. In another, the unit was successfully subjected to a gas stream at 3,200° F flowing at sonic velocity. The instrument is relatively simple in design and is readily adaptable to both laboratory and test-stand installations. The emf-temperature calibration of the iridium—iridium-rhodium thermocouple has been carried out to a temperature of



Left: an optical pyrometer is used in the calibration of a high-temperature thermocouple. Right: a single-cylinder supercharged test engine at the Bureau determines the preignition rating of aircraft and automotive sparkplugs.

2,800° F. Work is at present under way to extend the calibration up to the temperature limit of the thermoelements.

At very low temperatures (below 50° K) the research on thermometry has two major objectives: First, the absolute determination of temperatures by means of a gas thermometer and second, the development of convenient, sensitive, and reproducible secondary thermometers which can be calibrated by means of the gas thermometer. Since the development of a highly accurate gas thermometer for this purpose requires painstaking and time-consuming precision, the work on the secondary thermometer is being pursued concurrently. Resistance thermometers have been constructed of the semiconducting elements, silicon and germanium, and have proved to be extremely sensitive; in some cases the resistance changes more than 50 percent per degree. While satisfactory reproducibility still remains a problem, some of the thermometers already tested are quite acceptable in this respect, being reproducible within the present precision of calibration.

Rheological Physics

Two important investigations were completed in the field of rheological physics, which deals with the flow and deformation of matter. These were (1) an accurate determination of the absolute viscosity of water and (2) measurement of the absolute viscosity of bulk rubber (synthetic and natural) and of high-concentration synthetic rubber solutions.

Measurement of the absolute viscosity of liquids—of fundamental importance in many scientific fields—is almost universally based upon the absolute viscosity of water at 20° C as a primary reference standard. In view of the increasing need for a more accurate determination of this standard, the Bureau undertook to redetermine its value with the cooperation of the Society of Rheology and the Chemical Foundation. The

viscosity of water was found to be 0.010019 poise, as compared with the value of 0.01005 poise in use at the present time. The accuracy of the new determination is 0.000003 poise, which far exceeds that of any previous measurement of this constant. Adoption of the new value as an international standard is anticipated. Its use at the National Bureau of Standards for the calibration of viscometers and standard sample oils will make possible the evaluation of the viscosities of other liquids with an accuracy of 0.1 percent or better.

The development and extensive commercial use of the various types of synthetic rubber have made it necessary to learn more about their flow properties both from the standpoint of industrial processing of the raw rubber and of over-all quality in the finished products. In the past, chiefly because of the lack of suitable instruments, it has been possible to measure the flow properties of bulk rubber only to a very limited extent. Higher rates of flow could only be measured on relatively dilute solutions; otherwise the material had to be subjected to low stress. Through the use of the McKee Worker-Consistometer, recently developed at the Bureau, measurements have now been made for the first time of the viscosities of solutions containing 5 to 100 percent of rubber at widely different rates of flow. The data on 100-percent rubber serve as the first absolute calibration of the industrial laboratory instrument (Mooney Viscometer) which tests synthetic rubber for processing into manufactured articles. Data have been obtained showing the effects on viscosity of such variables as temperature, rate of flow, kind of rubber, sample preparation, aging, and concentration and nature of solvent. Further work is in progress, primarily on bulk rubbers and high-concentration solutions.

Automotive Research

Automotive research at the Bureau embraces fundamental studies directed toward the improvement of engines, fuels, tires, and accessories and the development of better methods for their evaluation. In addition, the Bureau maintains the national standard for knock-testing of gasolines.

To learn more about the knocking characteristics of the individual hydrocarbons of gasoline, an apparatus for investigating the burning mechanism of fuels was constructed in which measurements of pressure and volume are automatically made as a function of time. This equipment is capable of giving more detailed information concerning the entire combustion process, including the pre-flame reaction of the gaseous mixture, which is, in some manner, associated with knocking combustion. Future results from this study should lead to a better understanding of engine knock and point the way to engine or fuel improvement.

It is extremely important to the oil industry that errors made in measuring octane number of gasolines be kept at a minimum. The Bureau maintains national standard reference fuels, on which all octane number measurements throughout the country are based. These reference fuels,

"isooctane" and *n*-heptane, are now available at a purity of 99.99 percent as a result of improvements in the Bureau's purification process. A new technique for evaluating commercial reference fuels involving a precise measurement of the difference between the refractive indices of the national standard and commercial reference fuels, is now being used. This procedure is carried out in a Rayleigh interferometer in which the precision is about 0.000003 unit of refractive index.

Another way in which the Bureau aids in maintaining uniform gasoline quality is through its analysis of knock rating data obtained by several laboratories on exchange fuels. These exchange fuels are circulated each month by a member of the group and include motor, aviation, and Diesel fuels. In this way each laboratory is provided with a monthly check on the precision of its measurement. This program is a joint endeavor between the Federal Government, petroleum refiners, and the American Society for Testing Materials.

The use of resistances in series with automotive spark plugs considerably reduces interference to radio reception. The Ordnance Department of the U. S. Army requested the Bureau to determine whether resistor spark plugs would operate effectively in military vehicles at low temperature. A series of tests at temperatures down to $-40°$ F disclosed that there was no essential difference between resistor plugs and conventional types in their ability to start the engine.

The Bureau cooperates with the Federal Trade Commission and the Post Office Department by providing technical information and data on fraudulently advertised materials, including gasoline "dopes", oil additives, and antifreezes. Because of the numerous engine and operating variables, it is difficult to evaluate the effect of gasoline or oil additives on engine deposits. However, in investigating the effect of gasoline additives on valve deposits, it was found possible to eliminate these variables by comparing the average deposit per valve for a group of 20 single-cylinder engines run on a gasoline of high gum content with that for a similar group of engines run on the same fuel plus the additive. Work is in progress to develop a similar procedure for evaluating the effect of oil additives on piston and piston ring deposits. None of the gasoline dopes aided in removal of engine deposits.

The Federal Government spends about $12,500,000 each year for automobile tires. Since the service life of tires of the same make may range from 5,000 to 55,000 miles, the Bureau has undertaken an extensive program to study the behavior of tires under many different conditions. A machine of unique design has been built which will give the amount of power lost in a tire under variations of load, tire pressure, speed, tractive effort, and cornering. Most of the power loss is manifested as heat generated in the tire and contributes to tire breakdown by subjecting the rubber and fabric to excessive temperatures. Thus a measure of the power loss should provide a basis for predicting the expected normal life of a tire.

Aircraft Accessories

During the past year, the National Bureau of Standards, under the sponsorship of the Bureau of Aeronautics, Department of the Navy, continued to work toward the development of improved equipment and methods for testing aircraft accessories, particularly those which are components of the fuel and electrical systems.

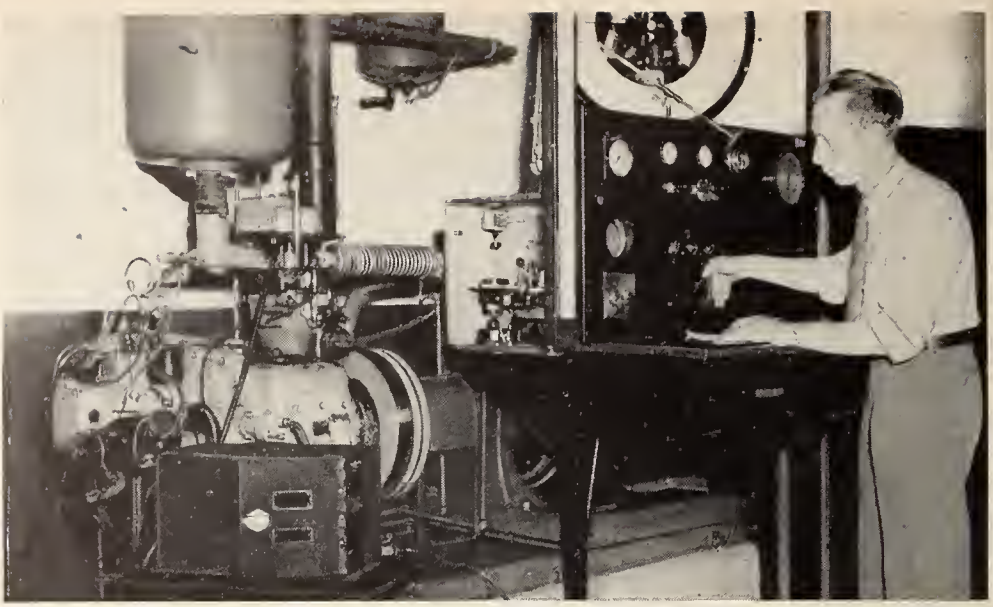
The performance of carburetors, fuel nozzles, and the float-type flowmeters used for carburetor testing has been found to depend upon the density and viscosity of the test fluid. Since liquids of widely differing properties are currently used for this purpose in various laboratories, an effort is being made to promote agreement on a single pure, or nearly pure, hydrocarbon compound which will be generally acceptable as a universal calibrating fluid for all fuel accessories. The problem has become more urgent and more complex with the advent of jet engines, which must operate on fuels varying from light gasoline to heavy kerosine. Meanwhile, a calibration procedure has been developed for the flowmeters which makes possible accurate corrections for the density and viscosity of the fluid, and modifications to the floats have been made which reduce the sensitivity of existing flowmeters to viscosity. A prototype instrument, designed for continuous indication of viscosity, shows considerable promise. Other work in this field included studies of the effects of carburetor-jet configuration upon metering characteristics, of test methods applicable to regulators for the injection of water, and of methods for reconditioning fixed spray nozzles.

Work on aircraft electrical network equipment consisted mainly of evaluations of various experimental devices produced under development contracts. These included such 400-cycle a-c devices as trip-free circuit breakers and frequency relays, and such d-c equipment as magnetic-type circuit breakers, a latching relay, special-purpose switches, and hermetically sealed toggle switches. Studies were made to determine the cause of failure in service. Qualification tests were also conducted on circuit breakers and electrical connectors for rockets in accordance with military specifications.

Gas Turbines and Jet Engines

Although gas turbines and jet engines are becoming increasingly important, particularly to the military services, much research and development remains to be done on components in order to attain the desired reliability, economy, performance, and safety. Thus, operation of the combustion chamber at high altitudes has been the subject of much investigation. Further development of temperature-sensitive devices for indicating performance and controlling operation is also needed urgently. Through continuing projects sponsored by the military services, the Bureau is contributing to the solution of these problems.

To permit studies of combustion in streams of moving air at pressures below one atmosphere, large vacuum pumps have been procured, and addi-



Reference fuels for the knock rating of gasolines are calibrated by the Bureau (p. 29).

tional facilities are being designed in which burners for ramjet and turbo-jet engines can be operated at the pressures prevailing at high altitudes.

In the field of basic combustion studies, an extensive program has been undertaken which seeks to measure true burning velocities and flame temperatures by the spectral line-reversal method.

In the field of gas-temperature measurement, shielded tragets for optical and radiation pyrometers were investigated and found to have small promise for such an application. On the other hand, reliable pneumatic temperature-sensing devices were developed and evaluated. These employ two small orifices or nozzles in series, and permit calculation of gas temperature from an observed drop in pressure across the hot orifice. It has been demonstrated that the hot orifice may be cooled, to a limited degree, without decreasing the accuracy of the caluculated temperature. Thus instruments of this type may be used in gases which are above the melting point of the orifice.

The mechanical stresses to which thermocouples installed in turbo-jet engines are subjected have proved to be unexpectedly high, so that conventional units have very short service lives. Metallurgical studies of units that have failed in service show that alumel thermoelements are subject to changes in crystal structure which greatly reduce their ability to withstand vibrations induced by the gas streams. To overcome this difficulty, a promising prototype instrument has been developed with complete and effective support of the thermocouple wires from the measuring junction to the terminal head.

Low-Temperature Physics

Significant discoveries were made in those areas of low-temperature physics which deal with superconductivity—the loss of electrical resistance

at very low temperatures—and the properties of liquid helium II, a form of helium existing at temperatures near absolute zero. Both these subjects are now of active interest in low-temperature laboratories because of the unusual effects involved and the lack of completely satisfactory fundamental theories for their explanation.

A new and wholly unexpected relationship was discovered between superconductivity and the constitution of the atomic nucleus. It was found that the pure mercury isotope of atomic weight 198 becomes superconducting at a temperature about 0.02 Kelvin degree higher than does natural mercury, a mixture of five different isotopes having an average atomic weight of 200.6. As the difference between the isotopes depends entirely on their nuclear masses, this shift, which is proportionately quite large for a temperature so near absolute zero, indicates that the nucleus must exert an important effect on the superconducting properties of the metal.

Until now it has been generally supposed that superconductivity is concerned exclusively with the properties of the electronic configuration outside the nucleus. However, the results obtained at the Bureau, in combination with an independent and almost simultaneous discovery of the same phenomenon in other mercury isotopes at Rutgers University, establish the validity of the nuclear effect beyond question. The two researches are complementary and when taken together provide a conclusive demonstration of the effect.

Since the initial discovery of the isotope effect in the superconductivity of mercury, a sample of tin consisting mainly of Sn^{124} has been investigated at the Bureau and found to exhibit a similar shift in transition temperature. In both cases the effect is very small, 0.007° K per mass unit for mercury and 0.012° K per mass unit for tin. However, it has been observed that these shifts are such that the thermal energy of the lattice is the same for each isotope at the transition temperature. The work is being carried forward, and other isotopically enriched elements are under investigation.

The theoretical understanding of liquid helium II, often referred to as the fourth state of matter because of its unique properties, is sufficiently well advanced that crucial experiments may be performed for testing specific postulates. During the last year the Bureau discovered that there is a considerable increase in the velocity of *second sound,* a unique wavelike process of heat transfer occurring only in helium II, as temperature is lowered below 1° K. This result, which had been sought by a number of low-temperature laboratories in several countries, enabled a definite decision to be made between two fundamentally different postulates that had been advanced concerning the nature of liquid helium II. Certain consequences of the apparently correct postulate are very interesting: for example, it appears that one component of liquid helium II, the so-called superfluid, may be completely lacking in thermal energy. If so, there is a possibility that extremely low temperatures may be reached by forcing liquid helium II

through narrow orifices. This possibility is now under investigation in several other laboratories.

A striking demonstration of the validity of the two-fluid theory of liquid helium II was provided by the development of a very simple yet highly accurate mechanical technique for investigating second sound. The two-fluid theory states that in the presence of a heat current two kinds of atoms which make up helium II flow in opposite directions to produce second sound. The new technique, known as the Thermal Rayleigh Disk Method, makes use of the torque exerted on a light disk suspended in the path of standing waves of second sound. It thus constitutes the first mechanical means for detection of this phenomenon. By quantitative evaluation of the torque on the disk at various temperatures, the relative amounts and properties of the two fluid components have been studied, and the results fully confirm theoretical expectations. An associated effect that has also been predicted and observed is a hydrostatic pressure difference between regions of different heat-flow density, which is the thermal analogue of the Pitot tube. It has been found possible to include both effects as consequences of a generalized theory of the hydrodynamics of liquid helium II, similar to the Bernoulli expression of ordinary hydrodynamics but with an additional term relating heat current and hydrostatic pressure. These studies are also being actively pursued and extended.

5. Atomic and Radiation Physics

The results of basic research in atomic and nuclear physics are now being applied to an increasing extent in medicine, industry, and national defense. This has made necessary new techniques, instruments, standards of measurement, safety provisions for workers and consumers, standard samples for calibration purposes, and methods of testing and evaluation in this rapidly expanding field. The Bureau is now engaged in a broad program of fundamental research and standardization dealing with atomic and molecular spectra, radiometry, physical electronics, electron optics, mass spectrometry, X-rays, radioactivity, and atomic and nuclear constants. A portion of the work specifically directed toward the atomic energy program is supported by the Atomic Energy Commission. Much of the remainder is in closely related lines of research and is carefully coordinated to avoid duplication of effort.

Omegatron

A new instrument was developed which makes use of the cyclotron resonance frequency of ions to discriminate between particles of different masses. This device, known as the *omegatron,* is basically a miniature cyclotron. Its successful development for the first time permits the use of the simple cyclotron resonance condition for the determination of the values of several important atomic constants. For example, the faraday—a constant of basic interest to both physicists and chemists—can now be evaluated directly by physical methods in addition to the usual electrochemical procedure.

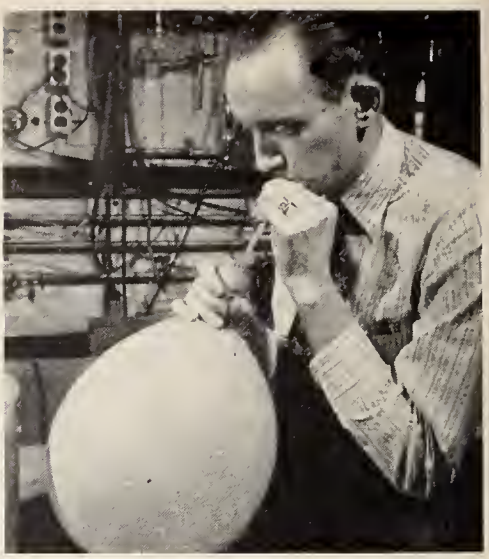
This work provides an independent check on the electrochemical method, and preliminary results indicate that use of the omegatron will provide increased accuracy. In addition, development of the omegatron has made possible the very precise determination of the magnetic moment of the proton in nuclear magnetons, so that the ratio of the mass of the proton to that of the electron can now be known with greater precision than ever before.

The resolution attained with the omegatron for light masses is already comparable with the best that has ever been reached with precision mass spectrographs that have been built in the past. This makes it ideal for analysis of gases and vapors and immediately suggests its use in measuring atomic masses, which are so closely related to atomic energy. In the past year the instrument was used to measure the mass difference between the hydrogen molecule and an atom of heavy hydrogen.

Electric and Magnetic Field Mapping

An accurate, sensitive technique was developed for experimentally determining the electric-field distribution and space-charge density within a magnetron. The new method, which is also well suited to investigations of electron-optical lenses, gas discharge, and other space-charge problems, is a modification of the electron optical shadow technique developed last year at the Bureau for the quantitative study of minute electric and magnetic fields. A magnetic lens is used to produce shadow images of two fine wire screens placed at either end of the magnetron in the path of an electron beam. Then, from the distortion in the shadow network caused by deflection of the electron rays as they pass through the magnetron field, the radial electric field is computed. These results are used to obtain the space-charge distribution.

The magnetron is a vacuum tube widely used for generating power at microwave frequencies. The high space-charge density within the tube is known to have an important bearing on performance. However, very little is actually known concerning the electric-field distribution and space-charge configuration within the tube. Although the problem has been investigated theoretically by many workers, the formidable mathematics involved have not permitted an exact solution, and the various simplifications of the theory that have been suggested have led to widely divergent results. Attempts at direct measurement have also proved unsuccessful because the very critical symmetry of the field under study was disturbed. A promising approach to the problem has now been provided by the method developed at the Bureau. This technique has been used to map the charge distribution within a cut-off or steady-state magnetron. Further application to oscillating magnetrons should lead to a much better understanding of their operation and should yield information of considerable value to the engineer who is interested in designing improved types of magnetrons or in predicting the performance of existing types.



To protect the health of persons engaged in the handling and processing of radium, the Bureau maintains careful check over the quantity of radium ingested by these workers (p. 93). Left: a sample of a worker's breath, obtained by inflation of a balloon (right), is drawn from a sampling flask submitted by a manufacturer of radium-painted dials.

Another problem still under investigation is the application of the electron-optical shadow method to the measurement of the domain structure of ferroelectric and ferromagnetic materials. This subject has assumed considerable technical importance in recent years because of its bearing on the usefulness of commercial magnetic materials. Until the shadow method was introduced, only indirect or qualitative methods existed for the study of domain structure.

Electron Optics

Many of the devices that make use of the focusing and dispersive properties of magnetic fields must undergo considerable improvement before they can be considered ideal. Examples are the beta-ray spectograph, which is used to identify radio isotopes, and the mass spectograph, which has become the chief analytical instrument of the petroleum industry. Until now much of the design of these instruments has been on a trial-and-error basis since the theory of the magnetic fields used is incomplete and the mathematics are formidable. During the past year these difficulties have been attacked, and progress has been made in developing better design methods. A start has also been made on a systematic study of electron lenses, which it is hoped will fill important gaps in present knowledge and allow improvement of the performance of the electron microscope and other instruments.

Semiconductors

At present, one of the most active fields of physics is the study of the semiconductors. The Bureau is conducting a program of research in this

field to investigate promising semiconductor materials and to evaluate their utility as rectifiers, transistors, and eventually as photocells.

The first material to be studied was titanium dioxide in the form of rutile. This material, while normally an excellent insulator becomes a semiconductor with controllable properties when it has been treated to cause a loss of oxygen. A study was made of the Hall effect and conductivity in both single crystals of titanium dioxide and ceramic rutile for various conditions of preparation, and a reasonably clear picture of their properties was obtained. A parallel development was carried out on rectifiers using titanium dioxide, and a very promising technique, which uses a film of oxide produced directly on titanium metal, was evolved.

As the exploratory work on rutile is nearing completion, another material, "grey" tin, has been chosen for a similar study. This interesting substance, which is a low-temperature form of ordinary "white" or metallic tin, has the same crystal structure as silicon or germanium, the elements that are used in most of the present-day high-frequency rectifiers and transistors. Grey tin has recently been shown to be a semiconductor but has not yet been obtained in a useful crystal form, only powder samples being available. Some evidence has been obtained for a successful electrolytic codeposition of grey tin with germanium. Since this material should have very desirable electrical properties, it is planned to carry the work forward on a larger scale. At present, a complete understanding of conduction in semiconductors is prevented by the absence of information about the number of lattice defects in the crystals. New apparatus for studying these defects has now been developed and applied to alkali halide crystals, where the data can be compared with those obtained with other techniques. A considerably revised and improved version of the apparatus has recently been placed in operation; and when further precise information has been obtained on insulating crystals, the instrument will be applied to available semiconductors.

Negative Ions

Studies have been initiated to determine the processes by which negative ions are formed at the surface of oxide-coated cathodes. Results to date show that some kinds of ions are formed which have not been previously accounted for, but their identities have not yet been established. Since these ions occur at comparatively high yields and may be presumed to occur in any vacuum tube in which an oxide-coated cathode is used, the successful completion of this phase of the study will be of considerable importance to the electron tube industry in addition to solving a long-standing problem in basic physical phenomena.

In connection with this work, a nonmagnetic radio-frequency mass spectrometer was developed in which a radio-frequency field replaces the usual magnetic field. The new mass spectrometer has been found ideally suited for use in rockets to determine the composition of the upper atmosphere. It also appears that a modification of the device should be well

suited for the direct observation and identification of ions in the upper atmosphere; development projects for this application have been undertaken jointly by the Bureau and other Government-supported laboratories.

The uniquely high sensitivity of the spectrometer makes possible its use for the rapid scanning of an entire mass spectrum and the presentation of the spectrum on an oscilloscope screen. The instrument provides a new experimental method of value in a wide variety of investigations—for example, biological studies employing stable isotopes and the control of industrial processes such as helium mining and oil refining.

Radioactivity

The Bureau's program for the calibration and distribution of standard samples of artificially produced isotopes has continued to grow with the increase in the demand for such standards in medicine, science, and industry. Effort has been continuously directed toward more precise calibration and toward the development of uniform standards for measurement of radioactive isotopes. For example, a system of calibration was devised for users of radioactive phosphorus and radioactive iodine receiving these substances from Oak Ridge, in order to reconcile a divergence in calibrations amounting in some cases to as much as 200 percent. As a result, participating laboratories are now consistent to ± 10 percent. In addition to their value to hospitals and laboratories, these measurements will also help to establish the true value of the absolute millicurie of radioactive iodine and radioactive phosphorus. Work is being done to establish similar standards for other radioactive isotopes. Thus a 4π absolute beta counting chamber is now being prepared to further refine the calibrations of iodine 131 and phosphorus 32, and a new statistical procedure has been devised for the calibration of radium D+E standards.

A table of Fermi functions was completed and is now being printed. The Fermi function is widely used in determining the maximum energy of a beta spectrum and in comparing such a spectrum with that predicted by the Fermi theory of beta emission. However, the accurate computation of this function is so difficult and tedious that it has been necessary to make use of various rather inadequate approximations. The table will provide a convenient and accurate tabulation of the Fermi function applicable throughout the useful range of atomic number and energy; it should prove extremely useful to all workers in the field of beta-ray spectroscopy.

Protection Against Radiation

The recent availability of large amounts of radioactive materials and the diversity of machines for generating radiation have caused problems of radiation measurement and protection to grow steadily more complex. Investigation of two general problems in this field was initiated during the year: (1) the development of instruments for measuring electrons and (2) the development of instruments for measuring high-intensity X-ray dosages. These investigations will be of particular value in new methods of therapy

now being utilized by the medical profession, for various kinds of research being performed by the Atomic Energy Commission, and to answer the demands of Government agencies, research workers, and industry, where use of such radiations is increasing.

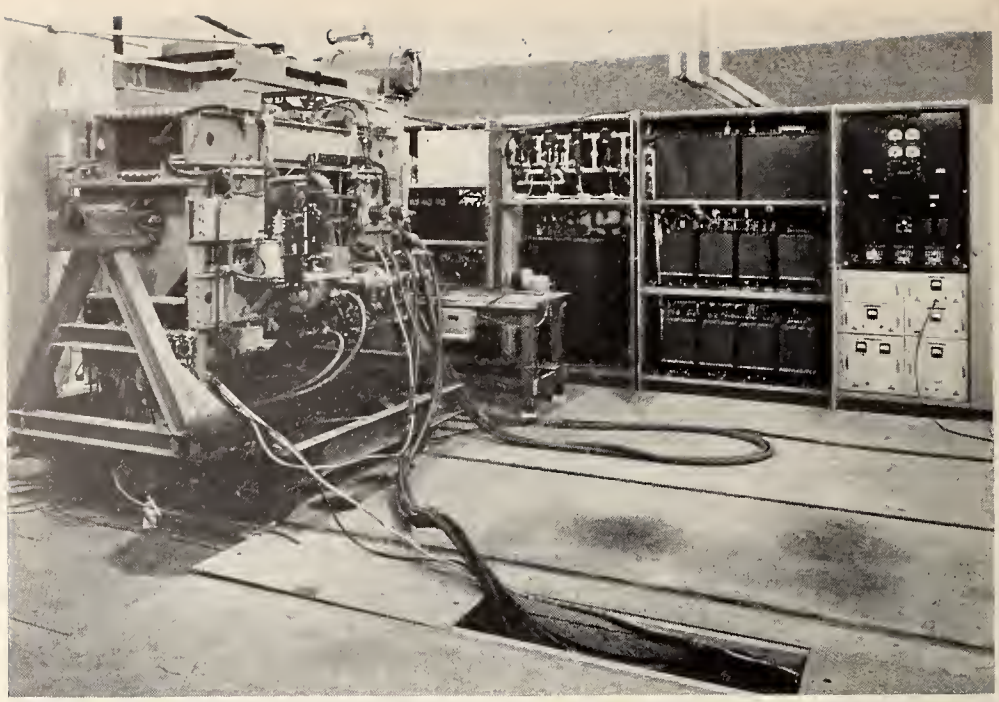
With the large-quantity availability of radioactive materials emitting beta-rays (streams of electrons) and their use for experimental animal therapy, a serious protection problem has arisen. However, ionization chambers now used for measurement of X-rays and gamma radiation are not readily adaptable for electron measurement. Photographic film is therefore being calibrated for this use in terms of the equivalent dose for gamma rays.

Low-voltage, high-intensity X-ray units are now available commercially. Here again, radiation-measuring instruments made for use with ordinary X-rays do not give the proper reading, largely because of absorption of the radiation and loss of ionization due to recombination. The Bureau has therefore undertaken the development of an instrument without these disadvantages.

At the request of several military agencies, the sensitivities of various photographic emulsions are being investigated for a wide range of energies of penetrating radiations. The ultimate goal of the work is the design and construction of film badges for monitoring exposure of personnel to various quantities and qualities of radiation. The emulsions studied cover, within their useful density ranges, exposures from about 0.1 to 10^5 roentgens. The effect of secondary electrons from objects in the path of the primary radiations and the influence of spectral distribution on emulsion response at various exciting potentials have been studied. The results of these studies have led to the employment of sheets of bakelite in the film badge in front and back of the film packet to effect electronic equilibrium and have suggested the use of a metal filter over the packet to compensate partially for the increased sensitivity of the emulsion for radiations excited at potentials between 30 and 100 kv.

A study of the quality dependence of survey-type Geiger counters and ionization chambers, as well as pocket chambers and dosimeters of the health physics type, was carried out in connection with a project supported by the Atomic Energy Commission for the X-ray calibration of these instruments. The results of this study have permitted the manufacturers to effect improvements in their instruments.

With the support of the Office of Naval Research and the Atomic Energy Commission, the problem of protection against radiation has also been attacked theoretically. The study has involved a theoretical approach to the penetration and diffusion of X-rays through thick barriers—a complex problem which has never yet been satisfactorily solved. At the close of the year the principal elements of the problem appeared to be well under control. Attractive possibilities have opened up for applying the same methods and techniques to a study of the penetration and diffusion of electrons



The NBS 50-million-volt betatron with its associated control cubicle for research in high-energy X-rays.

and to the major problem of the development of electromagnetic cascade showers.

With the installation of a new 50-million volt betatron, NBS research in radiation physics has now been extended into the realm of extremely high energies. The Bureau's program in this field involves the investigation of means for measuring high-energy radiations, the setting up of standards for the calibration of medical instruments and other radiation-measuring devices, and the determination of dosage and shielding requirements. This program is basic to the continued use of high-energy accelerators by industry, Government, and the medical profession. The essential measuring equipment for this work has now been installed; it is so designed that it can be remotely controlled and moved in three directions in the path of the X-ray beam. By interposing shielding materials, such as lead, concrete, or steel, the attenuation of X-rays of different energies can be determined and suitable shielding requirements established.

Considerable progress has been made toward removing the electron beam from the betatron. The "peeler" or removal unit has now been constructed and tested. In this way, radiation can be delivered at controlled depths for the treatment of deep cancer. However, before hospitals can use the treatment, adequate instructions for measurement of the radiation and for the protection of personnel must be provided by the Bureau. Progress has also been made in the measurement of betatron radiations by means of nuclear emulsions. This information is important to medicine in determining the distribution of energy within the X-ray beam for medical and industrial purposes.

Field X-ray Equipment

Ordinary civilian hospital X-ray apparatus is not suitable for field service in wartime: it is too heavy and bulky; at the same time it is not rugged enough to withstand the rough handling of military use. Field equipment should combine ruggedness with light weight, using standardized components and as few separate parts as possible. These features must be embodied in apparatus which is easily assembled, simple to operate, and flexible enough to be used for diagnostic work under a wide variety of conditions.

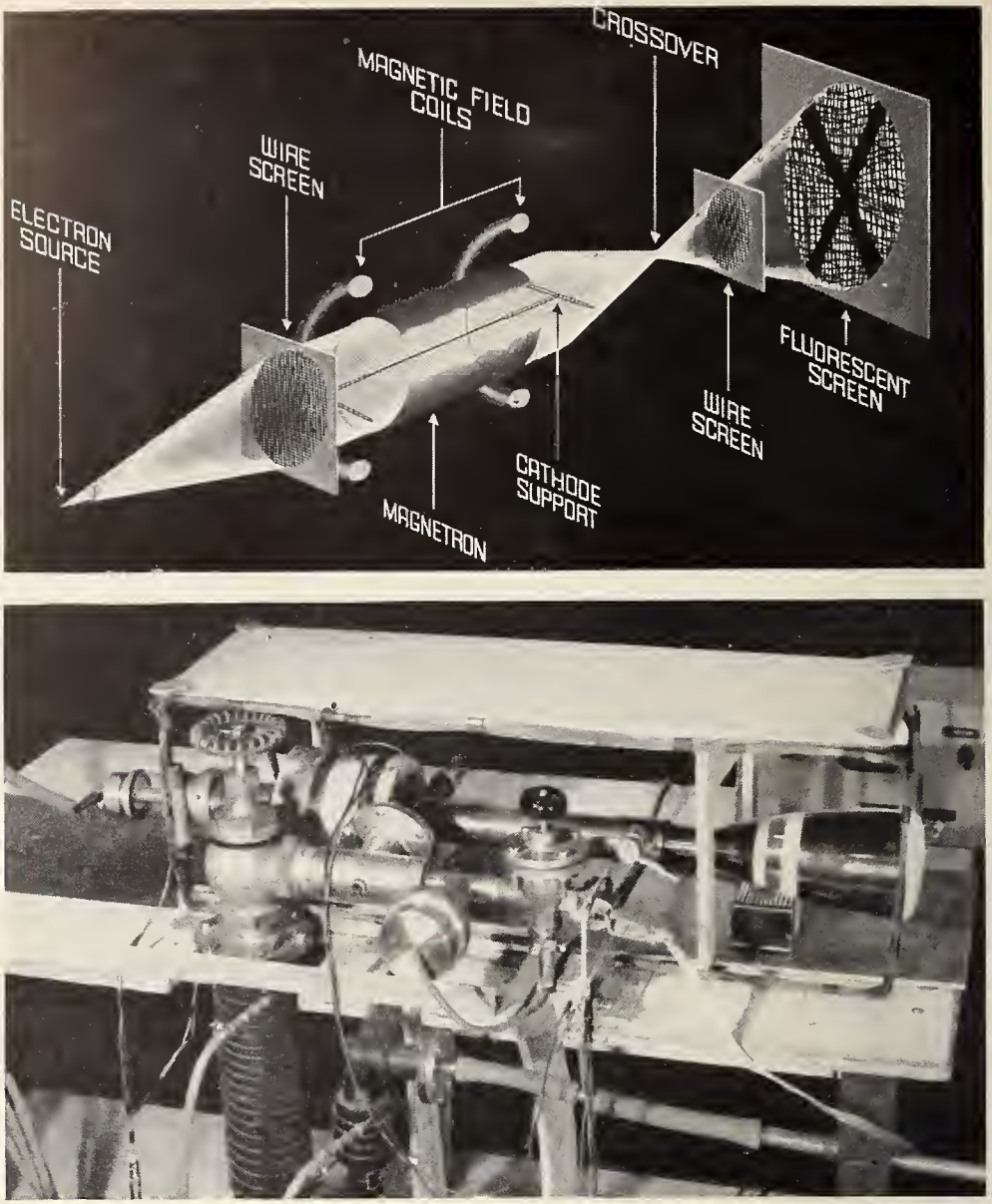
Experience in World War II revealed the need for good field X-ray equipment and led to a program at the National Bureau of Standards to coordinate the development of field X-ray components for the Research and Development Branch of the Surgeon General's Office. At the request of the Army, the Bureau began work on the initial phases of the program, in which research consultants, X-ray manufactures, and Army roentgenologists, as well as the Bureau, combined their efforts. The intial phase of the development work has been completed with the production of prototype models for laboratory studies and field tests. These studies and tests are now under way, and it appears probable that a large part of the equipment will soon be ready for standardization as items of supply for the Armed Forces. The advances in design resulting from this program promise also to be significance in the improvement of civilian X-ray apparatus. For example, a civilian version of the military tilting X-ray table designed for field use has already appeared on the market in a form that results in significant saving in weight and cost.

Analysis of Solids by Mass Spectrometry

A method for analysis of solids by mass spectrometry was developed and applied to samples of stainless steel. The simplicity of interpretation of the new method and the linearity of the reponse as a function of concentration make it apparent that this technique will be a powerful addition to present analytical methods.

Although mass spectroscopy has been applied with outstanding success to the analysis of gas mixtures during the past 10 years, until now none of these techniques has been found applicable to solids. Ordinarily the vacuum spark is the best source of ions, but it is too erratic for use with conventional instruments except with photographic detection, which has a number of limitations. In addition, the absence of the rich spectrum of lines which are available in optical spectroscopy presents further difficulties in mass analysis.

The method developed at the Bureau combines electrical recording with the use of the spark source. To demonstrate its effectiveness, the percentage of nickel and chromium in six standard samples of stainless steel was determined. In the least accurate case the maximum range for



A new electron-optical technique was developed (p. 35) for experimentally mapping the electric-field distribution within a magnetron. Electron rays are deflected as they pass through the magnetron's field, causing distortion of the shadow network on the fluorescent screen. From this distortion, the electric field distribution is obtained. Below: specially designed cathode-ray tube developed at the Bureau for application of the method.

five different measurements was 5.3 percent of the mean value, and in most cases the maximum range of values was 3 percent or less. This is considerably better than had been anticipated, and it seems likely that these early results may be improved.

Standard Wavelengths for Spectrometer Calibration

Use of photoconducting detectors has made available high-resolution techniques for the one-to-three-micron region of the infrared spectrum,

sometimes called the combination-band and overtone region. For correct and adequate interpretation of the new data, better wavelength determinations are necessary. This is also true in the region beyond 3 microns, where other types of sensitive detectors may be employed. To meet the needs in the short-wave region, 19 lines in the emission spectrum of mercury between 1.0 and 2.3 microns were selected as secondary standards. Wavelengths of those lines which occur beyond the photographic limit were determined by grating measurements. In addition to determinations of 27 wavelengths from the emission spectrum of mercury 198, wavelengths of lines in the emission spectra of neon, argon, and krypton were precisely obtained.

To provide adequate standards for the calibration of prism spectrometers in the region from 3 to 25 microns, wavelengths of many absorption bands of several materials were accurately determined with grating spectrometers. The bands were selected from the absorption spectra of polystyrene, 1,2,4-trichlorobenzene, methylcyclohexane, and toluene.

Ultimate Standard of Length

Continued investigations of the artificially produced mercury isotope of mass number 198 have determined the relative wavelengths of 27 characteristic radiations with higher precision than ever yet attained. These measurements demonstrate (1) that the green wavelength of mercury 198 provides a practically perfect primary standard of length and (2) that the spectrum of artificial mercury provides superior spectroscopic standards for critical tests of the constancy of differences among vacuum wave numbers and for tests of the validity of various formulas relating the refractivity of standard air to wavelength.

Spectra of Artificial Elements

Several milligrams of technetium and promethium, new chemical elements produced by uranium fission, were loaned the Bureau by the Atomic Energy Commission for spectroscopic study. Preliminary description of the emission spectra of these artificial elements is almost complete, providing reliable wavelengths and intensity data for about 5,000 new spectral lines. Regularities were discovered in the first two spectra of technetium. The absorption spectrum of promethium was also observed.

Absorption Spectrum of Water Vapor

Since the beginning of infrared spectroscopy, the existence of a region of strong atmospheric absorption near 2.7 microns has been recognized. With each advance in experimental techniques permitting higher resolution, more and more fine structure has been observed in this absorption band. During the year, still greater resolving power was realized by the development of a new high-resolution grating spectrometer utilizing a 15,000-line-per-inch grating and a lead sulfide photoconducting cell as the

detector. With this instrument, the band structure between 2.43 and 2.87 microns was resolved into over 450 lines. These lines have been identified as components of two fundamental vibrational-rotational bands of the water vapor molecule and two combination bands of the carbon dioxide molecule. Of the three fundamental vibrations of water vapor, two fall within this region, and in this work their respective components have been distinguished for the first time. The new instrument clearly resolves lines 0.30 cm^{-1} apart and frequently makes it possible to distinguish the presence of two components in lines separated by 0.15 cm^{-1}. This high resolution was indispensable in the theoretical analysis.

Atomic Energy Levels

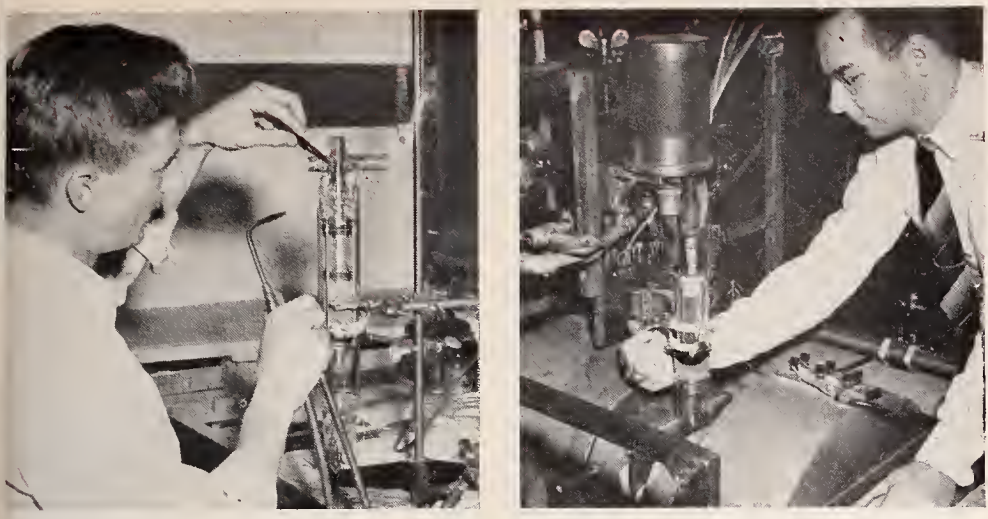
The first volume of *Atomic Energy Levels* was completed by the Bureau and is now available from the U. S. Government Printing Office as NBS Circular 467. Designed to meet the needs of workers in nuclear and atomic physics, astrophysics, chemistry, and industry, this volume is an up-to-date compendium of all energy levels for the first 23 elements exclusive of those due to the hyperfine structure ascribed to atomic nuclei. Similar data on the next 19 elements, chromium through niobium, has been compiled and sent to press; this information will constitute a large part of volume II of *Atomic Energy Levels.*

Volumes I and II of *Atomic Energy Levels* are the first of a series being prepared at the Bureau as part of a general program on atomic energy levels derived from observations of the optical spectra of atoms and ions. The new series represents the cooperative effort of scientists throughout the world and will constitute the first compilation of atomic energy levels in the last 18 years, during which time the number of known energy levels has increased by a factor of 4 or 5. New descriptions and essentially complete interpretations of Cr I, Cr II, Mn I, and As I spectra will be included as NBS contributions to volume II, and considerable progress has been made on Mo I, Mo II, Ta I, Ta II, Re I, Re II spectra as contributions to volume III.

Tables of Nuclear Data

The first edition of the tables of *Nuclear Data,* containing information available up to January 1, 1950, was completed. These tables present a comprehensive collection of experimental values of important physical constants, such as half-lives of radioactive materials, radiation energies, relative isotopic abundances, nuclear moments, cross-sections, and nuclear decay schemes.

At present over a thousand new measurements of different nuclear properties are being reported each year in some 30 different journals and in the technical reports of dozens of laboratories. The first table, and the supplements to follow, are therefore designed for easy assimilation of new material in loose-leaf form. The reactor engineer and the industrial or medical user of radioactive tracer materials, as well as the nuclear



Left: techniques employed in the construction of the new three-stage nonmagnetic mass spectrometer (p. 37) resemble those used in the manufacture of radio tubes. Right: the *omegatron,* a new instrument developed by the Bureau for absolute measurements of mass (p. 34), is basically a miniature cyclotron.

physicist, have long been in need of such a compilation of available data which can be kept up to date automatically.

All the more recent values of a given nuclear property are listed in the tables. Thus, from the degree of uniformity of the results, the reader can tell at a glance which nuclear constants are now fairly certain and which are doubtful. Work is now in progress on the first supplement, which is to contain new information obtained between January 1 and July 1, 1950.

6. Chemistry

A wide range of fundamental and applied research is carried on in physical, analytical, organic, and inorganic chemistry. Special laboratories are devoted to organic protective coatings, detergents and adsorbents, carbohydrates, metals and alloys, pure substances, electrodeposited coatings, gases, acid-base indicators and pH standards, and hydrocarbons. Highly varied techniques are used in the analytical work of the several groups; many types of physico-chemical measurements are made: an entire section, by way of illustration, is occupied with emission spectroscopy as an analytical tool. Most of the Bureau's Standard Samples, critical in industrial quality control and in research throughout the Nation, originate in this division.

Spectrochemistry

Spectrochemical analysis offers advantages of speed, high accuracy for minor and trace constituents, and small sample consumption. Methods utilizing these advantages were developed and applied to the analysis of various materials. The flame photometer was adapted to the determination of calcium in sugar solutions, spectrographic procedures for the analy-

sis of tin metal and bronze alloys were improved with a gain in speed of testing, and methods were developed for the determination of magnesium in cast iron and for the identification of extremely small samples weighing as little as one microgram. The latter method was applied to studies of deposits in special electronic tubes for radio research.

The application of a direct-reading spectrometer to the electronic recording of line intensities promises marked improvement in the speed with which spectral analysis of materials can be made. During the year the direct-reading equipment was modified, making the procedure more precise than the older photographic method. The instrument is now being used for the rapid testing of standard samples of steel for homogeneity.

Work continued on the preparation and testing of steel standards, including stainless steel and alloy tool steels. A high-manganese steel standard was issued at the end of the year; it is planned to issue several of the high-alloy steels during the coming year.

Color Phase-Contrast Microscopy

During the war, a German optical firm developed the phase-contrast microscope, in which hitherto indistinguishable details of microscopic objects are made readily visible. In 1948, Professor F. Zernike, who discovered phase-contrast microscopy, suggested a modification of the phase-contrast method by means of which details of structure might be shown as differences in color. His attempts at realization, however, were unsuccessful.

The Bureau has now developed new color phase-contrast equipment with which ordinarily invisible differences in texture are revealed as bright differences in color. The color at any place is an indication of optical density and hence gives an intimation of chemical constitution. These color effects are superimposed upon differences in darkness which may also be exhibited by the sample. The results are very striking, but the importance of the method will only be known after biologists, pathologists, bacteriologists, and other users of the optical microscope have had an opportunity to put it into actual service.

Standardization of pH

Measurements of the degree of acidity and alkalinity play an important part in the research laboratory and in the regulation of such modern industrial processes as food preparation, sugar refining, and the manufacture of paper, textiles, and dyes. These measurements are expressed in terms of hydrogen ion concentration, or pH, on a scale ranging from a pH of almost zero (very high acidity) to a value near 14 (very high alkalinity). Three NBS standard samples are used widely here and abroad to provide fixed points for the practical scale of pH at pH 4, 7, and 9. Unfortunately, this scale is not uniform at its ends, and additional standards are needed to reduce the error of measurement at low and high pH. During the past year,

20 possible pH standards were studied in detail. This work has recently culminated in the selection of four of these, at pH 2, 3.5, 10, and 11.7, which are expected to improve the accuracy of measurements below pH 4 and above pH 9. The four new standards are, respectively, potassium tetroxalate, potassium hydrogen tartrate, a mixture of sodium carbonate and bicarbonate, and trisodium phosphate.

Combustible Gas Indicator

At the request of the Bureau of Aeronautics, Department of the Navy, a new type of instrument was developed for detecting gasoline vapors or other combustible gases in such spaces as airplane cabins or cargo holds. In the past, the more common devices for this purpose have made use of the heating effect of combustion at the surface of a wire. However, the wires are subject to change at the high temperature necessary for combustion, and the older instrument is also greatly affected by changes in pressure. The instrument developed at the Bureau, which is based on thermal conductivity, is independent of altitude and rate of air flow, moderately independent of applied voltage, and is direct-reading. It has a full-scale range of 20 percent of the lower explosive limit but can also be made to read to the explosive limit by throwing a switch. The instrument will also indicate the presence of carbon dioxide.

Standard Methods of Gas Analysis

Gas analyses are performed on samples that are only momentarily available, and their interpretation, which is often of great importance, must be made immediately. As a result, gas analysts have tended to become isolated workers with varied individual techniques which they have had little opportunity to compare with the methods used by other analysts. In an effort to standardize gas analysis methods, the Bureau conducted an extensive investigation in which identical samples of gas were supplied to a large number of cooperating laboratories. The laboratories made detailed reports to the Bureau on the results of analyses and the methods employed in obtaining them. From a study of all the data, the better procedures were chosen, and "standard" methods were recommended. Two of these standard methods (ASTM Tentative Method for Analysis of Natural Gas by Volumetric-Chemical Methods, and ASTM Tentative Method for Analysis of Natural Gas by Mass Spectrometer) were prepared in detail and have been adopted as tentative standards of the American Society for Testing Materials.

One great difficulty in gas analysis has been the fact that the most used and generally the best of the reagents employed for determining oxygen produce small but sometimes significant volumes of carbon monoxide, which cause erroneous results. Employing for the first time a sensitive reagent for carbon monoxide recently developed at the Bureau, a thorough study

was made of the conditions under which the unwanted gas develops. This study has resulted in the preparation of a reagent for determining oxygen which produces a minimum of carbon monoxide and thus gives reliable results.

Hydrocarbons

Several paraffin hydrocarbons were isolated from petroleum, and samples of recycle styrene were analyzed for C_4 hydrocarbon and styrene contents. Some mixtures of olefins produced by codimerization of the butenes were also analyzed. A large number of hydrocarbons obtained from other laboratories were purified and added to the list of standard samples of hydrocarbons which are made available to various laboratories, mainly for spectrometer calibration. In connection with this program, the purities of three sulfur compounds which were synthesized and purified by the Bureau of Mines were determined by measurement of freezing points, and the three sulfur compounds were issued as standard samples. Measurements were made of the boiling points at 20 pressures, densities at three temperatures, and refractive indices at three temperatures and seven wavelengths of seven monoolefin and six diolefin hydrocarbons. Approximately 30 loose-leaf sheets were issued listing such properties of hydrocarbons as viscosity, density, vapor pressure, boiling points, and refractive index. Numerous tables of infrared, ultraviolet, Raman, and mass spectral data were also collected from various experimental laboratories and issued in loose-leaf form.

Thermochemical Measurements

Heats of combustion in oxygen in a flame at constant pressure were determined for the four butenes (1-butene, *cis*-2-butene, *trans*-2-butene, and 2-methylpropene). A report was prepared on the heats of formation, combustion, isomerization, and hydrogenation of the four butenes, the two butanes (*n*-butane and 2-methylpropane), the two butadienes (1,2-butadiene and 1,3-butadiene), and the two butynes (1-butyne and 2-butyne). This report clears up a former discrepancy between calorimetric data and equilibrium data on the heat of isomerization of *n*-butane to 2-methylpropane. It confirms direct data on heat of hydrogenation, except in the case of *trans*-2-butene, and yields thermochemical data on some compounds for which data were not previously available. Most of the experimental work has also been completed on the determination of the heats of combustion in a bomb at constant volume of liquid *n*-decylbenzene, *n*-hexadecene, *n*-hexadecane, *n*-decylcyclopentane, and *n*-decylcyclohexane. These data will yield heats of vaporization of these compounds since values have been previously published on their heats of combustion in the gaseous state. Heats of formation, combustion, and vaporization of homologous series of these compounds will also be obtained from these data.

The heat of formation of boron trichloride and the heat of reaction of diborane with water were determined. These heats of reaction confirm the data obtained earlier by the Bureau for the heat of formation of boric oxide, which differed greatly from previously published data. An investigation now under way on the heat of formation of decaborane will provide additional data on the peculiar molecular structure of the boron hydrides.

Electrodeposition

The work on electrodeposition was principally concerned with the application of electroplating to weapons and other military devices, but some time was also devoted to projects of interest to industry and the general public. For example, a novel method was developed for measuring the adhesion of electroplated coatings. In this method, a nodule of some metal such as cobalt, for which the conditions of very adherent deposition are known, is deposited on a small defined area of the plated surface that is to be tested. The force required to remove the nodule is then measured with a spring balance. From the measured force and the observed area of detached plating, the adhesive force per unit area is computed.

Efforts to deposit such metals as molybdenum and tungsten from aqueous solutions at temperatures up to 300°C proved unsuccessful. Studies were therefore begun on the possibility of plating these metals, and others such as titanium and zirconium, from nonaqueous media, either fused salt electrolytes or organic solvents. In the course of this investigation many new types of compounds and solutions are being investigated.

Research in Analytical Chemistry

Three new methods of analysis were developed. One of these, a rapid semimicro method for determining nitrogen in steel, was related to an investigation of the hardenability of boron-treated steel. Another, a method of determining small amounts of magnesium in cast iron, was required in connection with the production of the new "modular" or "ductile" iron. The third was for the analysis of thallium bromide-iodide crystals, which are used in optical parts for transmission of radiation in the far infrared region.

The ratio of carbon to hydrogen in synthetic rubbers was determined to the highest precision yet reported. This analysis is the basis for a physical method of controlling the composition of the rubber during its manufacture. As small differences in the ratio are important, the highest precision is desired.

Commercial Solid Adsorbents

Bone char is used in enormous quantities in the refining of sugar. Increased understanding of the properties of this material, as well as those of other solid adsorbents, has resulted from a long-range cooperative program of research initiated at the Bureau in 1939 for a fundamental study

of sugar-refining problems. The work is so planned as to yield information not only of direct interest to the sugar-refining industry but also of basic scientific value. During the year substantial progress was made in several phases of this program.

Many properties of solid adsorbents depend appreciably on particle size, which is determined by sieve analyses. A detailed investigation just completed shows that the testing sieves constitute the largest source of error in these determinations. However, corrections can be made if the actual sizes of the openings of the sieves are determined independently. Promising results were obtained using glass spheres of known size distribution to determine the effective openings of the sieves. Samples of the glass spheres have been prepared and are now being tested in service by the laboratories of the sponsors of the program.

The industrial regeneration of carbon adsorbents, such as bone char, is accomplished by thermal treatment. This operation may consist of a destructive distillation (absence of oxygen), a controlled oxidation (air roasting), or some combination of these two treatments. An analysis of the several methods of thermal treatment was made, providing much useful information on the kilning operations employed in the revivification of bone char.

The presence of combined oxygen within or on the surface of carbonaceous materials has long been known to have significant influence on their surface properties. In an investigation now in progress, an experimental procedure has been developed by which oxygen balances can be obtained. The new technique separates the process of burning from that of chemisorption. This method shows that repeated adsorption of oxygen and desorption of oxygen products has a gradual aging effect which influences the properties of the adsorbent. Apparently, a prior treatment with hydrogen has an important effect on the subsequent adsorption of oxygen.

Although enormous quantities of water are employed to wash bone char in each cycle of operation, considerable ash is retained by the char, and this is detrimental to efficient operation. It was discovered that the accumulation of adsorbed ash can be prevented and much water can be saved by the inclusion of simple ammonium salts in the wash water. The recommended process has now advanced from the laboratory to pilot-plant stage.

Punch-Card Catalog of Infrared Absorption Spectra

Probably no branch of chemistry is developing more rapidly than the study of the infrared absorption spectra of chemical compounds. Not only are these spectra useful analytical tools, but they also provide important information on the intermolecular forces which determine chemical properties. As the available literature on the subject is already large and rapidly expanding, there has been a need for some means by which workers in the field could quickly find what has already been done. To meet this need, work has begun on the preparation of a comprehensive card catalog.

By use of these cards, the reported spectra of any compound can be quickly found, the more important chemical linkages associated with a given spectral line can be determined, the work of any given author can be quickly assembled, and the properties of a compound which will aid in its identification can be found without loss of time. Many industrial laboratories will supply data they have collected and will subscribe to the punch-card "library."

Carbohydrate Chemistry

In the continuing program on the fundamental chemistry of sugars, further progress was made toward an understanding of their structure and the mechanisms of the reactions by which they are formed and through which they take part in life processes.

From studies of the hydrolysis and mutarotation reactions of the glycosylamines, an electronic interpretation was developed to account for the effect of acid and base catalysts in addition reactions. The glycosylamines were found to have alpha and beta modifications like the sugars. They were acetylated, and proof was established that acetyl derivatives of glucosyl-, mannosyl-, and galactosyl-amines all contain the pyranose ring. Optical rotation was found to provide a means for the classification of pyranosyl amines.

A project for the study of the infrared spectra of sugars was initiated July 1, 1949, with the partial support of the Office of Naval Research. To date, about 100 compounds have been purified and more than 60 have been examined. Ultimately this work will throw light on those details of the structure of sugar molecules that have escaped other methods of study.

Pure samples of difructose anhydrides I, II, and III, products of repeated crystallization, were prepared for X-ray studies. Observations of the refractive indices of maltose in concentrations from 1 to 65 percent were completed, and a method for the separation of dextrose, maltose, and dextrins was developed for the analysis of syrups and molasses.

7. Mechanics

The mechanics of solids, liquids, and gases are the broad topics of research in this field. In scope the work varies from long-range investigations of basic mechanical phenomena to short-range studies of the mechanical action of practical apparatus.

Research and development now under way in mechanics include studies of "talking book" systems for the blind, improvements in techniques for measurement of sound pressure, development of methods of measuring hearing loss in the deaf, development of techniques for the calibration of pressure gages for extremely high pressures and of altimeters for extreme altitudes, extension into the supersonic range of the hot-wire technique for measuring air turbulence, development of calibration methods for hygrometers, determinations of stress distribution and strength of large

The first step in the preparation of an NBS standard sample of steel (center) is a lathe operation (upper left), in which chips of a special form are cut from a bar. The cuttings are next broken up into finer size (upper right), sifted, thoroughly mixed, and then analyzed (lower left). When the composition of the metal has been established, it is packed (lower right) in bottles for distribution.

structures such as bridge columns and bulkhead intersections of ships, stress analysis of structural elements of aircraft with sweptback wings and with large cutouts, development of techniques for determining the effect of high temperature on the strength of aircraft structures, analysis of the vibration in aircraft caused by the landing impact, development of a precise method of measuring forces up to 3,000,000 pounds for the calibration of the largest testing machines, and the development of a theory for the capacity of plumbing systems based on hydraulic principles and on statistical methods.

NBS Stick-Force Indicator

An important consideration in flight-testing new types of aircraft is the relation between the force applied to the controls by the pilot and the actual deflection of the controls in various maneuvers and at different air speeds. To aid the Department of the Navy in this work, an instrument

was developed which automatically indicates the force applied to the control stick of an airplane. The new instrument, which makes use of the flexure in a cantilever spring incorporated in the stick handle, is compact, easily attached to the aircraft, and requires little attention from the pilot. As it is unaffected by the ordinary fluctuations of aircraft battery voltages, is of adequate sensitivity, and permits the taking of a photographic record of stick-force indications, it is expected to aid materially in aircraft test work.

Until the NBS Stick-Force Indicator was developed, the two components of the force exerted on the stick were generally measured in one of two ways: either by pressing a single-component grip-type spring scale successively in the two required directions or by attaching strain gages to some part of the system used to transmit the control force. Both of these methods had their disadvantages. The first was inconvenient and distracting to the pilot, did not give simultaneous measurements of the two force components, and did not permit a permanent record to be made. Strain gages are still used and useful, but their readings are sensitive to voltage variations, and an amplifier is required if more than one indicator is used. The instrument developed by the Bureau, on the other hand, operates satisfactorily on varying aircraft voltages and makes possible a complete photographic record of the forces in the two required directions without disturbing the pilot in the normal operation of the controls.

Photo-Grid Technique

With the use of higher-strength sheet metal in the aircraft industry, interest in the formability of sheet has increased markedly since processes which improve strength frequently reduce ductility. The requirement on elongation in a 2-inch length usually found in sheet-metal specifications is not a reliable guide for predicting formability because the elongation may not be uniformly distributed and may often be confined to an extremely small area. In a recent investigation at the Bureau, an improved photogrid technique for determining elongation of sheet metal was developed, overcoming difficulties involved in other methods as well as providing a more reliable procedure for establishing the behavior of sheet metal during forming. The new technique is now proving useful in the investigation of plastic deformation in the vicinity of holes and in studies of other structural discontinuities which result in excessive stresses.

Aircraft Structures

With the increase in size and speed of modern aircraft, it has become increasingly important that aircraft structures have adequate stiffness as well as sufficient strength. High stiffness raises the flutter speed, prevents wing divergence and aileron reversal, and decreases the dynamic response of the airplane to landing impact, gust loads, and maneuvering loads. It

is thus desirable that the aircraft designer be able to compute the stiffness of a proposed design in order to determine whether the completed airplane will give adequate performance. To an increasing extent, influence coefficients are being used as a measure of stiffness.

During the year methods of computing influence coefficients of typical aircraft wing structures with discontinuities such as bulkheads and cutouts, and with varying amounts of sweepback, were developed for a wide range of loading conditions. The methods make use of stress analysis of the structure based primarily on equilibrium considerations. Where equilibrium conditions are not sufficient in themselves to specify the stress distribution, use is made of the fact that the actual distribution corresponds to a minimum of the strain energy.

An experimental check of these methods was undertaken in cooperation with the Massachusetts Institute of Technology. Tests were conducted at the Bureau on wing specimens with cutouts and with both single- and multiple-cell construction. Those at MIT were made on wing specimens with sweepback and with taper. The experimental results indicate that the techniques developed for computing influence coefficients are satisfactory.

Ship Structures

The failure of several welded steel ships during the early part of World War II indicated that many problems relating to welded ship structures remain to be solved. Design details at structural discontinuities in welded tankers are of special interest since failures have been known to originate at hatch corners, bulkhead intersections, and in interrupted longitudinal members.

The Ship Structure Committee, through the Department of the Navy, is now sponsoring at the Bureau a program of research on the stress distribution in bulkhead intersections and interrupted longitudinals as part of a general study of design details in welded ships. Four full-size bulkhead-intersection tensile specimens and four interrupted longitudinal specimens, each differing in design detail, have been tested in the Bureau's 1,150,000-pound tension testing machine. Elastic stress distribution at room temperature, strain distribution to failure at 0° F, and energy to fracture at 0° F were determined. The results indicate considerable difference in the load carrying capacity of the different designs for the bulkhead intersections and suggest desirable changes in design details.

Water Levels in Shallow Lakes

The emphasis in the investigation of water waves was shifted this year to studies of the changes in water levels of shallow lakes and reservoirs caused by wind. The Corps of Engineers of the Department of the Army became interested in these studies early in the year because the results can be applied directly to the "setup" produced by tropical hurricanes in Lake

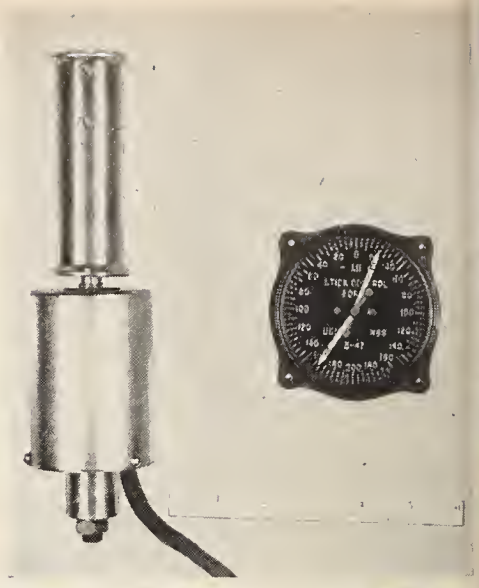
Okeechobee and in large artificial reservoirs under construction or planned in Florida. Further theoretical work was done on this problem, and numerous tests were conducted under various conditions in the 70-foot flume built for such studies the previous year. This flume has a closed cross section and has blowers mounted at both ends to create an artificial wind over the water. The experimental work is now complete and will soon be published.

Flow of Stratified Liquids

A comprehensive theoretical and experimental investigation of the flow of stratified liquids, known as density currents, was continued with the financial assistance of the Office of the Chief of Engineers, Department of the Army. An important objective of this work is to develop model laws pertaining to models of rivers, harbors, and canals, where density currents are involved. The problem is of considerable economic importance, since it involves contamination of public water supplies, as in New Orleans, and of farm lands by intrusion of salt water from estuaries in the Sacramento River and possibly from navigation canals. The experimental work was completed on the movement of a wedge of salt water issuing from a lock and progressing through a canal, and the problem is now being analyzed theoretically. The final tests were made in a new glass-walled flume 9 inches wide and 200 feet long. Tests have begun on the next phase of the investigation, an experimental study of conditions that exist when a stream of fresh water flows over a layer of salt water at the mouth of a river.

Drainage Systems in Buildings

The question of how heavily a vertical soil stack of a given diameter can be loaded with drainage from plumbing fixtures in a building is a very controversial one on which little experimental data have been available. Plumbing codes differ widely in the number of fixtures that they permit to be discharged into a stack of given diameter and in the way in which these fixtures may be distributed between different floors. A fundamental investigation of this problem, sponsored by the Housing and Home Finance Agency, was continued. The experimental work was completed with tests on an actual 3-inch stack. Pressure conditions at the horizontal branch connections and the distribution of air and water over the cross section of the stack were studied. Another investigation, also sponsored by the Housing and Home Finance Agency, was begun to study the minimum safe sizes of pipes for use in the sanitary drainage system of a small dwelling. Various arrangements of connecting fixture drains to 2- and 3-inch stacks are being investigated, and pressure conditions in the stacks and drains are being measured. The effect of adding food waste disposal units to the drainage system is also under study.



Left: square panels of the type used as a stressed covering for airplanes are subjected to compressive loads in a horizontal testing machine. Right: the NBS Stick-Force Indicator (p. 52), developed by the Bureau for the Department of the Navy, shows the force applied to the control stick of an airplane at any instant.

Humidity Apparatus

The problem of production and measurement of relative humidity was successfully solved by the development of a recirculator type of apparatus which produces a known relative humidity from about +40° C to about −40° C. The apparatus was developed principally for the test of radiosonde and other small hygrometer elements. In this device, air is first saturated at a measured, controlled temperature and then warmed to a second measured controlled temperature; from these data relative humidity of the warmed air is computed. The tester has four humidifiers and four test chambers so arranged that a hygrometer element can be conveniently subjected to four relative humidities at the same temperature or the same relative humidity at four temperatures, or combinations of these, at controlled ventilating speeds up to 1,500 feet per minute.

Dispersion of Sound in Gases

Dispersion in the velocity and attenuation of sound at high frequencies and low pressures was observed for the first time in monatomic gases. Ultrasonic measurements gave results in good agreement with both classical and modern theory insofar as the two are consistent.

The kinetic theory of nonuniform gases is of importance in the study of explosion-wave phenomena and upper-atmosphere research. Until these dispersion studies, however, no experiment capable of assessing the value of this theory had been designed except for simple cases. Indications are that more refined experiment will make it possible to distinguish between the classical and modern theories of nonuniform gases and perhaps furnish a basis for their modification.

Standards for Calibration of Microphones

For many years the Bureau has maintained standards for the absolute calibration of microphones over the frequency range from 50 to 10,000 cycles. Recently, increased interest has been shown in the supra-audible range of frequencies by medical and military groups. Work was therefore begun on the design and construction of equipment for extending the basic reciprocity technique for absolute measurement of sound pressure to frequencies of the order of 100 kilocycles.

Sound Absorption

Determination of the absorption coefficients of acoustic materials after they are installed has long been a problem of considerable economic importance. A long tube for making such measurements has now been developed and has been successfully applied in determining the effect of different methods of painting on preservation of the sound-absorbing power of the acoustic treatment in the Pentagon Building.

8. Organic and Fibrous Materials

Rubber, plastics, textiles, leathers, and papers—the organic and fibrous materials investigated by the Bureau—have important characteristics in common. All are high polymers of very complex chemical structure, and their long, chainlike molecules have intricate physical arrangements. Consequently, the relatively simple chemical and physical techniques of a few years ago are inadequate for obtaining more than the most elementary data about these materials and their behavior. In recent years, however, rapid progress has been made in the theoretical science of high polymers, and new techniques have been developed for measuring their properties and studying their reactions. Many of the new mathematical methods and experimental techniques are being used by the Bureau in an integrated approach to the study of high polymers. This program seeks to improve present knowledge of high polymers, to develop new materials of this type, and to provide for their practical utilization. Emphasis is placed on methods that are applicable to several high-polymeric substances, so as to get the greatest possible yield of results in proportion to the resources expended.

Synthetic Rubber

A program for the standardization of Government synthetic rubbers, involving the development of methods for chemical analysis and physical testing, is being carried on at the request of the Office of Rubber Reserve. During the year, comprehensive chemical and physical measurements were made on the reference lots of GR–S and GR–I rubbers that were used to standardize testing and thus to insure uniformity of production in different plants making synthetic rubber. New test recipes were developed for

GR–I and for GR–S rubbers made with the incorporation of carbon black. A number of improvements were made in the strain tester previously developed for the accurate measurement of the modulus of elasticity of rubber samples. A complete-solution method was developed for the analysis of GR–S rubber, and significant improvements were made in various other physical and chemical tests.

Low-Temperature Potentialities of the Silicone Rubbers

In an investigation sponsored jointly by the Office of Naval Research and the Quartermaster Corps, it was shown that the silicone rubbers, developed especially for high-temperature applications, have better potentialities for use at extremely low temperatures than any synthetic or natural rubber studied thus far. The silicones are synthetic rubbers in which some of the carbon atoms normally present are replaced by silicon and oxygen. Since these materials are highly resistant to heat, retaining their elasticity and electrical resistance at temperatures as high as 200° C, they have been found especially well suited for hose and gaskets in airplane engines and for insulated cables. In recent years a need has also arisen for a type of rubber capable of withstanding low temperatures without loss of its characteristic rubberlike properties. Tires, belting, or other articles of ordinary rubber lose their elasticity around −50° C, presenting many difficulties in connection with the operation of motor vehicles and machinery in the arctic or of airplanes at great height. To learn more about the possibilities of using the silicones for such low-temperature applications, the Bureau undertook an investigation to determine the lower limit of the temperature range in which they retain their characteristic elasticity.

This lower limit was determined by locating the second-order transition temperature, a temperature at which a marked change in the slope of the length-temperature curve occurs. Such a change is observed in all rubbers and plastics and can be recognized as a discontinuity in the derivatives of volume, heat content, index of refraction, compressibility, dielectric constant, and other quantities with respect to temperature. A second-order transition differs from the ordinary first-order transition, or change of phase, in that no volume change or latent heat is involved. However, below the second-order transition temperature the type of molecular motion responsible for the useful properties of a rubber ceases, and the material behaves essentially as an ordinary solid.

Resin Bonding of Offset Papers

Further advances in making resin-bonded papers indicate that vast quantities of hardwoods may be effectively utilized in the manufacture of offset papers. The synthetic resin, which imparts the desirable printing properties to these papers, acts as a substitute for the natural fiber-bonding gel usually developed through the use of large amounts of softwood pulps.

Current investigations in the Bureau's experimental paper mill show that resin-bonded papers containing 75 percent of hardwood pulps compare favorably with papers made in the conventional way with the customary combination of equal parts of hardwood and softwood fibers. An increase in the proportion of hardwood fibers in printing papers would greatly extend critical pulpwood resources not only in this country but also in Europe, where the stands of hardwood suitable for paper-making are much more extensive than those of softwood.

Abrasion Studies

The Schiefer Abrasion Machine, developed by the Bureau two years ago for studying the abrasion resistance of textiles, is now being applied in other related fields. For example, it is being used to produce uniform soil in a fabric sample in connection with the evaluation of different detergents and washing procedures, to grind plastic disks accurately for precise measurements of dielectric properties, to measure the effects of chemical modifications of cellulose and wool on abrasion resistance, and to test the pile of carpets.

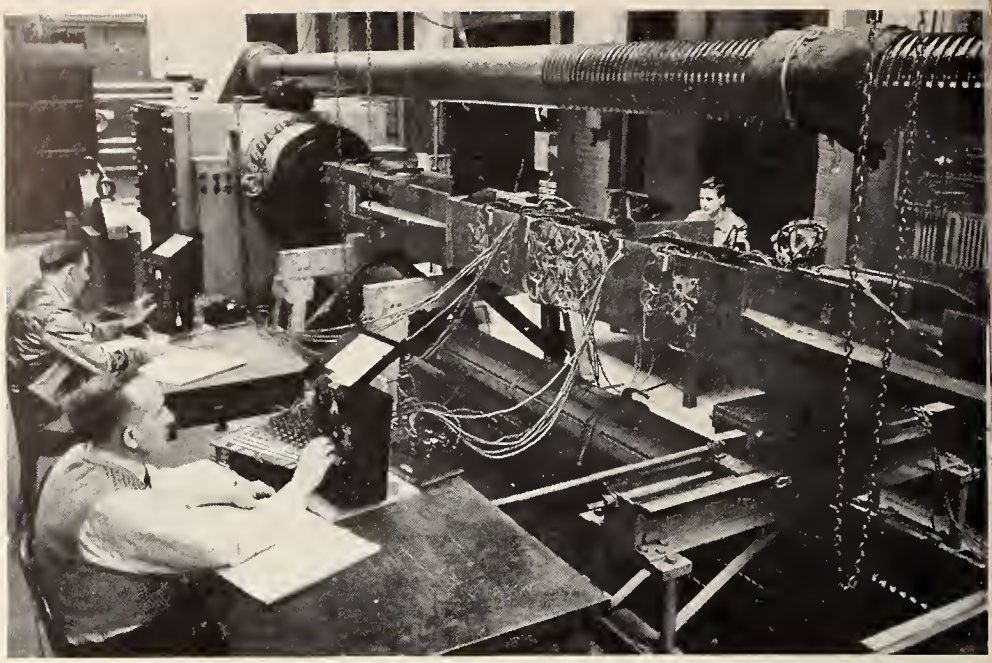
Another important application is the determination of the abrasion resistance of yarns without the expense of weaving or knitting them into fabrics and without the introduction of effects due to complex geometrical form factors of weaving and knitting. Thus, the tests can be made on small lots of yarn in the laboratory under widely varying but carefully controlled conditions. The effects of finishing materials, chemical modifications of fiber, kind of fiber, fiber blends, amount of twist, and number of plies on the abrasion resistance of the yarns are being determined.

Properties of Laminated Plastics

Use of laminated plastics in aircraft has increased during the past few years, especially in accessories and semistructural parts, such as bulkheads, partitions, linings, propellers, wing flaps, and ducts. A need has thus developed for more comprehensive information on the properties of these materials in order to evaluate them for aircraft application and to prepare suitable specifications. To provide the necessary data, the Bureau has conducted a continuing program, sponsored by the National Advisory Committee for Aeronautics, on the properties of plastic laminates. During the year, projects were completed on the effect of simulated service conditions, fuel immersion, and extreme temperatures on laminated plastics.

Surface of Cotton Fibers

At present very little is known concerning the external and internal surfaces of cotton fibers. Inasmuch as these surfaces may have an important bearing on the performance of the fibers in processing and use, further information about them should be of considerable practical importance.



A welded ship girder is studied under tension in the Bureau's large horizontal testing machine. Strategically placed strain gages indicate deformations to the seated observers. This girder failed at a load of 843,000 pounds.

The external and internal surfaces of a series of cottons differing in variety and in previous chemical and mechanical treatments are now being measured at the Bureau. The external surface is calculated from the quantity of nitrogen adsorbed at −196° C by the original fiber. The internal surface is obtained by subtracting the external surface from the total surface, which is calculated from the nitrogen adsorbed at −196° C after the fiber has been swollen in water and dehydrated with absolute methanol and benzene. In all cases the internal surface is large in comparison with the external surface; in some instances the internal surface is as much as eighty times the external surface.

Volume Changes at High Pressures

Many important properties of matter are affected by the independent variables temperature and pressure. While the effect of temperature has been the subject of intensive studies for many years, the effect of pressure has received scant attention, primarily because of the difficulties involved in experimentation at high pressures. To obtain information on the behavior of natural and synthetic high polymers under pressure, an apparatus was constructed to evaluate the volume change of solids and liquids at pressures between 1,000 atmospheres (15,000 lb/in.^{2}) and 12,000 atmospheres (180,000 lb/in.^{2}). In collaboration with the Geophysical Laboratory of the Carnegie Institution of Washington, data in this pressure range have been obtained on the natural organic polymers, leather and cellulose; on synthetic polymers such as fluorocarbons and synthetic rubbers, and

on feldspathic and pyroxenic minerals such as jadeite and oligoclase, which are inorganic polymers.

Compressibilities of the minerals were approximately the same as that of steel, while those of the organic polymers were 20 to 50 times as large. The results appear to classify organic polymers in a category lying between true solids of low compressibility and true liquids, which have high compressibilities. All materials appeared stable under pressure, and no second-order transitions were observed. Polytetrafluorethylene (Teflon) exhibited a polymorphic transition in a small pressure interval centered at 5,500 atmospheres.

Water-Vapor Relations of Leather

An example of fundamental research which rapidly developed into a practical application was the work on the water-vapor relations of leather. The adsorption of water vapor by collagen and by leathers was determined at relative humidities from near 0 to 96 percent at 28°, 50°, and 70° C. From the results, the heats of adsorption, free energy, and entropy values were calculated for the adsorption. Methods were also derived for estimating moisture contents under conditions not studied experimentally. The change of water adsorption with temperature was expressed by a relation involving the logarithm of the percentage of water adsorbed and the inverse of the absolute temperature.

The investigation was then extended to a practical study of the permeability of leather to water vapor, an important factor in determining the comfort of shoes. The permeability of shoe leather to perspiration in the form of water vapor is inherently high, but the use of fats and greases to improve the resistance of shoes to liquid water may lower their permeability so as to make them uncomfortable. Studies on leathers impregnated with different materials showed that water-vapor permeability decreases in the following order: Sulfonated oils, acrylate resins, rubber, and stuffing greases. A new method was developed that permits the measurement of the water-vapor permeability within 1 day, instead of the 4 or 5 days required by the older method. This new method is being incorporated into Federal Specifications for leather and leather products.

Deterioration of Furskins

The occasional rapid deterioration of fur coats, evidenced by brittleness of the skin and loss of resistance to tearing, is a cause of concern to consumers, retailers, and manufacturers alike. Chemical and physical analyses of aged pelts of Karakul lambskins, furnished by the Department of Agriculture, and Alaska sealskins, made available by the Department of the Interior, showed the presence of small quantities of copper salts in weakened pelts. It thus appears that the presence of copper, sometimes used as a mordant in dyeing the pelt, may be a cause of deterioration. The extent of

deterioration was conveniently measured by determining either bursting strength, breaking strength, or furrier-sewn stitch-tear values. These losses in strength were accompanied by lowered grease content, increased water-soluble content, and increased soluble nitrogen.

9. Metallurgy

The work in physical metallurgy is concerned with the melting, working, and heat treatment of metals and alloys; determinations of their structure and properties; and studies of the effect of various factors on structure and behavior under normal and abnormal conditions of service. In general, this program is directed toward a better understanding of the properties and behavior of metals in order that improved or new metals and alloys may be developed for better performance in established uses and to meet the requirements of new applications. Projects now under way are concerned with iron, steel, copper, aluminum, magnesium, zinc, tin, lead, and alloys of two or more of these metals.

Corrosion

The investigation of the corrosion of aluminum, magnesium, and stainless steel sheet metal for aircraft use was continued with exposures in a marine environment at Hampton Roads, Va., and in an inland atmosphere at Washington, D. C. Specimens of titanium and its alloys are being included in the test program as rapidly as the material can be obtained. This program is sponsored by the National Advisory Committee for Aeronautics; the Bureau of Aeronautics, Department of the Navy; and the Air Force.

A study of the susceptibility of some wrought magnesium-base alloys to stress-corrosion was completed. Results showed that the susceptibilities to atmospheric corrosion of all the alloys tested increased when the specimens were exposed under stress, but the various alloys differed in the minimum stress required to produce an appreciable effect.

Experimental work on the corrosion of aluminum alloys for use on building exteriors was completed. The results show the importance of proper installation in preventing early failures of aluminum roofing or siding.

Properties of Metals at High and Low Temperatures

Precise measurements of the creep of metals, i. e., their gradual extension under load at elevated temperatures, showed that the extension is nonuniform or cyclic rather than continuous. The nonuniformity is ascribed to periodic "relaxation", or internal readjustments to correct strains developed in the specimen during the test. These internal readjustments frequently result in small but actual decreases in length. The phenomenon was

demonstrated for ingot iron and has been confirmed for copper. Additional studies of the deformation and failure of metals at elevated temperature are in progress.

In a study of the formation and propagation of cracks in ship plate at temperatures slightly below room temperature, an apparent relationship was developed between the carbon and silicon contents of the steel (within specification limits) and the tendency to crack. Certain phases of this work are sponsored by the Ship Structures Committee, representing the Army, Navy, Coast Guard, Maritime Commission, and American Bureau of Shipping.

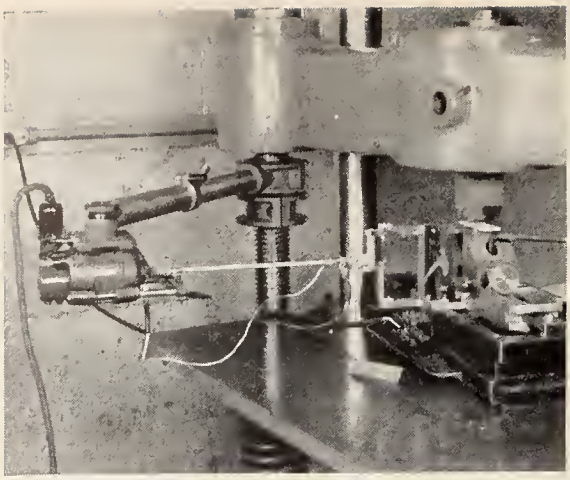
Determinations of curves of true stress versus true strain for ingot iron from room temperature to −196° C showed that the tensile properties in general increase with decreasing temperature within this range, but that ductility decreases irregularly with decreasing temperature. Irregularities in the ductility of this metal are ascribed to precipitation, either by cold working or by strain aging, of carbon previously in solution in the iron because of prior heat treatment. This investigation was made possible by the development of a reduction-in-area gage for use at low temperatures. Work is now in progress on the effect of nitrogen and aluminum on the impact properties of carbon steels at low temperatures.

Fatigue of Metals

The service life of many metals in numerous applications is limited by the susceptibility of the metals to fatigue, i. e., to failure under repeated loading at stresses below the ultimate tensile strength. In attempts to determine why metals fail in fatigue, and how incipient damage can be detected and corrected, it was found that progressive changes in the strained lattice structure, as revealed by X-ray diffraction, reflect hardening by cold working and do not relate to fatigue damage as had been proposed by Slocker in Germany. A new instrument for the measurement of diffraction patterns was developed to expedite this work. In another phase of the investigation, it was shown that prestressing by static or dynamic procedures may improve materially the fatigue characteristics of aluminum alloys.

The fatigue characteristics of steels used in aircraft were found to be appreciably affected when the steels are plated with chromium. Extent of the damage varies with the thickness of the chromium plating and with conditions of deposition; the damage may be partially avoided by baking the specimen at the proper temperatures.

In an investigation of printing plates used by the Bureau of Engraving and Printing, it was found that the fatigue failures originated in the spot welds and metallic solder used to bond the electroformed printing sheet to the supporting metal plate. It was shown, experimentally and in service tests, that bonding the plates with a plastic adhesive, instead of spot welds and solder, materially reduced the fatigue failures of the printing plates.



Left: special apparatus used at the Bureau to measure the flexural strength of laminated plastics for aircraft use (p. 59). Right: plastic specimens are subjected to a 240-hour accelerated weathering test approximately equal to 1 year of outdoor exposure.

10. Mineral Products

Research in the general field of nonmetallic mineral products was concerned with pottery and porcelain, the high-temperature oxides, glass, refractories, enameled metals, building stone, concreting materials, lime, and gypsum. The efficient application of these products in commerce, industry, and national defense requires an understanding of their chemical and physical properties. During the year, the Bureau investigated the chemical constitution and phase-equilibrium relationships of the refractory oxides and the viscosity, density, and other physical properties of the molten optical glasses. Study of the corrosion and the weathering of glass and of building stone was continued. The properties of graphite at elevated temperatures were studied as background information for the proper utilization of materials in atomic energy installations. Work on the growing of thallium bromide-iodide crystals for transmission of infrared light was practically completed. A better understanding was obtained of the chemical reactions that take place in the manufacture, setting, and hardening of portland cement. Important technical improvements were made in ceramic dielectrics for capacitors, high-temperature ceramics for jet and rocket propulsion, large glass elements of high optical quality for special lenses, and protective ceramic coatings for metals and alloys used at high temperatures.

Ceramic Coatings for Metals and Alloys

A project is under way, sponsored by the National Advisory Committee for Aeronautics, for the development of high-temperature coatings to protect metals and alloys used in jet engines against rapid deterioration from the effects of hot gases. During the past year one of the coatings developed

by the Bureau was adopted as an item of regular current production for coating heat exchangers used in large aircraft. This protective coating, coupled with certain design changes, has resulted in a multifold increase in service life of the heat exchangers.

Laboratory experiments showed two sources of deterioration of heat-resisting alloys which can be minimized by ceramic coatings. One such source is attack by the lead bromide fumes present in the exhaust gases from combustion of leaded fuels. Another source of deterioration is carbon penetration, which occurs at high temperatures when the exhaust atmosphere contains carbon monoxide or hydrocarbons. The effect of these several vapors was found to vary among the different high-temperature alloys, but the deterioration was greatly reduced by the presence of the ceramic coatings.

A new type of coating that shows considerable promise has been developed for the high-temperature protection of molybdenum, a metal which has a higher melting point than any other of equal availability but which burns rapidly in air at elevated temperatures when not protected. The new coatings, unlike conventional ceramic coatings, consist of powdered chromium suspended in varying amounts of a vitreous, alkali-free ceramic medium, fired in a hydrogen atmosphere in the temperature range from 2400° to 2700° F. The particles of chromium under these conditions are bonded to each other and to the molybdenum base by diffusion welding, forming a glass-metal network that is firmly anchored to the molybdenum. The imperviousness imparted to the coating by the glassy phase contributes largely to durability. Loaded specimens heated in air at 1,800° F lasted as long as 3,275 hours before failure, under a load that produced 1.2 percent elongation.

Ceramic Dielectrics

The constantly increasing requirements for ceramic dielectrics of high capacitance for use in miniature electronic devices for the Armed Forces has resulted in two types of studies: one concerning materials of low temperature coefficient and high dielectric constant, the other involving special development of dielectric components. As a part of the first study, an investigation of the properties of dielectrics in the system calcium oxide-barium oxide-titanium dioxide was completed. Many of these dielectrics have properties fitting them for use in the field of special electronic instrumentation. A study of the possibility of mixing two ceramic dielectric compounds, one with a negative temperature coefficient and the other with a positive coefficient, has shown that it is possible in this way to obtain a useful dielectric material having a temperature coefficient of practically zero over a fairly wide range.

A technique was developed for the laboratory fabrication of ceramic dielectric wafers, 3 to 6 mils thick and possessing a high degree of flatness. These dielectric shapes are well adapted to the fabrication of miniature

multiple-plate capacitors. Such capacitors are potentially of unusually high capacitance and favorable temperature compensation. Moreover, when silver-coated, they can be die-stamped into capacitor components of exact dimensions and intricate shapes.

Properties of Graphites

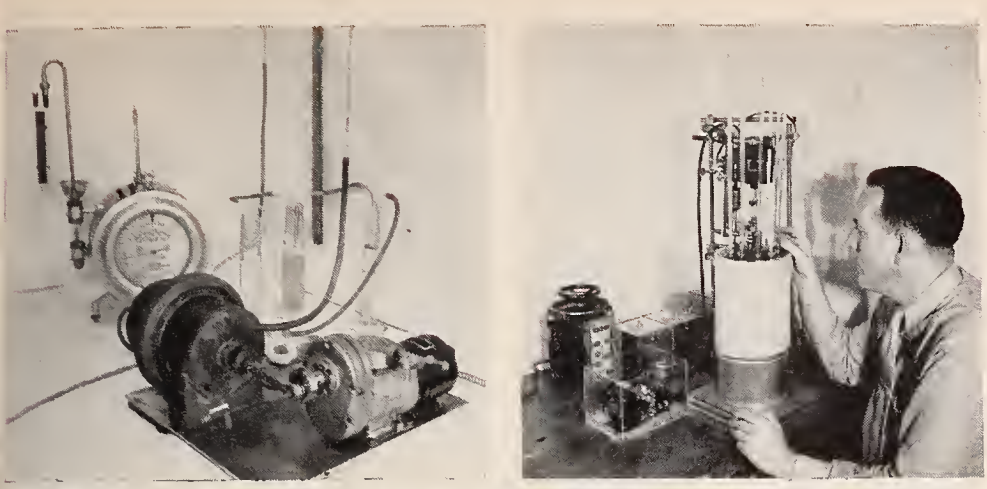
As background information for the the proper utilization of materials in atomic energy installations, the properties of graphite at elevated temperatures are under study. For observations of elongation and ultimate strength, a furnace was developed in which the uncoated graphite is exposed under tension at temperatures ranging from 1,800° to 2,400° F for many hundreds of hours. The extremely low resistance of graphite to oxidation at these temperatures made it necessary to pass a controlled stream of very pure helium through the furnace chamber. With this apparatus, it is believed that length changes as great as 230 microns can be determined with a precision of ± 6 microns. Elongation data and strength values were collected for three grades of graphite in several orientations with respect to the direction of extrusion or the direction of pressure when molded.

Phase-Equilibrium Relationships

The determination of phase-equilibrium relationships over a wide range of temperatures provides important background information for the development and use of a variety of nonmetallic mineral products such as high-temperature oxides for jet and rocket motors, optical glass, steel-making refractories, and portland cement. Studies of this kind during the year were concerned with the systems $BaO\text{-}Al_2O_3\text{-}TiO_2$, $MgO\text{-}BeO\text{-}ZrO_2$, $MgO\text{-}BeO\text{-}ThO_2$, $BeO\text{-}Al_2O_3\text{-}ZrO_2$, $BaO\text{-}B_2O_3\text{-}SiO_2$, $Mn_3O_4\text{-}Fe_3O_4$, $BaO\text{-}Al_2O_3\text{-}H_2O$, and systems of portland cement constituents. In connection with this work, much progress was made in developing instruments and apparatus for attaining high temperature under controlled conditions and for measuring temperatures of phase changes. The thoria-resistor furnace used for very high-temperature work was modified and improved so that useful phase-equilibrium experiments can be carried out at 2,000° C. A centrifuge was developed which permits separation of crystals from liquids at temperatures in the neighborhood of 1,100° C. Improvements in apparatus for differential thermal analysis were introduced, including an arrangement by which the material can be pressed as a pellet on the differential thermocouple junctions.

Crystal Synthesis and Growth

Studies of crystal synthesis and growth continued with emphasis on infrared transmitting crystals, fluorine-substituted artificial minerals, and crystals for X-ray analysis. Work on thallium bromide-iodide crystals for transmission of infrared light was practically completed during the year. Extreme care in purification of the raw materials and use of a principle of



Left: apparatus developed at the Bureau for studies of the water-vapor permeability of leather (p. 61). The ultimate aim of this work is to discover a material for shoes that will be highly permeable to perspiration but not to liquid water. Right: measurement of the thermal expansion of a rubber sample.

crystallization from the top down enabled crystals to be grown which, for clarity and transmissivity in the far infrared, are far superior to specimens hitherto available. Control of the direction of growth of crystals of fluorine-containing mica was achieved by subjecting the growing crystal to vertical as well as lateral temperature gradients. Minute crystals of a fluorine-substituted amphibole asbestos were grown, and experiments are in progress on the crystallization of a fluotourmaline for piezoelectric uses.

An ingenious method was devised for growing crystals of pure cement compounds suitable for X-ray structure analysis. Raw materials from which the desired crystal can be formed are fused into a globule at the junction of a thermocouple by the passage of a high-frequency current through the thermocouple wires. Crystallization is induced by reducing the temperature at the junction. The growing crystal is observed through a microscope, and adjustments can be made in the composition of the liquid by adding the proper raw materials. By the use of filters, the d-c potential produced by the electromotive force at the junction can be separated from the a-c voltage and the temperature thus determined. Well crystallized homogeneous tricalcium aluminate was grown in this way.

Heat of Hydration of Portland Cement

During reactions between cement compounds and water a considerable amount of heat is liberated. In massive concrete structures, such as dams, the low thermal conductivity of the concrete prevents rapid radiation of the heat of hydration, and the mass of concrete may thus attain high temperatures. These temperature rises cause expansion while the concrete is hardening and may result in contractions and cracking when the structure eventually cools.

Determination of hydration heats of the cement used in the construction of the Hoover Dam required the work of two shifts a day, consisting of four

and five men per shift, for a period of several years. Since then a simpler calorimeter has been devised, but the method and the calculations involved are still rather time-consuming.

Recently the Bureau made a statistical study of the reproducibility and bias of repeated heat-of-hydration measurements made by three relatively inexperienced operators on a single sample of portland cement in accordance with the Federal Specification Method. Similar studies were made of the results obtained by the same observers using two simplified methods of calculation. These simplified methods require only three observations of the calorimeter temperature at 20- or 25-minute intervals and reduce to a minimum the attention necessary by the operator during the test, thus making possible the simultaneous operation of two or more calorimeters by a single worker. No significant bias or differences in reproducibility were found among either the three operators or the three methods of calculation.

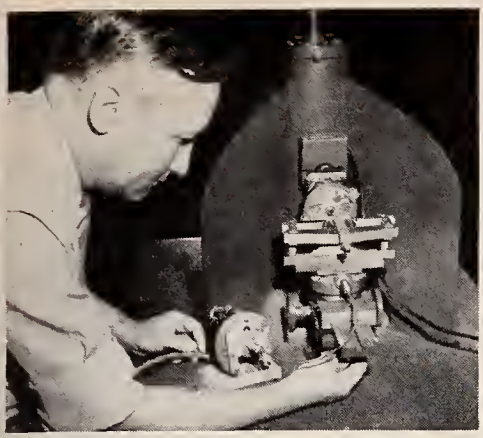
Permeability of Refractories

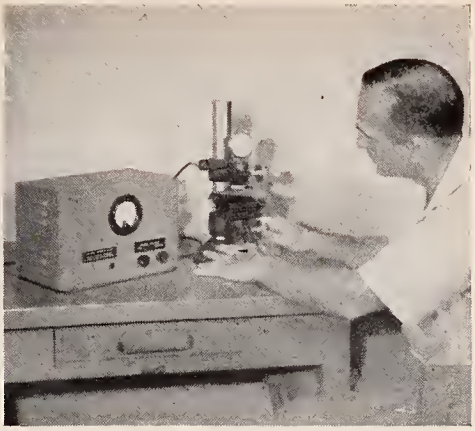
An investigation of the air permeability at room temperature of fireclay and other types of refactory bricks in the flatwise, endwise, and edgewise directions is under way. Permeability, although a difficult property to measure, is useful in indicating uniformity of structure, resistance to slag penetration, and heat losses through furnace walls. It was found that, within the range of pressures used to measure the permeability, the volume of air passing through a specimen was directly proportional to the pressure differential across the specimen. Porosity, dynamic modulus of elasticity, and bulk density of the specimens, although correlating well in some cases with permeability, apparently cannot be considered reliable indicators of this property. In general, within the broad range of temperatures used, the permeability increased directly with the heat treatment the refractory received. Bricks formed by the dry-pressed process were found to be least permeable in the flatwise direction, which is the direction of application of pressure during manufacture.

11. Building Technology

The Bureau continued to conduct laboratory research on technical problems relating to building construction and maintenance, and to assist Government and industry in applying scientific principles and information to building design and standardization. Projects were active in structural engineering, fire protection, heating and air conditioning, and the chemical and physical properties of bituminous materials.

Study of the factors affecting the strength of reinforced concrete beams was continued, with special emphasis on resistance to diagonal tensile and bond stresses. A concrete was developed which is believed to be superior in durability, moisture resistance, and heat insulation value. Fire resist-





Left: special apparatus assembled at the Bureau for the X-ray measurement of strain in metals (p. 63). Right: the Bureau's new ceramic thickness gage measures directly the thickness of nonconducting coatings on nonmagnetic metals without destruction of the coatings.

ance classifications were determined for 12 floor, wall, and column constructions; and 136 panels were tested to evaluate the fire hazard properties of such finishing materials as acoustical tile and paints. Other activities in the field of fire protection included research and development on improved methods for determining self-heating, flash, and ignition temperatures; studies of the spontaneous heating of liquids, films, and plastics; and determination of the fire hazards of such emergency equipment as signal flares and smoke bombs.

In the field of heating and air conditioning, numerous measurements were made of the thermal conductance of materials and of heat transfer through wall, roof, and floor constructions. Heat exchangers for aircraft and base-board heating elements for buildings were investigated. Improved apparatus was developed for measuring the water-vapor permeability of coatings for buildings, and studies were made of the durability of such materials. Further progress was made toward the formulation of a code for safe walkway surfaces.

Structural Properties of Reinforced Concrete

Under the sponsorship of the American Iron and Steel Institute, the Bureau is conducting a long-range program on reinforced concrete. The object of this program is to develop technical information as a basis for specifications for reinforcing bars and to obtain engineering design data for the preparation of codes and specifications for reinforced concrete structures. The initial phase of the investigation was the study of bond strength. As a result of the findings, the first standard for deformations on reinforcing bars was adopted, and major changes in allowable bond stresses were proposed by the Committee on Bond Stress of the American Concrete Institute.

The current phase of the study deals with the resistance of reinforced concrete to diagonal tension. It has long been recognized that this property

is determined not only by the quality of the concrete and the amount of web reinforcement but by the amount of longitudinal reinforcement as well. Research by the Bureau had also indicated the importance of certain geometrical properties of the beam and the support and load systems. The current program is designed to furnish data on the effect of these variable factors in order to determine the shearing resistance of beams reinforced with the improved deformed bars.

Fire Protection

The Bureau conducted research on the fire resistance of building materials and constructions and on the severity of fires in ship staterooms. Constructions subjected to fire tests included eight floor constructions, two walls, two fireproofed steel columns, and one type of corrugated steel sheet with asphalt coatings. One hundred thirty-six horizontal panel tests were made; these included tests to classify three types of acoustical tiles, two types of structural fiber insulation boards with factory-applied fire-retardant finishes, and 12 types of fire-retardant paints.

Grease-Filter Test Methods

A new approach was made to the problem of measuring the efficiency of a filter for removing grease from an air stream. The new method made use of sampling tubes upstream and downstream from the test filter. One of the downstream tubes was maintained at the temperature of the grease-laden air while the other was cooled with ice water. It was found that the removal of grease was partly a filtering process and partly a condensation process since the cold sampling tube caught considerable grease that passed through the warm sampling tube.

Equipment for Accelerated Tests

Materials intended for outdoor use are frequently subjected to regular cycles of exposure to light, heat, and water to accelerate deterioration. While such exposure is generally accepted as a means for determining the relative resistance to weathering of similar materials in a short time, results from different laboratories, or from the same laboratory at different times, do not always show good agreement. The principal causes of this lack of correlation are uncontrolled variables such as temperature, solids content of the water supply, and irregular operation of the system.

During the year, the Bureau put into service a conditioned room for accelerated testing which eliminates most of these variables. Automatic control of all functions assures uniform operation at all times. Air and water temperatures and water purity are kept within narrow limits. While the equipment was designed primarily for testing asphalts and other organic coating materials, it is sufficiently flexible to meet the requirements of most materials subjected to weathering.

12. Applied Mathematics

The mathematics laboratories of the Bureau were established in recognition of the need for a centralized national computational facility equipped with high-speed automatic machinery, capable of providing a computing service for other Government agencies and staffed to undertake further development of electronic computing machinery. In this area the Bureau engages in basic mathematical research and in addition acts as a service organization, particularly in the fields of engineering statistics and quality control, for the Armed Forces, other governmental agencies, and industry.

Numerical Analysis

Many important problems in physics, engineering, astronomy, and other sciences involve directly or indirectly the solution of large systems of simultaneous linear algebraic equations. Examples are found in such fields as stress analysis, least squares, reduction of data, and heat transfer. A concerted attack was made this year on the solution of simultaneous equations and related problems in matrix theory, with a view to selecting optimum methods for various types of computing machinery. Several definitely new procedures were developed. One of these, an iterative method, has proved valuable for use with punched-card machinery in solving certain types of systems of equations.

Progress was made on the general problem of finding the eigenvalues, or characteristic values, of matrices and systems of differential equations. Considerable effort was also expended in seeking methods of solution for the differential equations of physics, which describe the phenomena of motion and change in the physical world. Emphasis was placed on solution by the Monte Carlo method, in which a physical or mathematical system is represented by a statistical sampling operation set up in such a way as to satisfy the same probability laws as the system itself.

Computation

In addition to performing computations requested by Federal agencies, universities, and private industries, the Bureau works continuously to create a stockpile of mathematical tables which can be used to facilitate such computations. At the same time, an effort is made to develop new or improved techniques for numerical computation, particularly those adaptable to automatic computing machines, and to train mathematicians in the application of numerical methods. In this way, the use of mathematical techniques for the solution of technical problems is promoted and extended, bringing increased effectiveness to the national research program.

With the completion of SEAC (the National Bureau of Standards Eastern Automatic Computer, page 80) and the acquisition of several new types of punched-card computers, the Bureau is now provided with the most up-to-date equipment available for carrying out its function as a central-

ized national computational facility. As a result, solutions are rapidly being obtained for problems in science, engineering, and administration which would have required a prohibitive amount of time by desk machine methods.

Twenty mathematical tables were completed or in progress during the year. In general, the tables prepared by the Bureau are of a type essential in the solution of problems in such fields as atomic energy, aerodynamics, radio and radar navigation, and military ordnance. To date, considerable work has been done on the tabulation of the Jacobi elliptic functions, Gamma functions for complex arguments, and spheroidal wave functions.

Of considerable importance to workers in nuclear physics are the tables of Coulomb wave functions which were recently completed. These tables, soon to be published, will tabulate the solutions of an important differential equation which arises in the quantum mechanical treatment of two particles moving in a Coulomb field of force, particularly in problems of proton-proton and proton-neutron interaction.

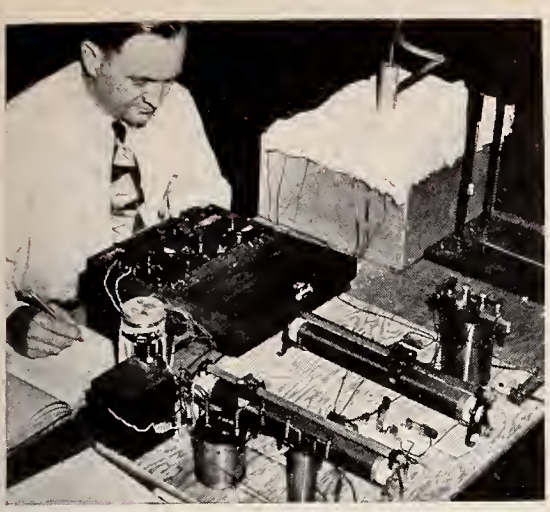
Statistical Engineering

The program in statistical engineering is concerned with the application of modern statistical inference to complex engineering experiments and sampling problems and with the analysis of data arising in physical experiments. Work in this field at the Bureau has shown that statistical principles and techniques are even more useful in physical-science and engineering measurement than they are in agricultural and industrial work, where many of them were first developed. Thus special statistical designs, such as cross-overs, Latin squares, and Youden squares, have been adapted in the road testing of truck tires, in precise determinations of radioactivity, in rating the adherence of enamel, and in measuring the temperature of chemical cells.

A large part of the statistical engineering program takes the form of cooperation with other laboratories on the statistical phases of scientific experimentation and engineering tests. In addition to these consulting services, several other activities are carried on which contribute to the further development of statistical theory and statistical methodology. Manuals on selected phases of statistical methods, glossaries of statistical engineering terms, and guides to statistical literature are prepared; special tables of statistical functions, as well as other aids to the application of modern statistical methods, are compiled and published as the need arises; and basic research is conducted on appropriate topics in the mathematical theory of probability and mathematical statistics.

13. Electronics

In electronics the Bureau carries on research relating to electronic materials and methods as well as pioneering development work on the frontiers



Left: the thermal conductivity of cement is measured in a Bureau laboratory. Right: baseboard heating elements for buildings were studied (p. 69) in the Bureau's test bungalow. Note the thermocouples suspended from the ceiling for measurement of temperatures at various heights.

of applied electronics. New and highly specialized types of electronic circuits and components are developed to meet the particular requirements of industry and national defense. Much of the work is classified and involves the development of new ordnance devices for the National Military Establishment; a large part of the remainder consists of projects in basic and applied electronics conducted primarily for other Government agencies.

During the past year, the work in electronics included investigations of the fundamental behavior of cathodes and gases in electron tubes; development of testing and evaluation procedures for electron tubes; development of special-purpose electron tubes; investigations in circuit miniaturization, embracing printed circuitry as well as the use of subminiature components; design and development of components for electronic digital computing machines; and design and development of electronic instrumentation for remote indication of steam turbine clearances and temperatures, the telemetering of information on the stresses encountered in parachutes, and the measurement of air turbulence in wind tunnels. In addition, several specialized electromechanical devices were under development for other Government agencies.

NBS Electronic Currency Counter

At the request of the Treasury Department, an automatic electronic machine was developed for counting old paper money. This machine, known as the NBS Electronic Currency Counter, counts 30,000 bills an hour.

Rapid counting, combined with accuracy, was the principal objective of the program. The removal of worn bank notes from circulation before new ones are substituted involves the redemption of some 8 tons of currency every day. The bulk of this—about 5 million dollars' worth—consists of

$1 bills. Although new paper money has been machine-counted for many years, the mechanieal handling of worn-out notes has until now been a difficult problem. Old money is limp, wrinkled, and difficult to handle. Single, torn notes are oecasionally taped together. These and similar problems have meant that the condition of returncd notes is variable, and tedious counting by hand has been necessary.

Money returned to the Treasury is in the form of stacks of 100 notes, cut in half lengthwise. The NBS Electronic Currency Counter counts the half-notes in these packets and automatically rejects those with more or less than 100. Packets of stapled half-notes are automatically fed into the machine and clamped to a revolving spindle. The ends of the curreney are released as they come around in turn and are swung outward individually by a jet of air, which breaks a light beam actuating a phototube. The resulting current changes in the phototube eircuit are formed into suitably shaped pulses and applied to an eleetronic eounting mechanism.

Ceramic Thickness Gage

An electronic thickness gage for measuring the thickness of nonconducting coatings on nonmagnetie metals was developed under the sponsorship of the National Advisory Committee for Aeronautics. The new instrument provides a simple, direct, nondestructive measurement. Such measurements have become important with the increasing use of ceramic materials as protective coatings for metals and alloys in high-temperature service. The new electronic gage can be used with nonmagnetic high-temperature alloys on which magnetic thickness gages cannot be used. The instrument consists essentially of a small probe coil, an induetance-indicating system, and a device for positioning the coil and measuring its distance from the test surfaee. The measurement is based upon the change in induetance of the probe coil due to the proximity of the coated metal surface.

Characteristics of Electrocardiographs

A study of the characteristics of electrocardiographs, undertaken at the suggestion of the Veterans' Administration, was cssentially brought to completion. The object of this project has been to determine the adequacy of commereially available eleetrocardiographs for recording the electrical signals dérived from the beating of the heart. The investigation has been directed primarily at the band-width and response requirements of such instruments and has involved a series of laboratory tests supplemented by the clinical evaluation of wide-band electrocardiograms by cardiologists. This work is of direct importance in providing a quantitative basis for speeifications to be used in the Government's procurement of electrocardiographie equipment. It will also aid scientific researeh in eardiography by providing an initial step toward the standardization of electrical characteristics of eardiographic recorders and the recordings which they provide.

Electronic Miniaturization and Printed Circuits

In a program of electronic miniaturization, sponsored by the Bureau of Aeronautics, Department of the Navy, progress was made on several different projects. The project for the development of a subminiature high-gain wide-band intermediate-frequency amplifier of radar type is now concentrated on a single and final model. Construction of the prototype of this model is about two-thirds complete. The outstanding feature of the new design is its simplified construction. Practically all electrical connections are available as test points and for servicing without any disassembly of the unit. Newly developed circuit elements incorporated into the design are much smaller than any equivalent components previously used.

Design and development work is very nearly complete on a miniature self-contained battery-powered radio transceiver for use by the Navy in rescues at sea. At the close of the fiscal year, two models of the transceiver were in process of fabrication.

Progress was also made on a subminiature radio-range receiver for the Bureau of Aeronautics, Department of the Navy. During the year the first model of this device was constructed.

Development of improved techniques for printing electronic circuits continued under Navy sponsorship. Properties of capacitor dielectrics were studied to determine those materials and construction processes capable of high-quality performance and to determine their adaptability to mechanized production. Carbon-composition resistor formulations were studied to improve electrical characteristics under high-temperature conditions. Properties of miscellaneous printed-circuit assemblies involving combinations of ceramics such as steatite and zirconite porcelains with vitreous enamel coatings were investigated. In connection with this program, efforts are being made to utilize printed circuits in the development of a high-temperature mutual-inductance probe for instrumentation in steam turbines.

Electron Tubes

Studies of the effects of impurities in cathode base metals were continued, with special attention to magnesium. This impurity was studied in gross by carefully eliminating all contaminants from the magnesium insofar as possible. The next step was the addition of controlled amounts of magnesium to the cathode base metal. Significant results were obtained regarding the effect of magnesium as an impurity on the activation of cathodes and on the total emission and life of cathodes.

A new technique that proved useful in this work was the application of pulsed voltages to the tubes under study. An investigation was made of the effects of pulse loading on diodes when the number of complicating factors is carefully controlled. In this way, information of significant value to industry for the improvement of vaccum tubes was obtained.

An important new concept was developed regarding the prevailing mechanism responsible for the disappearance of filler gases in electron tubes filled with noble gases such as argon, neon, or helium. This phenomenon—known as "gas clean-up"—at present limits the performance of such tubes.

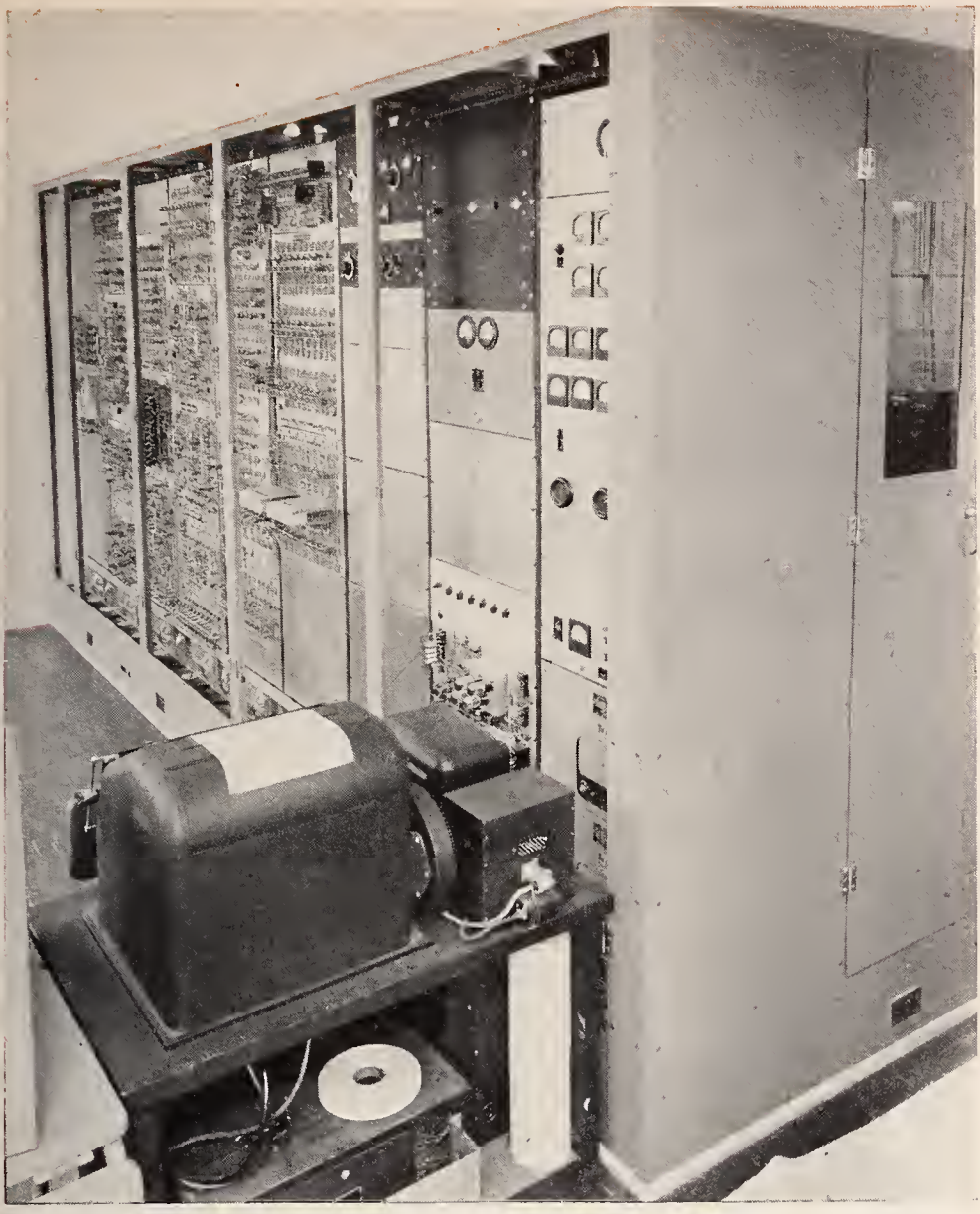
Rugged electron tubes are indispensable wherever electronic equipment is used under severe conditions of vibration, shock, or acceleration. In view of the importance of tubes of this type in civilian as well as military use, considerable emphasis was placed on the program of tube ruggedization initiated the previous year. Efforts were continued to improve and calibrate high-impact shock-testing and vibration equipment for use in studying the mechanical conditions to which tubes may be exposed. In connection with this work, an accelerometer for use at vibration frequencies higher than those obtainable through the use of other instruments was brought to a promising stage of development.

A project for the investigation of noise in microwave tubes has emerged from the preliminary stages of noise-source study and instrumentation, yielding a method which promises to be very valuable in the study of noise output from microwave tubes under conditions of mechanical vibration. Further development of the new method, which clearly indicates the mechanical resonances of internal tube parts, should eventually provide a means for obtaining quantitative information on frequency and amplitude modulation resulting from mechanical shaking. It is expected that standards for permissible internal tube noise will be established during the coming year.

Curve Generator for Electron Tubes

A curve generator was developed which gives an instantaneous visual display of electron tube characteristics. The new instrument plots directly on the screen of a cathode-ray oscilloscope the family of plate-current-versus-plate-voltage curves for any receiving tube. A standard rectangle is displayed along with the characteristic curves to provide a direct scale for voltage and current readings. In cases where the tube characteristics are not known or where an unusual combination of supply voltages is to be used, the curve generator can provide the necessary tube data at a great saving in time and labor.

In addition to producing plate-characteristic curves, the curve generator can provide a visual representation of plate current versus grid voltage. In this case the oscilloscope display is particularly convenient since grid voltage increments are directly defined by calibrated vertical bars appearing on the oscilloscope screen; a standard current reference is given by a horizontal bar. All of the possible displays are produced by the curve generator without overloading the tube under test. Over-all accuracy of voltage and current readings from the oscilloscope screen is within ± 5 percent.



View of SEAC (National Bureau of Standards Eastern Automatic Computer) with operator's control table in the foreground. The teletype is used to transmit numbers and instructions to the machine.

A complete family of curves is retraced 60 times a second; the resulting image is stationary and free from flicker. Characteristic curves may be quickly obtained in permanent form by photographing the screen image with a regular oscillograph camera. This procedure should prove extremely valuable to electronic research and development organizations.

High-Speed Reversal of Electric Motors

A method was developed for reversing a small electric motor in three to four milliseconds. Designed specifically to meet the need for high-speed

reversal of magnetic tapes in the memories of electronic digital computing machines, the technique may prove useful in many other applications.

While it is relatively easy to stop a motor quickly by the use of brakes, rapid starts in either the same or the reverse direction are limited by the low torques which can be obtained by electromagnetic means alone. In the Bureau's rapid-reversal motor, the kinetic energy of the rotor, instead of being dissipated as heat in a brake during deceleration, is converted into potential energy in a spring, which is then used to accelerate the rotor rapidly in the opposite direction.

Rapid Selector for Microfilm Copying

An unexposed-film transport that will keep pace with a high-speed microfilm transport in a transcriber was developed to operate in conjunction with a rapid selector designed for the Office of Technical Services, Department of Commerce. The rapid selector consists essentially of a machine for scanning a master microfilm recording which contains many thousands of entries, each accompanied by a black-and-white dot code. This film is run without interruption at 300 frames per second past the reading head and through a copying camera. Whenever the dot pattern of the code matches the holes of a pre-punched card, a copy of the data frame is made on a piece of unexposed film by a flash gun at an exposure of 2 microseconds. The unexposed film is immediately advanced to a new position to be ready for the next flash. The difficulty with the machine has been that the fresh film could not be advanced fast enough to keep pace with the master film.

In a new copy camera now under construction, the fresh film can be advanced or stopped in approximately a millisecond. This is accomplished by means of clutches and brakes operated by mechanisms similar to those used in dynamic loud speakers. Designs for a completely new machine are also being prepared with a view to considerable simplification of the entire device. Machines of this kind will find wide application in both Government and industry wherever large quantities of data must be searched and copied.

Shaft Seal for the NBS Magnetic Fluid Clutch

In certain applications of the NBS Magnetic Fluid Clutch, the Bureau of Ships, Department of the Navy, experienced an undesirable amount of wear in the clutch shaft. It was found that this wear was due to the heat developed during slippage, which caused evaporation of the lubricant in the magnetic fluid, resulting in oxidation and other chemical changes in the internal parts of the clutch. To prevent oxidation due to "breathing," in which oxygen is alternately drawn into the clutch and given out by the expansion and contraction of the gases within, a hermetic seal seemed indicated. However, the presence of abrasive iron particles in the magnetic

fluid soon destroys ordinary shaft seals. A new type of hermetic seal was therefore developed by the Bureau under sponsorship of the Bureau of Ships. This seal consists of a reservoir of clear oil, mounted adjacent to the clutch proper, so designed that the clear oil is continuously pumped along the shaft into the interior of the clutch. The clear oil is then returned to the reservoir through a magnetic separator which prevents iron particles from flowing with the oil. Clutches sealed in this way have operated at speeds from 120 to 1,440 rpm, and at slips varying from zero to 200 percent, for 30 days with no visible evidence of iron particle leakage.

Loud-Speaker Clutch

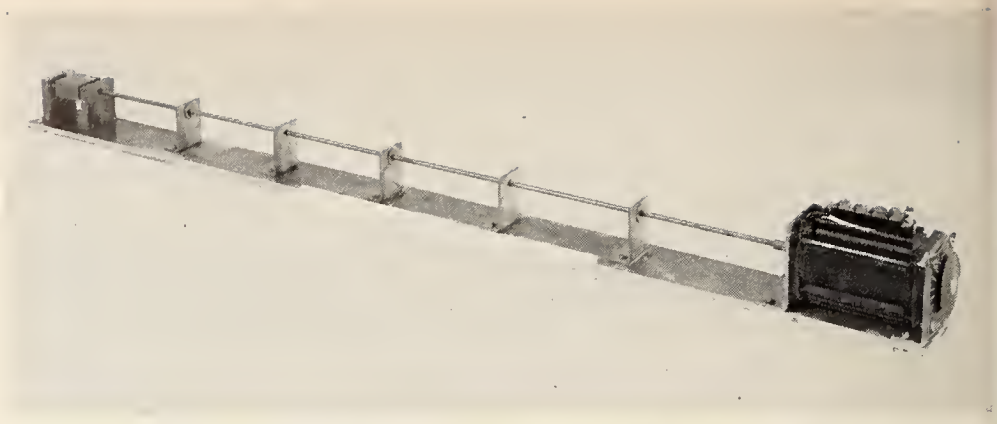
To provide a means for rapid starting and stopping of rotary motion, a novel type of clutch was developed which utilizes the principles of the dynamic loud-speaker. The new device is a friction clutch in which the actuator is a coil moving in a permanently energized magnetic field. The coil form is the input member of the clutch; the output member is a metal disk connected to the output shaft. Because no large magnetic field must be built up or destroyed in operating the clutch, the action can be made very rapid. In the latest model of this device, response times of one-half millisecond have been obtained. This length of time includes both the electrical and mechanical delays.

Wire-Transporting Device

Wire-recording equipment that can be started or stopped very rapidly has been required in connection with the further development of SEAC (the National Bureau of Standards Eastern Automatic Computer). However, one of the problems in designing such equipment has been the inertia in large reels of wire. Recently the Bureau solved this problem by constructing a wire-transport device in which the wire is put off and onto the reel by mechanisms similar to those used in the textile industry. Thus, the reels of wire do not turn, but two rigid arms spin about the reels, guiding the wire on and off. In the first model of this device, the wire moves at 10 feet per second and starts and stops in approximately 15 milliseconds. In a second model, now being designed, the speed of the wire will be increased to 50 feet per second, with a further decrease in starting and stopping time.

Rapid-Action Punch

A high-speed device which punches holes in any combination of 60 spaces on a standard IBM card at the rate of 600 cards per minute was developed for the Bureau of the Census. Such a punch was needed since the punches that have been used operate at speeds far lower than that at which the cards are read on sorting equipment. The new punch is electrically set and mechanically operated; that is, a mechanically oscillated plate moves



Small electric motor, modified by a new method developed at the Bureau which permits quick reversals in three- to four-thousandths of a second (p. 78). During deceleration the kinetic energy of the rotor is converted into potential energy in a torsion bar (left), which is then used to accelerate the rotor rapidly in the opposite direction.

at 600 strokes per minute without actuating the individual punches until electrically-operated interposers set each punch into operation.

14. Automatic Computing Machines

The completion and successful operation of SEAC—the National Bureau of Standards Eastern Automatic Computer—was achieved by scientists of the Bureau's Applied Mathematics Laboratories and its Electronics Division. SEAC is the fastest general-purpose, automatically sequenced electronic computer now in operation. It was developed and constructed, in a period of 20 months, by the staff of the National Bureau of Standards under the sponsorship of the Department of the Air Force to provide a high-speed computing service for Air Force Project SCOOP (Scientific Computation of Optimum Programs), a pioneering effort in the application of scientific principles to the large-scale problems of military management and administration. SEAC will also be available for solving other important problems of general scientific and engineering interest.

SEAC automatically performs all of the logical and arithmetical operations required to solve a particular problem when it is supplied with coded instructions and numerical data. Its high speed permits the use of many simple steps that can be combined into a complex and powerful sequence for the solution of difficult problems. This makes it possible to solve important mathematical, computational, and statistical problems which would otherwise be impossible of solution in any reasonable period of time, or which would be prohibitive in cost if attempted by conventional methods.

SEAC's high computing speed is largely the result of two design features: its rapid pulse rate (1 megacycle per second) and its large memory (512 words) capacity. They make it possible for SEAC to add or subtract pairs of 11-digit numbers 1,100 times a second and multiply or divide them 330

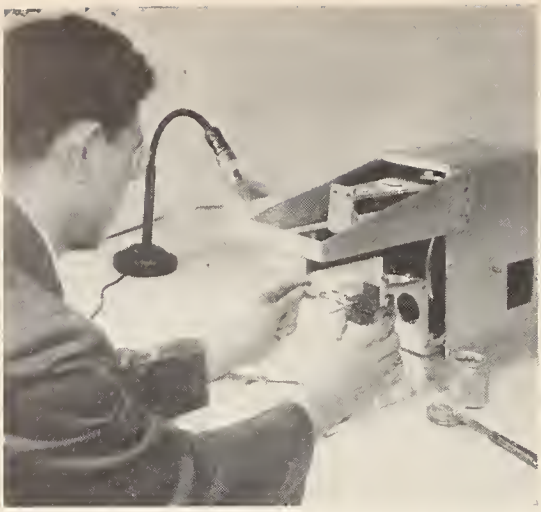
times a second. These rates include the time it takes for the machine to search its memory for the numbers, operate upon them, and return the result to the memory. An arithmetical operation of addition or subtraction alone is completed in 50 microseconds; multiplication or division is completed in 2,500 microseconds.

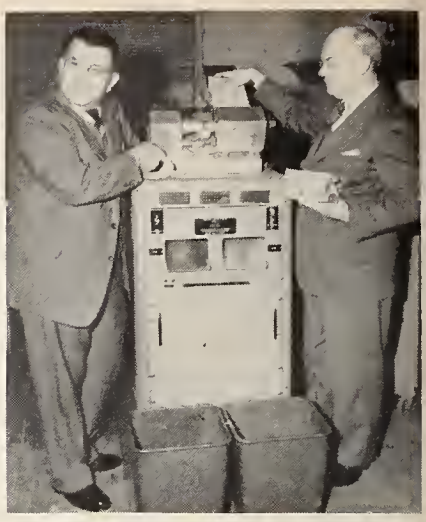
SEAC has already solved an important problem in optics in the design of lenses and one in thermodynamics; and several mathematical problems of general interest to pure mathematicians were solved earlier for the purpose of testing the machine. In one of these the machine was directed to compute the factors of any given number up to 100 billion. It rapidly determined, for example, that the number 99,999,999,977 has no factors and is therefore a prime number. In order to do this, the machine divided 99,999,999,977 by 80,000 different trial divisors. SEAC generated each of these trial divisors, automatically establishing that each was a prime number. This problem, which would be two months' work for a man operating a desk calculator 8 hours a day, required 30 minutes for its solution.

In the development of SEAC, emphasis was placed on designing circuits especially for computer use rather than adopting the standard procedures of television and radar circuitry. All computing and switching in SEAC is performed by germanium crystal diodes rather than by electron tubes; tubes are used only for power amplification. Standardized tube-and-transformer combinations are used throughout the machine to simplify maintenance. The transformer method provides high-frequency coupling with a minimum of cross-talk between circuits. These advances in circuit design as well as several unique construction features make it easy to add units to the machine, and the present version of SEAC could serve as the nucleus of a much larger computer.

At the close of the fiscal year, a second high-speed, general-purpose electronic computer, sponsored by the Office of Air Research of the Air Force, was nearing completion at the Bureau's Institute for Numerical Analysis in Los Angeles. This machine will be known as SWAC—the National Bureau of Standards Western Automatic Computer.

The NBS computer program includes the research, design, and development work necessary to produce faster, simpler, and more versatile computers and to make more effective use of the machines already in existence. In addition to the construction of machines for its own use, the Bureau is acting as the technical coordinating agency for contracts placed with industry by other Government agencies for five other large-scale computers: One for the Bureau of the Census to tabulate and compute statistical information, one for the Air Force Comptroller for further work on program planning problems, one for the Army Map Service for calculations arising in map adjustment, one for the Office of Air Research to handle engineering computations, and one to be operated by the NBS Computation Laboratory for the Office of Naval Research.





Left: work on printed electronic circuits (p. 75) emphasized the development of improved techniques. The press shown was recently designed for automatic printing on cylinders. Right: the NBS Electronic Currency Counter (p. 73) automatically counts 30,000 notes per hour.

15. Radio Propagation

The radio propagation laboratory of the Bureau is the primary agency of the United States Government for research in radio wave propagation and for the coordination and centralization of information in this field. The laboratory is also assigned responsibility for development and maintenance of the national primary standards for electric quantities at frequencies above 10 kilocycles per second.

Comprehensive programs of basic and applied research are undertaken in radio physics and associated geophysical phcnomena of the upper atmosphere and the troposphere. Extensive laboratory studies are also under way dealing with properties of matter at radio and microwave frequencies and the development of techniques for precise measurement of electric quantities in this region. In addition to such research activities, the Bureau does a large amount of advisory and consulting work on radio for other agencies of the Government such as the National Military Establishment, the State Department, and the Federal Communications Commission, and participates in an advisory capacity in international radio conferences.

The work in radio propagation is divided into three branches: The Ionospheric Research Laboratory, the Systems Research Laboratory, and the Measurement Standards Laboratory. The Ionospheric Research Laboratory conducts basic research on the nature of the upper atmosphere and its ability to reflect radio waves. The Bureau maintains a widely separated network of 14 ionospheric sounding stations extending over the American continents and the Pacific area, the largest network operated by any one government. Seven of these stations are controlled directly; the other seven are operated in close coopcration with other agencies. Data supplied by these observatories provide basic material for scientific research and for

determining frequencies to be used in long-distance radio communication. In addition, a radio propagation field station is operated at Sterling, Va., for performance of special experiments. Because of the important influence of extraterrestrial effects on ionospheric phenomena, solar and cosmic phenomena are studied. These include radio waves emitted by the sun and other celestial bodies, which also afford a new means for exploration of the universe.

The Systems Research Laboratory applies radio propagation information to the practical problems involved in such uses of radio as communication, navigation, and traffic control, with particular consideration to the advantages and limitations of the types of radio systems concerned. It prepares and publishes a monthly series of charts predicting, three months in advance, the best frequencies for long-distance communication throughout the world. These charts are based on data collected by the network of field stations and by agencies of other national governments. It also conducts research in propagation at frequencies in the VHF and UHF bands which are not reflected by the ionosphere. During the year this laboratory began an extensive program of research on the propagation factors affecting the use of radio for aircraft navigational and traffic control, and an experimental field station for making these studies was set up at Cheyenne Mountain, Colo.

The Measurement Standards Laboratory conducts research in methods for measuring electric quantities at radio and microwave frequencies. Advances of the last few years have carried this work to higher and higher frequencies, across the border where classical electromagnetic theory and quantum theory overlap, and have opened up a new field of basic research in physical science. An important function of this laboratory is the maintenance of standards of electric quantities at all radio frequencies, including time and frequency standards which are broadcast continuously from the Bureau's radio station, WWV, at Beltsville, Md., and from an experimental station, WWVH, at Maui, T. H.

Reflection of Low-Frequency Radio Waves by the Ionosphere

Advances were made in the theoretical study of the reflection of radio waves at very low frequencies by the ionosphere. The ray-type treatment, which has been used in previous investigations almost exclusively, was replaced by wave theory. The results thus obtained account for many of the effects observed experimentally. It was shown theoretically that, because of the high collision frequency in the lower part of the ionosphere, vastly different wavelengths are reflected from almost identical heights. It was also shown that when a radio wave of a given frequency progresses into the ionized region, reflections should be obtained at twice the frequency of the wave, or if radio waves of two different frequencies traverse the same region under certain conditions, radio reflections should be observed at frequencies equal to the sum and the difference of the frequencies of the

two primary waves. It is planned to extend this theoretical investigation to include low-frequency radio waves propagated at oblique incidence on the ionosphere, a matter of great concern for radio communication, particularly in Arctic regions, during times of radio disturbance, when communication of higher frequencies is ordinarily blacked out.

Effect of the Moon on the Ionosphere

Continued study of the effect of the moon on the F2 layer, or outermost region, of the ionosphere has revealed that at certain phases of the moon and at certain hours of the day this layer divides into two, the upper part of the layer rising to heights several hundred kilometers above normal. At opposite phases of the moon, the reverse action takes place, the upper part of the layer being pushed down to much lower heights. These results, which were obtained by direct study of photographic recordings made at Huancayo, Peru, explain the mechanism whereby lunar effects on the ionosphere are produced. They point to the existence of strong tidal actions in the ionosphere far greater than had previously been anticipated. The effects of this lunar variation on radio propagation are pronounced. At certain times of the day, the frequency which the ionosphere over Huancayo is capable of propagating over a distance of 4,000 kilometers changes from 37 to 25 megacycles, entirely as a result of the lunar action.

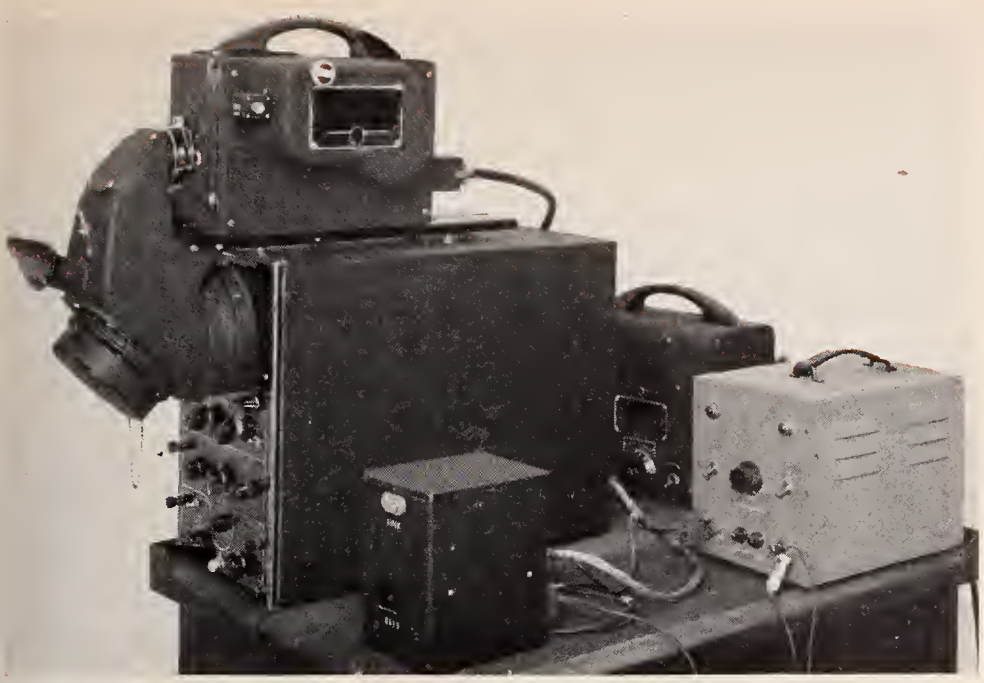
Ionospheric Winds

By observing the simultaneous fading of radio waves on several receivers connected to antennas spaced about 200 meters apart, winds were found to exist in the outer part of the atmosphere, where radio waves are reflected. These winds have velocities of the order of 100 to 200 kilometers per hour. During the day their directions over Washington, D. C., appear to shift so as to flow always toward the point on the earth at which the sun's rays fall most vertically. The interpretation of the results not only sheds considerable light on phenomena of the upper atmosphere but also indicates how radio receiver fading may be reduced by changing antennas.

Radio Astronomy

Cosmic and solar radio waves reaching the earth from outer space are manifested audibly as frying and hissing noises in a receiver at the higher frequencies. These forms of radio noise limit the range and minimum useable signal levels for frequency-modulation broadcasting, television, and communication and radio navigation services in the very-high-frequency range.

During the year regular recordings of steady background and sudden outbursts of radio noise from the sun were continued, and special detailed studies were made of small bursts of solar noise. The analysis of these observations yields information as to the breadth of the spectrum of the



Special wide-band electrocardiographic recorder used by the Bureau in a study of commercial electrocardiographs for diagnosis of heart disease (p. 74).

outburst of solar energy and the basic nature of the processes taking place in the sun.

Radar Observations of Meteors

Use of radar techniques to receive the reflections from the ionized trails left by meteors in the earth's upper atmosphere makes it possible to observe meteors during daylight hours as well as at night. These observations, pioneered by the Bureau as early as 1940, have yielded considerable data on diurnal and seasonal variations in the rate of arrival of meteors at the earth. The diurnal rate has been found to reach a maximum near sunrise and a minimum near sunset. The rate at midnight is generally about the same as at noon. Seasonal minimums occur at the vernal and autumnal equinoxes.

The observations show that the intensity of the radio reflections from a meteor trail pulsates rapidly. Such an effect would result if the ions produced in the meteor trail spread over an extended volume at a rate five to ten times faster than the normal diffusion speed. This rapid expansion could be caused by a shock wave traveling outward from the core of the trail as a result of volatilization of the meteor from impact with the molecules of the atmosphere. Thus, from this meteor research considerable information may be deduced regarding processes of recombination and diffusion of ions in the atmosphere. The work affords a basis for studying the behavior of hypersonic particles passing through an atmosphere, a field of research where experiment has lagged because of the difficulty of producing particles with velocities comparable to those of the meteors.

Propagation Research

The proper allocation of radio-frequency channels to very-high-frequency communication and broadcasting services requires a knowledge of the nature of radio wave propagation in the bands allocated to such services. During the past year, extensive research was done on this problem. Studies of the effects on propagation of irregularities in the terrain and of variations in the lower atmosphere were made. These effects were translated into the service areas to be expected for radio and television stations allocated in various ways. During the course of the investigation, a better understanding of the effects of irregularities in terrain on wave propagation was achieved; an understanding of the effects of correlation of the statistical variations of several television signals received at the same location was obtained; and a sample study of the effects of irregular distributions of population on efficient methods of television station allocations was made.

The experimental study of radio propagation at low frequencies was continued using pulse techniques. A pulse transmitter capable of developing peak-pulse output power in excess of 1 million watts was completed and put into experimental operation together with associated antennas and receiving equipment. In this way pulse observations of the ionosphere were extended down to 37 kilocycles. From the data obtained thus far, there is strong evidence that radio transmission at low frequencies is not insensitive to ionospheric disturbances, as had been believed. The effects of these disturbances on low-frequency transmission are being investigated further.

A broad program of propagation research in the frequency range from 1,000 to 1,600 megacycles was undertaken for the Air Navigation Development Board. Initial experimental efforts will be devoted to field-intensity measurements for simulated air-to-ground paths, with emphasis on the region near and below the horizon, where interference effects become important. The transmitting site chosen for this experiment is Cheyenne Mountain, Colorado, at an elevation of 9,000 feet above sea level, overlooking a plain at 5,000 feet which gradually slopes to 4,000 feet. A wide variety of terrain conditions is available for different radial directions from the mountain transmitter site.

Attenuation of Microwaves by Rainfall

Microwave radio signals decrease in intensity as they travel through the earth's atmosphere because absorption and scattering by oxygen, water vapor, or precipitation. The attenuation increases sharply for microwave frequencies above 10,000 megacycles, and quantitative information on this effect is important in the selection and allocation of microwave radio frequencies. While the severest attenuation is caused by rainfall, such attenuation cannot be immediately calculated from rainfall rates at a single point because rainfall intensities are not usually uniform in the horizontal

plane. Previously there has been no definite basis for using point rainfall data to calculate attenuation for extended lengths of path. Recently the Bureau developed an approximate relation of point data to instantaneous long-path data, and annual probability curves for the expected duration and magnetitude of atmospheric attenuation at microwave frequencies for both one-kilometer and 50-kilometer path lengths have now been prepared. These attenuation statistics were derived from meteorological records, using accepted theoretical and experimental coefficients for converting rainfall values into radio attenuation values.

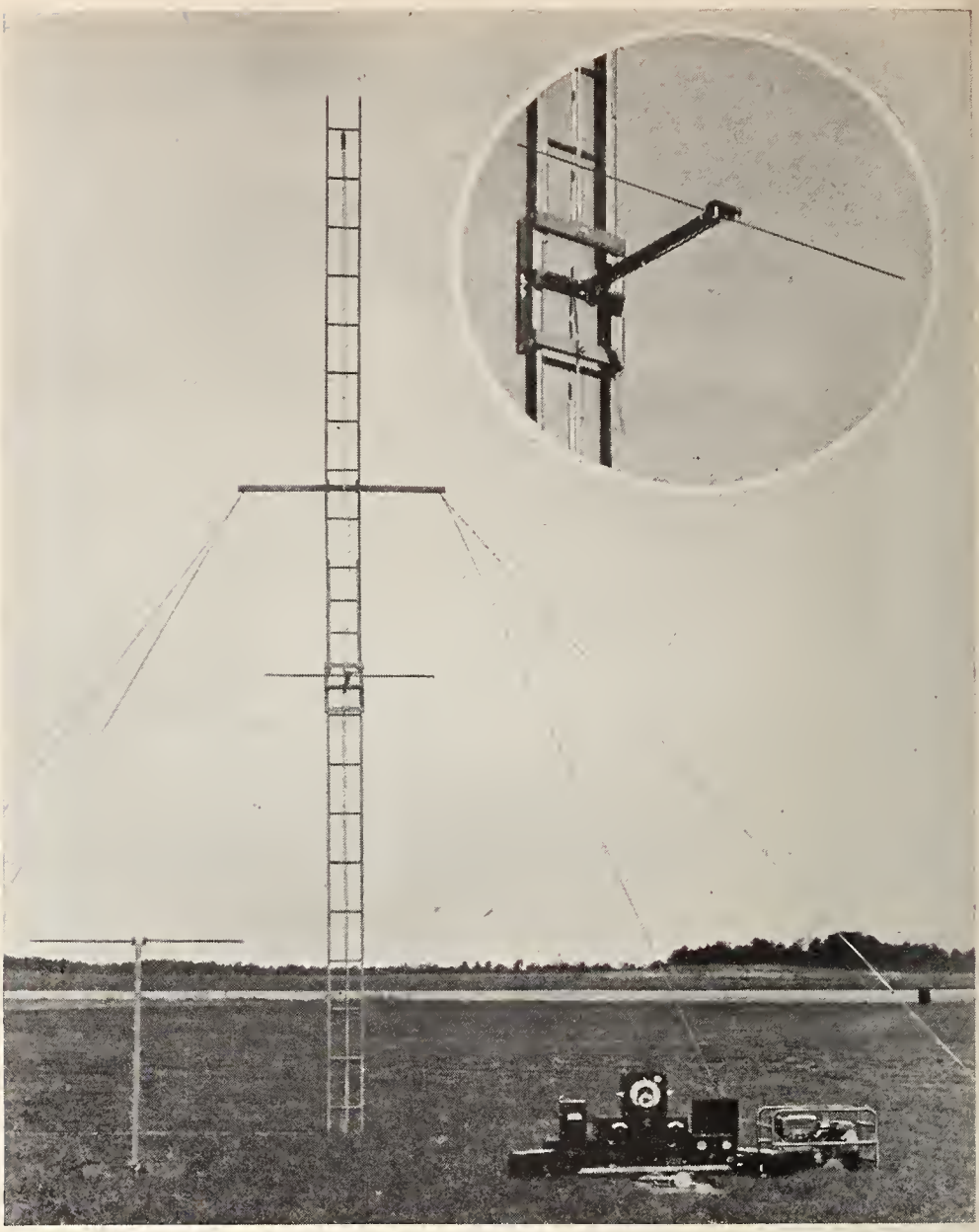
Atmospheric Radio Noise

In the absence of interference from other stations, the minimum field strength useful for radio reception at frequencies below 30 megacycles is determined principally by atmospheric radio noise, which originates in lightning discharges. Thus, to evaluate properly the field strength required for a given radio service, an accurate knowledge of existing atmospheric noise levels is desirable. The Bureau therefore initiated a program to develop suitable atmospheric noise recorders, and two experimental recorders were developed and installed at the Sterling Field Station, Va. Continuous recordings are now being made of the "average atmospheric noise" field intensity in a 1-kilocycle band-width centered on 539 and 2,180 kilocycles. Concurrently with the development of suitable atmospheric radio noise recorders, an analysis of noise data obtained by other agencies operating recorders distributed throughout the world was in progress.

Field-Intensity Recording Equipment

Instruments available for continuous measurement of radio field intensity have proved inadequate in several respects, particularly in regard to stability to gain with aging of tubes and changes in temperature, humidity, and supply voltage. The Bureau has therefore conducted a program for the development of field-intensity recording equipment that would be as free of these shortcomings as possible. The ultimate goal has been the development of a field-intensity measuring instrument that is fundamentally a stable, logarithmic, radio-frequency voltmeter or wattmeter, sufficiently rugged for use either in the laboratory or in the field.

In connection with this program, a totalizing voltage recorder was developed for use in analyzing radio field-intensity measurements. At present the most common field-intensity record consists of a plot of signal strength versus time. Much tedious work is required to obtain the necessary statistical information from such a record. The totalizing recorder, on the other hand, gives this information directly, without intermediate recording. The device consists of 10 channels, which are actuated by the direct-current output of the receiver. Each channel can be preset to record the time in



Apparatus with movable receiving antenna (left center and insert) used in the Bureau's program for the standardization of radio field-intensity measurements.

minutes that the signal strength has exceeded a different desired level. The resulting statistical distribution is recorded by photographing the counter associated with each channel.

High-Frequency Standards

A thermoelectric radio-frequency microvolt standardizing device, known as a micropotentiometer, was developed to provide simple, accurate voltage standards requiring no frequency correction at frequencies up to 300 megacycles and higher. It is expected that this development, which consists essentially of a thermoelement and thin metal disk, both well shielded,

will in part meet the great need for practical voltage standards in the r-f microvolt range.

A vertical one-meter air-dielectric impedance-measuring line of high precision was obtained. Methods of improving standard piston-attenuators were verified theoretically and experimentally. Construction of two improved attenuation standards was initiated. Intensive study and experimental work was under way to provide highly stable wide-range voltage-amplitude indicating devices for use in maintaining and improving standards of power, voltage, impedance, and attenuation.

The guarded-electrode method for determining dielectric constants was extended to 1 megacycle. The precision of dielectric-constant measurements was increased to 0.02 percent for frequencies up to several megacycles; accuracy was 0.1 percent. At frequencies above 100 megacycles a precision of about 0.1 percent was obtained. Two new r-f bridges were put in use, extending considerably the frequency range for dielectric measurements.

The noise properties of two-terminal and four-terminal networks were investigated experimentally and theoretically. A precise noise-figure measuring service was made available for frequencies up to 40 megacycles, and a method of determining impedance using a noise generator and noise-figure technique was formulated.

Microwave Power Standards

The problem of developing suitable microwave power standards is a difficult one, but it is fundamental to the entire microwave field. The effective range of search radar, blind-landing systems, and microwave relay systems is dependent upon their output power and detection sensitivity. Power measuring equipment is necessary to determine this range. As no really good power standards have been available, there has been a lack of agreement among different groups making power measurements in the microwave region.

During the year a microwave calorimeter was developed as an independent method for the accurate determination of power in the 1-milliwatt range. In this device radio-frequency energy is absorbed in two reflectionless loads of polyiron that are identical in every respect but are thermally isolated. Results obtained with the calorimeter were in agreement with power measurements by a bolometer method within a few tenths of one percent.

Dielectric Measurements

Since water vapor is a primary constituent of the atmosphere, knowledge of its dielectric properties is useful in the study of radio propagation. The dielectric constant of water vapor was measured at a wavelength of 3.2 centimeters over the temperature range 28° to 102° C. As was expected on theoretical grounds, no measurable dispersion (change in dielectric con-

stant) was found in the region of 9,000 megacycles, although an earlier investigation in England had shown a difference at this frequency from the low-frequency value. A dielectrometer was obtained for the accurate measurement of the dielectric properties of solids, and a method was developed for measuring the dielectric properties of very small samples of liquids and solids. By these techniques, the dielectric properties of a number of substances, including different types of plastics, wood, many kinds of liquids, and special insulating materials, were measured in the microwave region, some for the first time.

Microwave Spectroscopy

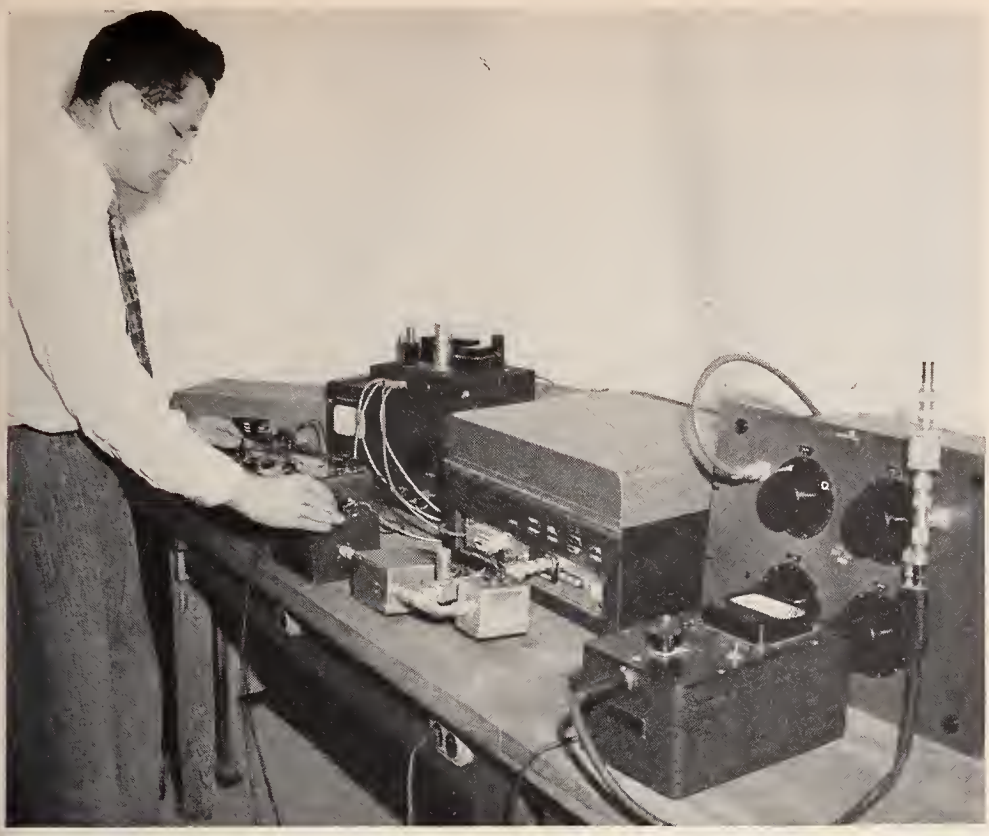
An improved precision-type of Stark-modulation spectrograph incorporating new features is being built. It will be used for the precise measurement of microwave spectrum lines as secondary standards in connection with a program for the compilation and publication of all known lines by the Bureau in cooperation with Columbia University. In addition, further refinement of the spectrograph is being attempted in order to provide a method for measuring the rotation of the earth against a spectrum line. Such a measurement will provide a new tool for geophysicists.

Further Development of Atomic Clocks

Since the first atomic clock, based on the constant natural frequency associated with the vibration of atoms in the ammonia molecule, was announced by the Bureau, improvements have been made in circuit designs and in the ammonia absorption cell. It is expected that accuracy of control will be improved from about 1 part in 10 million to 1 part in 100 million. This will provide a considerably more constant method for measuring time than astronomical methods which use the rotation of the earth. Since the "Q", or line sharpness, of oxygen at 60,000 megacycles is very much greater than that of ammonia at 24,000 megacycles, its use in the absorption cell of an atomic clock shows much promise for obtaining greater accuracy.

The Bureau now has three new types of atomic clocks, or frequency standards, under development, and a fourth type is being planned. One of the new clocks will make use of atomic oscillators, by means of which the frequency of a transmitter, laboratory oscillator, signal generator, or frequency divider can be controlled with microwave spectrum lines to high precision.

Another clock under development is similar to the first atomic clock but uses a beam of cesium atoms instead of ammonia gas. Much of the equipment for the development of this clock was designed and constructed during the year. With atomic-beam techniques, very much sharper spectrum lines are obtained since the broadening of the line due to collisions and the Doppler effect is eliminated. This method is expected to provide an accuracy of 1 second in 300 years—about 300 times that obtained with the ammonia absorption cell.



Noise-figure calibration of a radio receiver (p. 89). The noise figure, a fundamental measure of the quality of linear electrical networks, is of basic importance in communication and radar.

The aim of the Bureau's program in this field is a new atomic standard of time and frequency to replace the mean solar day. Such a standard may make it possible to change all of the present arbitrary units for physical quantities to atomic units. In fact, it should be possible to base both length and time standards on one spectrum line by multiplying the frequency of an atomic clock up into the millimeter bands and making use of an "atomic ruler," that is, an interferometer driven by the multiplied frequency from the clock. This would automatically give a new precise value for the velocity of light. More precise measurement of the mean sidereal year also seems to offer a means of comparing Newtonian and atomic time to an accuracy of at least one part in a billion. This would yield important results for relativity theory and cosmology.

Ultra-High-Frequency Instrumentation

Several precision instruments were designed for making accurate standing-wave ratio and impedance measurements in the UHF range of 300 to 3,000 megacycles. These devices are necessary for impedance determinations involved in developing and measuring the performance of antennas for television, guided missiles, and radar. The new instruments were made with the highest mechanical precision, and several unique

machining methods were developed for their fabrication to assure uniformity in coaxial cross sections. Theoretical and experimental analyses were made to determine the expected accuracy of such equipment.

Electroforming of Microwave Components

An electroforming technique was developed which assures consistently good results in the fabrication of microwave components. This process, in which a thick layer of pure metal is electrodeposited over a precision-built mandrel, takes on increased importance in the upper microwave region, where physical dimensions decrease and the need for mechanical accuracy increases in inverse ratio. In many cases where intricate geometrical shapes are involved, electroforming is the only possible method of fabrication. Mandrels for the electroforming process are machined to the highest accuracies and, if necessary, are ground and lapped to optical tolerances. Both expendable and permanent types are used. The expendable mandrels, made of duralumin, are dissolved away by a solution such as caustic soda while the permanent mandrels, made of invar steel, are removed by heating.

16. Testing, Calibration, and Standard Samples

The Bureau's testing and calibration activities are an outgrowth of its custody of the Nation's basic physical standards. In many cases master standards used in industry or by other laboratories must be checked periodically against these national standards. The Bureau is also responsible for testing many of the materials purchased by the Government to assure conformance with specifications. In the course of this work, many new instruments, new methods of measurement, and much technical data on the properties of materials are developed.

During the year, over 250,000 tests and calibrations were performed for other Government agencies and the public. In addition, about 19,000 standard samples were prepared and distributed. Services of this kind included the sample-testing of about 9,000,000 barrels of cement, the assaying of about 2,300 raw sugar samples to aid the Customs Service in determining import duties, the testing of nearly 500 samples of soaps and detergents for other Government agencies, the life-testing of more than 5,000 light bulbs (a sampling of over 4,000,000 purchased by the Government this year), the testing of 2,500 samples of microfilm for hypo content, and the sample-testing of about 74,000 clinical thermometers.

For many years, all radium preparations sold in the United States have been tested and certified by the Bureau as no commercial laboratory is equipped to do this work. During the year over 2,000 tests of such materials—principally medical preparations for hospitals and clinics—were made for the Government and private concerns. Nearly 1,100 radioactive standards were distributed, reflecting the constantly increasing demand throughout the country for this service by the Bureau. These included radium

gamma-ray standards, radium D+E standards, radioactive iodine, radioactive phosphorus, radioactive carbon, radioactive cobalt, radon standards, and rock samples.

To protect the health and safety of workers in occupations involving the handling or processing of radium, the Bureau maintains careful check, throughout the United States, over the quantity of radium ingested by such workers and over the quantity of radon present in their working areas. The breath of these workers or the air in the work room is sampled periodically and is measured for its content of radon, the gas produced by radioactive disintegration of radium. This analysis reveals the amount of radioactivity present and provides the basis for the establishment and maintenance of proper safety measures. During the year 898 radon determinations were made for Government agencies and commercial firms.

The radon testing program was inaugurated in 1941, when the Surgeon General's Office, Department of the Army, requested the Bureau to establish a program designed to prevent injury or death to personnel working with radium. Using highly specialized electronic equipment and ionization chambers that are continuously monitored by the national standards of radioactivity, the Bureau has developed a method for measuring radon of very low concentration to a high degree of precision. As a result of the cooperative efforts of the Bureau and the officials and hygienists responsible for the protection of workers from unsealed radium, deaths and injury from radium poisoning, such as occurred in the years following the first World War, are now being prevented.

Standard Samples are materials that are certified for chemical composition or for some physical or chemical property, such as heat of combustion, melting point, or index of refraction. Standard samples of steels control the quality of the steel industry's output. Primary chemical standards and metals with certified melting points make possible uniform measurements of heat and temperature in the same way that standard weights provide uniformity of measure in buying and selling. Standard pigments define the colors of paints, and a large variety of hydrocarbons, supplied as single substances of high purity, calibrate the instruments that control the composition of motor gasolines, aviation fuels, and synthetic rubber. The list of standard samples issued by the Bureau now includes about 500 materials.

Electricity and Optics

Standard apparatus was tested for manufacturers, electric power companies, State public utility commissions, university laboratories, and private testing laboratories, as well as for many agencies of the Federal Government. In the electrical field this work involved over 14,000 separate exact determinations, and in the optical field nearly 20,000. In addition, more than 5,000 light bulbs (a sampling of over 4,000,000 purchased by the Government this year) were life-tested. Another service was the testing of over

2,500 samples of microfilm for hypo content to make sure that the records would be permanent when stored in the archives.

Metrology

A major responsibility of the Bureau is the maintenance of the Nation's basic standards of physical measurement. This involves the testing and calibration of standard measuring apparatus and reference standards for precise measurement of length, area, angle, mass, volume, density, and similar quantities throughout the United States. During the year, 63,366 measurement standards were calibrated, certified, and sent out for service in laboratories, manufacturing plants, and commercial establishments.

Heat and Power

During the fiscal year, 214,521 separate determinations were made. A total of 3,078 liquid-in-glass laboratory thermometers, 132 resistance thermometers, and 289 thermocouples were calibrated; 11,819 clinical thermometers were tested for the Veterans' Administration, the U. S. Public Health Service, and the U. S. Department of Agriculture. Tests and calibrations were made of special types of thermometers and thermometric devices. The investigation for the Air Matériel Command of experimental thermometers and temperature control equipment for use in jet engines was continued and expanded.

Twenty-seven viscometers were calibrated, and 560 standard samples of oils were supplied to other laboratories for use in the calibration of viscometers. Seventy-three fuels and lubricants, 100 miscellaneous materials, and 53 oil filters were tested for compliance with Federal specifications. Automobile gasoline economizers, fuel additives, antileak preparations, and other automotive devices and materials were tested for the Federal Trade Commission and the Post Office Department for detection of dishonest and fraudulent advertising. Simulated service tests of various automotive antifreezes were made for the Federal Supply Service and for the Federal Trade Commission. Other automotive products tested for Government agencies included 5 pursuit cars, 18 motor truck speed governors, and 615 automotive spark plugs. A device for timing the speed of racing cars was tested for the American Automobile Association. Twenty-five nonroutine tests on aircraft electrical network equipment and tests and calibrations of flowmeters, spray nozzles, and aircraft carburetors were conducted for the Bureau of Aeronautics, Department of the Navy.

Atomic and Radiation Physics

Three hundred sixty-nine chemical and isotope analyses were carried out. A total of 2,140 tests on radium and radium compounds and 898 measurements of radon in the breath of workers or in the workroom air were made. In addition, 1,076 radioactive standards were distributed. Several neutron sources were calibrated for other laboratories in terms of the Bureau's pri-

mary neutron standard; requests for this service are steadily increasing in number.

All types of X-ray equipment and accessories used in general hospitals are now being studied in detail for various government agencies, especially the Veterans' Administration, to determine their suitability for use in the agencies' facilities. These studies include the electrical characteristics of transformers, control units, generating equipment and tubes, as well as their cooling and radiation output, the functioning of mechanical parts, and compliance with purchase specifications. Much of the testing program is devoted to the development of special tests and equipment for a better evaluation of the X-ray equipment submitted.

Chemistry

A total of 3,776 samples were received for spectrographic analysis; this was more than double the number received the previous year. Reports were made to other Government agencies on 843 samples of paint and related materials, nearly 500 samples of soaps and detergents, nearly 800 samples of metals and alloys, and about 500 samples of carbon paper, inks, and related materials. To aid the Customs Service in determining import duties, 2,275 raw sugar samples were assayed. Umpire analytical work on classified materials for the Atomic Energy Commission was continued. In addition to the testing of commodities there was, as usual, a considerable volume of investigative testing such as becomes necessary in connection with research projects. Devices submitted for calibration included 213 Magnegages, 13 saccharimeters, and 83 standard quartz plates for saccharimeters.

Approximately 19,000 standard samples, having a total fee value of about $100,000, were issued during the year. Six new standards for spectrographic analysis were issued. In the group of standards certified for conventional analytical procedures, six renewals were prepared for materials that had been exhausted, and three new samples were added to the list. Among the hydrocarbons there were 18 renewals and 22 additions to the list. Five more sulfur derivatives of hydrocarbons, prepared by the U. S. Bureau of Mines, were certified and made available by the National Bureau of Standards. Eleven benzoic acid thermometric standards were issued. Developmental work on diphenyloxide as a thermometric standard near 25° C has been completed, but samples have not yet been prepared for public issue.

Mechanics

There was again a pronounced increase over the previous year in tests made for other Government agencies. The number of water-current meters tested increased from 920 during 1949 to 1,239 during 1950. The number of master beer meters tested increased from 245 to 266; accurate calibration of these meters is essential for the correct computation of the Federal tax on beer, amounting to about $800,000,000 per year. Two hundred fifty-

eight elastic calibrating devices were tested in 1950, as compared with 221 such devices in 1949. These devices are relied upon for the calibration of testing machines as well as for the weighing of aircraft before takeoff.

Thirteen talking book reproducers were tested as part of an investigation of talking book systems for the blind which is being conducted for the Library of Congress. The test results were used as a basis for the purchase of 10,000 reproducers costing approximately $300,000. About 150 mechanical appliances, such as floor polishers, vacuum cleaners, and padlocks were tested for compliance with Federal specifications. Parking meters and postage meters were tested in connection with the development of standards of security; adding machines were tested for the Census Bureau; 40 oxygen regulators and associated apparatus were given evaluation tests for the Bureau of Aeronautics, Department of the Navy; about 100 pressure gages and barometers were tested for both public and Government agencies. A number of radiosondes and other humidity measuring instruments were tested for the Navy and the Weather Bureau. Several Pirani, thermocouple, thermopile, and cold-cathode ionization gages were tested against the new NBS low vacuum standard. Cup and propeller-type anemometers used in meteorological work and pitot tubes and vane- and thermal-type anemometers for measurements of air flow in heating and ventilating systems were tested for performance and accuracy in the Bureau's wind tunnels at speeds up to 180 miles per hour. Tension, compression, bending, torsion, and hardness tests were made on 1,267 specimens submitted by other Government departments, State institutions, and private organizations to determine mechanical performance and compliance with specifications.

Organic and Fibrous Materials

During the fiscal year, 48,983 separate determinations were made on 11,940 samples of products containing organic and fibrous materials. The major portion of the items tested were from individual Government purchases. Road tests of tires, carried out in collaboration with the Post Office Department and the National Capital Parks Police, showed a variation of almost 2 to 1 in the tread life of tires made by different manufacturers. Approximately 3,400 standard samples of ingredients for use in rubber compounding were issued to the rubber industry for specification testing of production. The paper being developed for the calibration of lamps employed in testing colorfastness of fabrics is now being used in 600 laboratories in the United States and foreign countries.

Metallurgy

A total of 311 items were tested for quality of material and compliance with specifications. One large item was 58 fusible plugs for marine boilers, examined for the U. S. Coast Guard. Material submitted for determination of causes of failure during transportation included 11 items from the Civil Aeronautics Administration, 32 items from the Civil Aeronautics Board,

and 13 items from the Interstate Commerce Commission. Five hundred forty-six salt-spray tests were made, and 322 items were heat-treated for various Government agencies. The experimental foundry prepared 1,033 castings of aluminum alloys, copper alloys, cast iron, lead, tin, and special compositions for Government agencies. Miscellaneous services included rolling, forging, swaging, and wire-drawing of metals and metallographic and X-ray diffraction examinations.

Mineral Products

As in previous years, the largest testing program engaged in by the Bureau was that on portland cement and related concreting materials for use in Federal construction projects. To insure compliance with Federal specifications, about 9,000,000 barrels of cement were tested during the year at the central laboratory in Washington and at four field stations. Shipments of approximately 7,500,000 barrels of portland cement, 15,000 tons of fly ash, and 4,000 tons of silicious materials were sampled and inspected by Bureau inspectors at cement mills. Testing and inspection increased 27 percent over that of the previous year. Tests for other agencies were also made on 4,800 samples of concrete, 300 samples of aggregates, 250 samples of soil, and 200 samples of fly ash.

Closely related to this work is the program of the Cement Reference Laboratory, which inspects the apparatus and test methods of cement-testing laboratories. This laboratory is located at the Bureau and is jointly supported by the Government and the American Society for Testing Materials. Field work in the laboratory includes demonstrations and inspections of test methods and cement-testing apparatus. During the year, 65 cement laboratories were inspected throughout the country. The Public Roads Administration contributes to the financial support of the project and requires that laboratories testing cement for Federal-aid projects must be inspected regularly by the Reference Laboratory.

In addition to the cement-testing program, refractories used for boiler settings, incinerators, and power plants in Federal installations were tested. Tests were also made on lime and gypsum for structural purposes and building stone for monumental purposes.

Building Technology

Many varieties of building materials, constructions, and equipment were tested for other Government agencies during the year. These included masonry units; pipe; various roofing materials; 2,100 samples of bituminous materials; prefabricated wall, floor, and roof panels; flashing materials; specimens of prefabricated steel bents for portable buildings; bonding compounds for concrete; and electric drinking-water coolers.

Many items such as signal flares, smoke bombs, and distress signals were tested for the U. S. Coast Guard for certification as lifeboat emergency equipment. Other items submitted by the Coast Guard included various

ship's stores which were tested for safety in stowage and use. Matches were tested for the Post Office Department, Veterans' Administration, and the Quartermaster Corps. Flammabilities of 22 lots of fabrics were determined for seven Federal agencies and the District of Columbia. Fire hazards of four packaged materials packed for transport in the mails were investigated for the Post Office Department. Combustibility of insulation and similar materials was determined on 12 lots of materials submitted by five Federal agencies. The hazard of cellulose nitrate film in partly decomposed condition was evaluated for the National Archives, and the fire hazard of a plastic reflector for a fluorescent light fixture was determined for the Public Buildings Administration.

Electronics

Various types of electronic equipment and components were tested and calibrated for other Government agencies. An example is the testing of electron tubes. Specially designed, highly accurate, and extremely flexible equipment has been installed for measuring the characteristics of a wide variety of tubes, ranging in size from subminiature types to large power tubes and ranging in frequency from direct-current to microwave. Typical of the tests conducted during the year were (1) determinations of the conformance of tubes to specifications, (2) evaluation of the suitability of tubes for special circuit applications, (3) examination and evaluation of tubes in electronic equipment which had failed or deteriorated, (4) measurement of the static curves of vacuum tubes in the positive grid region, (5) measurement of characteristics of tubes operating under nonstandard conditions, (6) evaluation of sample tubes which had been subjected to high-impact shocks and to conditions of extreme vibration, and (7) evaluation of foreign-made tubes and determination of their characteristics.

Radio Propagation

Instruments and devices tested included attenuators, bridges, diathermy generators, field-intensity meters, a modulation monitor, multimeters, a phase modulator, quartz-crystal oscillators, radio receivers, standard resistors, transmitters, vacuum-tube voltmeters, voltage generators, and wattmeters. In the frequency band below 300 kilocycles, calibrations and tests were made on 78 items of 18 types for three manufacturers, six radio consultants, five radio stations, and 11 Government agencies. In the microwave region, 16 frequency meters and 10 attenuators were calibrated. Standard frequencies and standard time signals were broadcast continuously from the Bureau's radio station WWV for use in the calibration and test of frequency and time standards by the armed services, research laboratories and various industries. The new experimental standard frequency station, WWVH, established last year on the island of Maui, T. H., was found to be of great potential value. Technical broadcast services of both stations were improved by the addition of time announcements in voice each

five minutes, 600-cycle modulation, and a more effective warning system for radio propagation disturbances.

17. Technical Services and Cooperation

The Bureau's consulting and advisory activities for other Government agencies arise from the broad scope of its program in the physical sciences and mathematics, its wide range of facilities, and expert staff. Since other branches of the Government as well as industry rely on the Bureau for extensive calibration and test work, the Bureau has taken a leading part in the development of improved methods for testing materials and equipment, in determining the physical properties and physical constants of an immense variety of materials, and in the study of technical processes. As a result, members of the Bureau staff are called upon by Federal agencies to act as consultants in a great number of fields; where experimental work is required, the necessary facilities are usually available at the Bureau.

The Bureau provides calibration services not only to the Federal Government but to State and municipal governments, universities, industry, and private laboratories. In addition, the Bureau offers a program of assistance to State and local departments of weights and measures, coordinating their efforts and advising them on technical matters. The Bureau also cooperates extensively with technical and trade groups, on a national basis, where the interests of the Government are involved. Such cooperation is not only of value to the Government but provides a means of disseminating the results of Bureau work to the Nation in a direct fashion.

The National Bureau of Standards is the technical spokesman for the United States on international agreements relating to the development and establishment of international scientific standards and the establishment of values for scientific constants. It is thus active in such groups as the International Union of Chemistry, International Telecommunications Union, International Committee on Weights and Measures, International Scientific Radio Union, International Commission on Illumination, and International Commission for Uniform Methods of Sugar Analysis. Another phase of international cooperation involves a program whereby scientists or diplomatic representatives from other countries are accepted at the Bureau as guest workers or visitors. Both aspects, which are important to the United States in terms of commerce and trade as well as the international policies of the Government, are coordinated on the diplomatic level by the State Department.

Advisory Services

Advisory and consulting services are rendered to all agencies of the Federal Government, as well as many State and municipal governments. Agencies assisted during the year included the Departments of the Army, Navy, and Air Force; State Department; Department of Agriculture; Post

Office Department; Atomic Energy Commission; Federal Communications Commission; Civil Aeronautics Board; Federal Trade Commission; Interstate Commerce Commission; Library of Congress; U. S. Capitol; Joint Chiefs of Staff; Veterans' Administration; Food and Drug Administration; Smithsonian Institution; Weather Bureau; Rural Electrification Administration; National Research Council; Central Intelligence Agency; Coast and Geodetic Survey; Federal Bureau of Investigation; National Advisory Committee for Aeronautics; Munitions Board; District of Columbia; Federal Housing Administration; Housing and Home Finance Agency; U. S. Maritime Commission; Office of Rubber Reserve; Public Roads Administration; Federal Prison Industries; Bureau of the Mint; Panama Canal; U. S. Tariff Commission; Bureau of Indian Affairs; U. S. Bureau of Mines; Social Security Administration; Bureau of Foreign and Domestic Commerce; Civil Aeronautics Administration; Bureau of Federal Supply; U. S. Coast Guard; Public Health Service; Public Buildings Administration.

Continuous and more extensive work is undertaken through various scientific and technical committees. The Bureau is represented on numerous committees, panels, and commissions of other Government agencies. These include the Research and Development Board of the National Military Establishment, the Federal Interdepartmental Safety Council, the Federal Fire Council, the Interdepartmental Radio Advisory Committee, the National Conference on Weights and Measures, the National Advisory Committee for Aeronautics, the Interdepartmental Committee on Photographic Papers and Films, the Interdepartmental Screw Thread Committee, the Joint Committee on Unification of Building Codes, and a number of similar groups.

Federal Specifications

An important phase of the Bureau's work consists in cooperation with the Federal Specifications Board and other standardizing agencies in the development and improvement of specifications. To avoid duplication of effort in Government procurement, the Federal Specifications Board compiles and adopts specifications for the purchase of supplies by the Federal Government. These specifications result in purchase economies by establishing criteria which guarantee quality and by providing an opportunity for all business to compete for Federal trade through the bid system. Under the chairmanship of the Director of the National Bureau of Standards and in cooperation with the Bureau of Federal Supply, the Board discharges its functions through 76 technical committees. A total of 116 positions on these committees, including 23 chairmanships, are filled by specialists of the Bureau's staff. Considerable experimental investigation is carried on at the Bureau in the development of test methods, which are so often indispensable before a specification can be framed or applied. Other laboratory studies become necessary in connection with the continual

revision of the specifications to keep them abreast of industrial practice and the changing needs of the Government. More than 2,000 Federal specifications are now in effect.

Radio Propagation

The Bureau was consulted by other Government agencies on a wide variety of problems in the radio field. For example, the Office of the Surgeon General, U. S. Army, was assisted in the development of methods to modify diathermy equipment so that it might be used in compliance with new FCC regulations soon to go into effect. Consultative and test services were performed for the Federal Bureau of Investigation in connection with a large order of FM transmitters and receivers. Field-intensity instrument standardization was discussed with members of the staff of the Federal Communications Commission. Assistance was given the Los Alamos Scientific Laboratory in planning improvement of its timing equipment. Several proposed specifications and amendments for electronic components were reviewed for the Armed Services Electro Standards Agency. Consultative services on voltage and impedance measurements were given 14 representatives of governmental and other laboratories. Information, advice, and design details on microwave equipment were furnished to other Government agencies, including the Naval Research Laboratory, Air Matériel Command, and the Naval Ordnance Laboratory; to a number of foreign institutions; and to numerous industrial, engineering, and educational institutions in this country.

Building Technology

As in previous years, the Bureau provided assistance to other Government agencies on a wide range of technical problems relating to building construction and to fire and other hazards to life and property. Typical subjects were the probable origin of a destructive explosion during a fire in a Government building, deterioration of safety devices for elevators in Government buildings, explosibility of ammonium nitrate, electrical hazards of electronic computing machines, hazards of dangerous cargoes on military aircraft, shipping hazards of television tubes, the design of chimneys for draft, methods of measuring thermal conductivities of building materials, methods of rating heating equipment for buildings, and performance characteristics of refrigeration and air conditioning equipment.

The National Resources Board was given information on fire protection needed for stock piles of strategic materials. Frequent requests were received from the Federal Housing Administration for opinions concerning the acceptability of new materials and new construction methods. The Post Office Department, the Treasury Department, the Departments of War and Navy, the Public Buildings Administration, the Architect for the White House, the National Institutes of Health, and other agencies were also

given information and advice on safeguards against fire and fire protection measures.

X-ray Problems

The Veterans' Administration was assisted in the preparation of a manual for the guidance of its X-ray personnel. The Bureau also analyzed the plans for a number of Veterans' Administration hospital X-ray departments to determine their requirements for protective barriers and provided consultative assistance in the preparation of specifications for medical X-ray equipment for purchase by the Veterans' Administration and other Government agencies. Assistance was given the Public Health Service in the preparation of a manual for the guidance of architects and others concerning protective barriers for hospital X-ray installations. In its capacity as technical consultant on radiographic equipment to the Surgeon General, U. S. Army, the Bureau participated on the Panel on Radiology of the Armed Forces Field Medical Matériel Group.

Failure of Airplane Propellers

The Civil Aeronautics Board sought the advice of the Bureau concerning the failure of propeller blades as a cause of airplane accidents. In order to add rigidity to the hollow metal propellers, rubber compounds are often vulcanized in place inside the blades to fill completely the inside space. Examination of the rubber compound inside a failed blade revealed that the compound had been overcured to the point that it had become brittle and that the vibration of the propeller had caused the compound to disintegrate and change position inside the blade. The same rubber compound, when cured at a lower temperature, produced a much stronger, tougher, and less brittle product.

Portable Electric Hot-Water Heaters

At the request of the Post Office Department and the Federal Trade Commission, the performance of small electric hot-water heaters of the "clamp-on" type was studied. It was found that several models of these devices were serious hazards. As the heating coil was bare and in contact with the water, they might easily have caused a fatal electric shock.

Rubber Technology

The Committee on Specifications for Government Synthetic Rubbers, Office of Rubber Reserve, was assisted in the development of a complete solution method for determing fatty acid and soap in synthetic rubbers, a method for determining Mooney viscosity of the polymer in GR–S rubber latices, and recipes for the evaluation of GR–I and GR–S black synthetic rubbers. Assistance was also given to the Office of Rubber Reserve in its educational program in the rubber industry on the merits of the strain test developed recently by the Bureau for the evaluation of rubber.

Automotive Tire Tests

The Bureau assisted in the application of modern statistical methods to the design of a comprehensive road test on the tread wear of tires and to analysis of the results. The test was conducted by the Government Tire Test Fleet at San Antonio, Tex., operated by the Copolymer Corporation, and was planned in conjunction with the polymer development work of the Office of Rubber Reserve. Five tires of each of 42 types were tested. In addition to the customary skid depth measurements, weight-loss determinations were made according to a method previously developed at the Bureau. The introduction of the statistical design and of the more precise weighing method resulted in a saving of approximately 65 percent in the cost of the test. In addition to a comparison of types of tires, this procedure yielded information not usually obtained by the customary method.

Codes and Specifications

The results of a large part of the research and testing carried on by the Bureau have a direct bearing on the development of technical requirements designed to assure safe working and living conditions. Through membership on numerous committees of national standardizing bodies, the Bureau has been able to put these results before qualified persons for interpretation and practical use. It thus provides a central source of information to which Federal, State, and municipal authorities, as well as industrial and trade associations, can turn when dealing with problems of safety or with building and plumbing codes. Similarly, the Bureau has participated in the development of numerous national standards and specifications that are universally used as basis for intelligent purchase of commodities.

During the year, representatives of the Bureau took an active part in work on revision of the National Electrical Code, the National Electrical Safety Code, the Code for Protection Against Lightning, the American Standard Elevator Safety Code, and other codes in the safety field. Other work in process was concerned with codes for mechanical refrigeration, electrical equipment in coal mines, electrical raceways, wood poles and cross-arms, and plumbing systems.

Weights and Measures

While the National Bureau of Standards is the custodian of the Nation's standards of length and mass, the Congress has left to the control of the individual States the regulation of commercial weighing and measuring devices and operations. As the Bureau has no regulatory authority over the weights and measures activities of the States, it functions only in an advisory and coordinating capacity in this field.

The translation of the basic standards of length and mass and of the derived standards of capacity to the channels of industry and trade is a matter of great economic importance to the producing, manufacturing, processing, and distributing agencies in this country and to all purchasers of commodi-

ties. To aid in this work, the Bureau established late in 1947 an Office of Weights and Measures whose over-all function is to promote the extension, raise the standard of efficiency and coverage, and increase the degree of uniformity of State weights and measures supervision throughout the United States. A definite program of assistance to State and local departments of weights and measures as well as to business and industry has been set up and successfully pursued.

A large part of the activity of the Office of Weights and Measures consists of consultative services rendered through correspondence; through visits to the office by representatives of Federal agencies, business and manufacturing concerns, and weights and measures officials; and through visits of members of the office to weights and measures officials in their own jurisdiction. The field of inquiries is broad, embracing the drafting of new legislation; the interpretation of laws, specifications, tolerances, and regulations; the design of testing equipment; methods of test of commercial equipment; the reporting of activities in different weights and measures jurisdictions; problems of and plans for weights and measures administration; planning and conducting weights and measures conferences; training schools for State departments; and other similar problems.

A major medium of cooperation with weights and measures officials, manufacturers of weighing and measuring devices, and associated interests is the National Conference on Weights and Measures. The thirty-fifth meeting of this organization was held in Washington in May 1950 under the sponsorship of the National Bureau of Standards. The official registration of 292 included 143 weights and measures officials from 34 States, the District of Columbia, and Puerto Rico; 123 representatives of business and industry; and 24 persons from Federal agencies.

Actions of the Conference included tentative approval of a model weighmaster bill, which establishes the office of "licensed public weighmaster"; amendment of the textile section of the model State law to govern the marking and sale of textile products by weight or measure; changes in the codes of specifications, tolerances, and regulations for commercial weighing and measuring devices (NBS Handbook H44); and recommended methods of sale for liquefied petroleum gas. A special committee was formed to investigate, in cooperation with railroad authorities, the testing of railway track scales by the States.

Research Associate Program

The research associate plan is an arrangement under which technical, industrial, and commercial organizations can support work at the Bureau on projects which are of special interest to them, yet of sufficient general interest to justify use of Government facilities. Research associate projects must not only be of value to all groups concerned in the particular field and to the Federal Government, but must also be important from the standpoint of the Nation's sum total of technologic knowledge. While the

arrangement is preferably made with an association or group representing a major part of the industry concerned, projects may be undertaken in cooperation with single companies or individuals when the results may be expected to be of value to the general public. In any case, the results become a part of the public domain and are published by the Bureau. Research workers acceptable to both parties are either assigned by the Bureau or employed by the supporting organization, which pays their salaries and other expenses incident to the project.

Since the research associate plan was established in 1920, more than 175 organizations and individuals have supported cooperative research at the Bureau. Many of the projects have been extremely specific and therefore of relatively short duration. Others, such as that supported by the Portland Cement Association, have been directed toward fundamental research in the field; this project has been active since 1924.

At the close of the fiscal year 13 groups were supporting 62 research associates at the Bureau. Cooperative projects were under way on dental materials, fuels, electron tubes, commercial adsorbents, electrodeposition, corn products, cement, concrete, standards for X-ray diffraction analysis, chinaware, porcelain enamel, and asphalt roofing.

Scientific and Technical Groups

Through active participation in the projects of professional societies and standardizing bodies, the Bureau plays an important part in the development of test methods and criteria, in the application of scientific discoveries, and in fundamental research programs of a national nature. It thus aids in developing and improving engineering standards, purchase specifications, and building and safety codes. Bureau staff members now hold approximately 1,600 positions on committees of over 100 national groups such as the Acoustical Society of America, American Society for Testing Materials, American Standards Association, American Society of Textile Chemists and Colorists, American Ceramic Socicty, American Concrete Institute, American Geophysical Union, American Institute of Electrical Engineers, American Leather Chemists' Association, American Society of Heating and Ventilating Engineers, American Society of Mechanical Engineers, Institute of Radio Engineers, Institute of the Aeronautical Sciences, Instrument Society of America, National Fire Protection Association, Optical Society of America, Society of Automotive Engineers, Society of Plastic Industry, and Society for Experimental Stress Analysis.

The Bureau was also active in about 30 international scientific and technical bodies such as the International Union of Chemistry, International Union of Pure and Applied Physics, International Telecommunications Union, International Committee on Weights and Measures, International Commission on Illumination, International Scientific Radio Union, and International Commission for Uniform Methods of Sugar Analysis. These international societies deal largely with the establishment and maintenance

of international scientific standards and the establishment of values for such quantities as scientific constants. The Bureau's participation in their programs is important to the United States in terms of both international trade and diplomatic policy.

Office of International Relations

Scientists and engineers from other countries are permitted to participate in certain normal work of the Bureau as guest workers. The program is conducted under procedures of the Department of Commerce and the Department of State, in accord with such legislation as the Fulbright Act (Public Law 584, 79th Cong.) and the Smith-Mundt bill (Public Law 402, 80th Cong.). The Bureau's Office of International Relations makes arrangements for foreign scientists to be accorded guest privileges at the Bureau; receives official visitors from abroad; correlates Bureau activities with those of other Federal committees handling international relations, and assists the Bureau in its own representation abroad at international meetings. Such a program not only strengthens the relations of this country with other nations but also permits the Bureau to keep more closely in touch with foreign developments and provides it with additional expert temporary staff associates.

During the fiscal year, a total of 636 persons from other countries were visitors or guests of the Bureau. Among them were 17 directors of foreign research institutions analogous to the National Bureau of Standards, 46 directors of specialized research institutions, 107 research scientists and engineers, 58 university professors, 25 government officials, 116 industrial engineers, and 12 delegations consisting of 165 persons. In addition, 29 scientists and engineers were accepted for programs ranging from three to twelve months, as well as 13 trainees sponsored and supported by the Department of State and 35 technical students of graduate level.

E. U. Condon,
Director, National Bureau of Standards.

SCIENTIFIC AND TECHNICAL DIVISIONS AND SECTIONS [1]

ELECTRICITY

Resistance Measurements
Inductance and Capacitance
Electrical Instruments
Magnetic Measurements
Electrochemistry

OPTICS AND METROLOGY

Photometry and Colorimetry
Optical Instruments
Photographic Technology
Length
Gages

HEAT AND POWER

Temperature Measurements
Thermodynamics
Cryogenics
Engines and Lubrication
Engine Fuels
Combustion

ATOMIC AND RADIATION PHYSICS

ATOMIC PHYSICS

Spectroscopy
Radiometry
Mass Spectrometry
Physical Electronics
Electron Physics
Atomic Physics
Neutron Measurements

[1] As of July 1, 1950.

RADIATION PHYSICS

Nuclear Physics
Radioactivity
X-rays
Betatron
Nucleonic Instrumentation
Radiological Equipment

CHEMISTRY

Organic Coatings
Surface Chemistry
Organic Chemistry
Analytical Chemistry
Inorganic Chemistry
Electrodeposition
Gas Chemistry
Physical Chemistry
Thermochemistry
Spectrochemistry
Pure Substances

MECHANICS

Sound
Mechanical Instruments
Aerodynamics
Engineering Mechanics
Hydraulics
Mass
Capacity, Density, and Fluid Meters

ORGANIC AND FIBROUS MATERIALS

Rubber
Textiles
Paper
Leather
Testing and Specifications
Organic Plastics
Dental Materials

METALLURGY

Thermal Metallurgy
Chemical Metallurgy
Mechanical Metallurgy
Corrosion

MINERAL PRODUCTS

Porcelain and Pottery
Glass
Refractories
Enameled Metals
Building Stone
Concreting Materials
Constitution and Microstructure
Chemistry of Mineral Products

BUILDING TECHNOLOGY

Structural Engineering
Fire Protection
Heating and Air Conditioning
Exterior and Interior Coverings
Codes and Specifications

APPLIED MATHEMATICS

Numerical Analysis
Computation
Statistical Engineering
Machine Development

ELECTRONICS

Engineering Electronics
Electron Tubes
Electronic Computers

ORDNANCE DEVELOPMENT

Mechanical Research and Development
Electromechanical Fuzes
Technical Services
Missile Fuzes—I
Missile Fuzes—II
Projectile Fuzes
Ordnance Components
Ordnance Tests

CENTRAL RADIO PROPAGATION LABORATORY

IONOSPHERIC RESEARCH

Upper Atmosphere Research
Ionospheric Research

SYSTEMS RESEARCH

Regular Propagation Services
Frequency Utilization Research
Tropospheric Propagation Research

MEASUREMENT STANDARDS

High-Frequency Standards
Microwave Standards

MISSILE DEVELOPMENT

Missile Engineering
Missile Dynamics
Missile Intelligence
Missile Instrumentation
Technical Service