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RESEARCH HIGHLIGHTS

OF THE

NATIONAL BUREAU OF STANDARDS

ANNUAL REPORT

The major purpose of standards for measurement is to provide a basis to assure the stability and compatibility of measurements from time to time and from place to place. If the accuracies with which measurement standards are known and utilized are less than the corresponding accuracies required in laboratories and on production lines then problems ensue. Data cannot then be exchanged with optimum confidence, and tests performed on the same materials or devices in different places may be incompatible or uncertain in terms of predicted performance. It is therefore imperative that those responsible for developing, maintaining, and disseminating the measurement standards keep ahead of the important needs of science and industry. Trying to meet this requirement is the dominant and never ending challenge to the National Bureau of Standards.

A. V. Astin, *Director, NBS.*

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UNITED STATES DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*
J. Herbert Hollomon, *Assistant Secretary for Science and Technology*
NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

1962
Research Highlights
of the
National Bureau of Standards

Annual Report, Fiscal Year 1962

December 1962

Miscellaneous Publication 246

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

Contents

1. GENERAL REVIEW

Programs in measurement standards, materials research, and radio propagation continued, during the past year, to constitute the major effort of the National Bureau of Standards. Because these programs are in direct support of science, technology, and industry, they contribute to that complex of forces, events, and factors which determine the rate of the Nation's economic growth. Science and technology are indeed prime factors in economic growth, and the Bureau plays a unique and vital role in science and technology.

As industrial technology becomes increasingly complex, urgent demands arise for greater measurement precision, for assurance of closer consistency among the countless individual measurements that are being made throughout the Nation. A radio transmitter, a space vehicle, an automatized production line—each requires hundreds and even thousands of individual parts and components whose electrical, mechanical, and chemical characteristics must be carefully controlled for successful operation. And as more complex systems are developed, requiring even more parts to perform more sophisticated functions, the acceptable production tolerances for individual parts are continually being reduced. Thus, to an increasing extent, technological progress—particularly in such fields as automation, nuclear power, and the space effort—has come to depend upon the ability to make measurements with extremely high accuracy and reliability.

The central mission of the National Bureau of Standards is to make this measurement competence possible—to provide national leadership in the development and use of accurate, uniform techniques of physical measurement. It is the Bureau's responsibility to develop and maintain the national standards upon which our measurements are based and to make these standards available to American science and industry through its measurement services program of calibrations, reference materials, and measurement assistance to other laboratories. Through an extensive program of research in the physical sciences, the Bureau continually strives to meet the expanding requirements of science and industry, to provide the standards and measurement methods that are required in new or rapidly-developing areas.

A second important NBS responsibility is to develop and apply measurement techniques for determining the intrinsic properties of matter and materials. Here effort is focused on obtaining and publishing accurate measurement data that are of great importance to science and industry. Methods of precise measurement are employed to make accurate determinations of natural constants such as atomic weights or the speed of light, and to measure the fundamental properties of metals, ceramics, plastics, rubbers, and other materials.

Other NBS responsibilities include the operation of central research and technical service programs for the Federal Government. Such programs are carried on by the Central Radio Propagation Laboratory, the Data Processing Systems Laboratory, the Building Research Division, the National Hydraulics Laboratory, and the Cryogenic Engineering Laboratory.

This report attempts to present the highlights of the Bureau's program for the fiscal year 1962. In section 2, the body of the report, studies and achievements from the various fields in which the Bureau is active have been selected for brief presentation. However, the breadth of the program and diversity of projects may make it difficult for the reader to obtain a coherent picture of the year's activity. The remainder of section 1 is therefore devoted to a brief summary of the more important accomplishments and activities of the year.

STANDARDS AND MEASUREMENT METHODS

Advances were made in the precision measurement of high voltages. Design of a highly stable, shielded 100-megohm resistor made it possible to measure d-c voltages up to 100,000 volts to within 20 parts per million. For determining the voltage ratio and phase angle corrections of instrument voltage transformers, a 1-picofarad, 350,000-volt free-air capacitor was designed and constructed. With this device an accuracy of 3 parts per hundred thousand is obtained in calibrating instrument transformers for use on 350,000-volt power lines.

In other work on electrical standards, a rapid, convenient method was devised for calibrating the standard-resistance voltage divider (volt box) at its rated voltage. In recent years the volt box has become part of the basic equipment of many standardizing laboratories. Although this type of standard has usually been calibrated at NBS in the past, its growing use made necessary the development of a method by which other qualified standardizing laboratories may perform the task.

The dielectric properties of materials often set operating limits for electrical equipment. Standard reference specimens of dielectric materials are thus needed to check techniques and equipment for measuring these properties. To aid in establishing the necessary standards, the Bureau designed and constructed an improved three-terminal dielectric specimen holder with which high-precision dielectric measurements can be made at room temperature.

Progress was made in research on methods for measuring both very high and very low temperatures. For temperature measurements up to 36,000 °F by spectroscopic means, an inexpensive analog computing device was developed which greatly improves the efficiency of spectroscopic studies of cylindrically symmetric temperature sources, such as high-current plasma arcs. Previously extensive calculations had been required in order to separate the contributions of the different radial zones of the arc. With the analog device, the true radial characteristics of the arc are available in the laboratory as the data are obtained.

In the very low-temperature region from 1.5 to 20 °K (i.e., from 2.7 to 36 Fahrenheit degrees above absolute zero), the Bureau has been investigating an acoustical interferometer as means for precise temperature measurement. With this instrument, temperature is determined by measuring the velocity of sound in helium gas. Preliminary results obtained during the year indicate that the acoustical interferometer is competitive with the gas thermometer for primary thermometry at low temperatures; in addition, the acoustical interferometer eliminates a number of the sources of error that are inherent in conventional temperature-measurement methods.

In research directed toward the extremely accurate measurement of distances up to a meter or more, a gaseous (helium-neon) laser was constructed and put into operation. Experimental results already obtained indicate that it is theoretically possible with this device to make measurements over a distance of 100 kilometers with a precision of a part in a million. Plans have been developed for using the laser to redetermine the speed of light with an accuracy that will meet the expected requirements of space technology.

The accuracy requirements of modern mass production have made necessary the use of master spheres, whose sizes are known to a very high degree of accuracy, for size control in manufacturing plants. During the last year methods were developed for measuring the diameters of master spheres up to 3 inches in diameter with a certified accuracy of 2 millionths of an inch. An interferometer was also developed for measuring deviations from sphericity of small spheres.

Modern technology is also imposing increasingly severe dimensional requirements on gear elements and gear teeth. Both research in precision gear metrology and the development of highly accurate master standards for industrial use are needed. To aid in this work, the Bureau established a gear metrology laboratory—believed to be the first of its kind in the country—in which equipment for measuring elements of both large and small gears is operated under closely controlled conditions of temperature and humidity. As a first step in the gear metrology program, master gear involutes were measured and compared with the standards of commercial gear laboratories scattered throughout the country; a need for precision-calibrated master involutes at the various company inspection departments was indicated.

Neutron sources are employed in a wide variety of scientific applications, including the production of radioisotopes, the study of the structure of atoms and nuclei, and the initiation of nuclear fission. In order that the emission rate of these sources may be accurately known, the National Bureau of Standards maintains a national standard neutron source consisting of an aluminum-covered beryllium sphere, inside of which is a platinum-iridium capsule containing 1 gram of radium in the form of radium bromide. During 1962 this source was absolutely calibrated by a new method involving the use of a manganese sulfate bath filled with heavy water. The uncertainty of this measurement is about 1 percent, representing a considerable improvement over previous determinations.

For almost all experiments performed with X-rays, such as measuring the X-ray energy incident on a patient being treated for cancer, it is necessary to know the total beam energy. To meet the need for a simple, accurate means of making such determinations, the Bureau developed an ionization chamber capable of determining the total amount of energy transported in a betatron or synchrotron X-ray beam to within 2 percent. For routine calibrations this ionization chamber will replace the more time-consuming absolute techniques that have been used in the past.

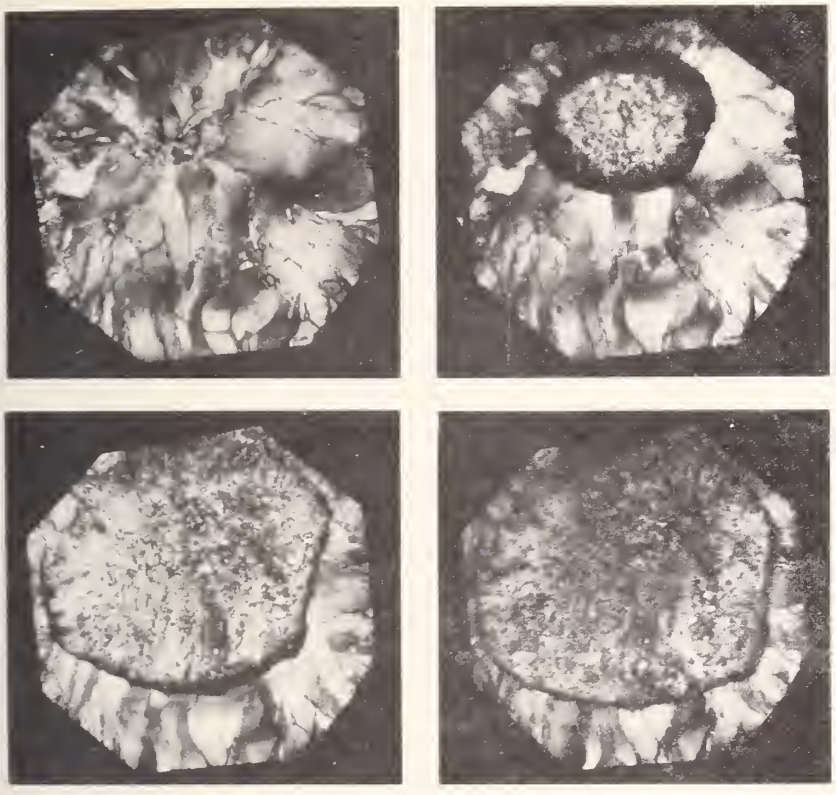
Two sets of transfer instruments were prepared and calibrated for use by the International Bureau of Weights and Measures in indirect comparisons of national standards for measurement of ionizing radiations. In October 1960 the General Conference of Weights and Measures approved the extension of the work of the International Bureau into this area, and NBS has been providing technical assistance in the program.

The United States Frequency Standard, which is derived from a natural frequency of the cesium atom, was improved to the point where its present accuracy is better than one second in 3,000 years. In addition, a complete multiplier chain and servosystem was added to control the frequency of a quartz oscillator with the cesium resonance frequency. This modification results in increased stability of the system, and greater precision than can be obtained with a manual method. In related work, two approaches, mechanical and mathematical, are being explored for counting the number of cycles which occur during elapsed time of atomic frequency standards. This is necessary in order to use atomic clocks to actually measure time.

MATTER AND MATERIALS

A new value for the atomic weight of chlorine was determined during the year. The atomic weight of this element, together with that of silver, forms a basis for the determination of atomic weights of many of the other elements. Natural chlorine consists of two isotopes of mass numbers 35 and 37 in relative abundance of about 3 to 1. The new atomic weight determination was based on a mass-spectrometric determination of the isotopic abundance ratio of natural chlorine which was carried out by the Bureau with the cooperation of the Atomic Energy Commission.

In an effort to learn more about the basic properties of matter, the Bureau has been studying the transformations and interactions that substances undergo at high pressures. During 1962 direct visual observations were made of phase transitions and other changes occurring in transparent solids and liquids subjected to pressures of more than a million pounds per square inch. The experiments were carried out with a tiny diamond pressure cell and a microscope which focuses through the diamond onto the specimen. By passing infrared radiation and X-rays through the diamond pressure cell or viewing the transformations through a microscope, the investigator can relate changes in crystal structure to changes in atomic bond energies, force constants, and vibration frequencies. An X-ray diffraction camera



A new technique developed at the Bureau makes possible for the first time direct visual observations of phase transitions and other changes occurring in materials under extremely high pressures. The four photomicrographs above show a crystal front growing through potassium nitrate as the pressure is raised. **(See p. 4.)**

which incorporates the diamond cell was developed to obtain detailed information on the phases present at the various pressures.

A preparative-scale chromatograph developed during the year makes possible fully automatic purification of liquids by gas-liquid chromatography. Using automatic, timed sample injections and automatic collection based on peak height on a recorder, the apparatus has produced materials of 99.95 percent purity. In purifying large quantities, it can be operated without interruption for an indefinite period. It has been found especially suitable for purifying the major component in a solution containing small amounts of impurities.

The requirements for extremely high-purity materials in such fields as atomic energy and semiconductors have brought about a corresponding need for samples of standard materials, certified for purity in the trace element (parts per million) region, which can be used to calibrate analytical instruments. The Bureau has therefore been working to extend the certification of present standard materials to include more trace elements, and to develop new standards for high-purity metals. As a beginning, two sets of

three samples each of zirconium and a zirconium alloy were prepared in cooperation with the Atomic Energy Commission and the Bureau of Mines. Zirconium is used for structural members in atomic power units and the presence of even trace amounts of neutron absorbers causes deleterious effects. These standards, when analysis is finally complete, will be certified for more than 25 chemical elements, at concentrations of a few parts per million or less. As a step toward standards for ultra-pure metals, a reference sample of selected platinum wire of highest purity has been prepared with the cooperation of other interested laboratories. This sample will be used in research for the extension and improvement of several methods of trace analysis.

By exposing substances to gamma radiation under high pressure, it was found possible to prepare polymers (long-chain molecules) from monomers, such as carbon disulfide, which do not normally polymerize. With such a combination of conditions, solid polymers can be obtained from monomers which, at best, normally produce oils. This work, which may provide a basis for the production of new types of polymeric materials, was part of a program conducted for the Office of Army Research to increase knowledge of radiation and polymerization processes.

An investigation of the fundamental chemistry of aromatic fluorocarbon compounds was conducted for the Bureau of Naval Weapons to provide basic data needed for the development of heat-resistant materials, especially elastomers. New methods for producing polyfluoroaromatic species from presently available aliphatic fluorocarbons were discovered.

Problems in the design of space vehicles have brought about a greatly increased demand for data on the heat radiation properties of materials. Although many new laboratories have been established to perform the required measurements, widely divergent values have been reported by different laboratories on supposedly identical materials. To help correct this condition, the Air Force requested the Bureau to establish standard equipment and procedures for measurement of normal spectral emittance, to prepare and calibrate working standards of normal spectral emittance for use in verifying equipment and procedures used by Air Force contractors, and to provide technical information in this area to interested laboratories. Equipment has now been developed for direct measurement of normal thermal emittance, and working standards representing low, intermediate, and high emittance have been prepared and calibrated for use by other laboratories.

Fatigue failures in metal parts are progressive and consist of two phases: the first, crack initiation, extending from the start of the stress application to the appearance of the first crack (which ultimately causes specimen failure); the other, a period of crack propagation, which terminates with abrupt fracture of the piece. In a study sponsored by the National Aeronautics and Space Administration, it was found that the rate of fatigue crack propagation through a metal specimen is significantly reduced by the presence of an organic liquid, such as dodecyl alcohol, on the test section. The

study indicates that the coating, by limiting the access of molecules of oxygen or water to the metal surface, reduces the rate of detrimental surface reactions that normally occur when specimens are stressed in air.

A fast, dependable method has long been sought for measuring asphalt degradation from weather exposure. The usual laboratory method in which the specimens are exposed to accelerated weathering conditions until failure occurs, is very time-consuming. During 1962, a rapid, reproducible method was developed for predicting the durability of roofing asphalts. In this method infrared spectroscopy is used to determine the oxidation rates of thin film specimens; these rates then provide an accurate measure of asphalt durability. Thus, data that would require weeks to obtain by the usual accelerated weathering techniques can now be secured in a few hours. The rapid method should be of particular value in developing improved specifications for asphalt roofing materials.

ASTROPHYSICAL AND PLASMA PHYSICS RESEARCH

The Bureau's program in this area is designed primarily to provide the measurement standards and basic atomic data that are needed to determine the fundamental properties of plasmas (extremely hot gases occurring in thermonuclear devices and outer space) and to solve important problems in modern astrophysics. The national space effort is now providing a great deal of spectroscopic data on the sun and the stars from equipment carried on rockets and satellites above the earth's atmosphere. The value of these data can be greatly enhanced if they can be accurately described in measurement units based on precise laboratory standards.

The Bureau has long been making accurate measurements of atomic properties which provide a basis for quantitative interpretation of astronomical observations. With the increased need for such information, the program has been unified and strengthened. Significant advances have been made in the determination and cataloging of data on atomic transition probabilities and in the detailed understanding of the more complex atoms through exhaustive analysis of their spectra. More precise information on atomic collision cross sections has also been obtained.

During the year, spectroscopic studies of hydrogen plasmas were carried out in a wall-stabilized high-current arc chamber operating at temperatures from 11,000 to 27,000 °F. Precision measurements of the line profiles of the Balmer lines of hydrogen were found to be in very good agreement with profiles predicted by line broadening theory; this result suggests that the theoretical profiles should be applied to the diagnostics of dense plasmas.

Thermal plasmas in the temperature range from 36,000 to 180,000 °F, which are needed for measuring the transition probabilities of ionic lines of excitation potentials, are conveniently produced behind energetic shocks. For studies of this kind, a magnetically driven shock tube was put into operation and temperatures of about 54,000 °F were obtained behind the

shock fronts. Measurements of relative transition probabilities for lines of singly ionized oxygen are now being carried out.

Experimental and theoretical studies on the special properties of perturbed spectral lines resulted in a new approach to the determination of the radiative and collisional lifetimes of molecules. Information of this sort, combined with measured spectral intensity distributions of such luminous gaseous systems as comets and the terrestrial upper atmosphere, should make it possible to deduce the physical properties and conditions of excitation of these remote systems. At present lifetime information on important cometary and upper atmosphere molecules is fragmentary.

Publication of *An Ultraviolet Multiplet Table*, NBS Circular 488, was completed during the year. This five-section series of publications has been prepared in conjunction with a program on atomic energy levels which has been in progress at the Bureau for approximately 10 years. It will help to fill the need for multiplet data in the interpretation of rocket solar spectra.

In April 1962, the National Bureau of Standards and the University of Colorado announced the collaborative establishment of the Joint Institute for Laboratory Astrophysics (JILA) on the campus of the University at Boulder, Colo. This unique organization will provide a center for both research and advanced training in areas of physics and astrophysics vital to the space program. It will bring together scholars in many specialties for exchange of ideas and data; it will also train graduate and postdoctoral students in atomic physics and astrophysics, fields in which there is now an acute shortage of qualified workers. Through laboratory and theoretical studies, it will endeavor to provide better understanding of the basic physical phenomena and properties of gaseous matter, such as the atmospheres of stars, which must be understood to interpret astronomical and geophysical observations.

RADIO PROPAGATION STUDIES

The NBS Central Radio Propagation Laboratory (CRPL) has the central responsibility within the Federal Government for collecting and disseminating information on radio-wave propagation. Its technical program includes research on upper atmospheric and solar phenomena, studies of radio-wave propagation, advance predictions of radio propagation conditions, and issuance of warnings of solar and ionospheric disturbances. Its findings are of value to radio and television broadcasters, the military services, space scientists, and operators of many types of communication systems.

An installation for ground-based explorations of upper atmosphere and outer space was constructed by CRPL and the Instituto Geofisico de Huancayo (Peru) at a site 17 miles east of Lima, Peru. Known as Jicamarca Observatory, this installation makes use of a scatter radar technique developed by NBS in 1959. It employs a 6,000,000-watt pulse transmitter and a 22-acre antenna to transmit to great heights a very high frequency radio wave lasting from 50 to 1500 millionths of a second. The antenna is also used to detect

the faint re-radiation of the pulsed radio wave by free electrons in the upper atmosphere. With this equipment, electron densities 3000 miles above the earth have already been measured. The installation will also be used in limited observations of radar echoes from the sun's corona and from solar gas clouds emitted by solar disturbances, in studies of small-scale irregularities in the earth's outer atmosphere, and in studies of the *D*-region of the ionosphere, particularly its turbulence and meteorology.

On October 13, 1961, a second suborbital rocket-borne sounding of the ionosphere was made at an altitude of about 600 miles. Data collected during this and an earlier rocket firing in June 1961 confirm that the proposed Topside Sounder satellite should be a valuable source of new information concerning the ionosphere. These experimental rocket launchings thus pave the way for placing in orbit the S–48 Topside Sounder satellite equipped to probe the ionosphere from above. The instrumentation to be contained in the S–48 satellite is expected to remain operational for 6 to 12 months. During this period studies will be made of such ionospheric properties as topside electron densities, ionization diffusion, vertical movements of the ionosphere, tidal fluctuations, and the mechanisms that produce ionospheric storms.

Both rockets were launched from the National Aeronautics and Space Administration's Wallops Island (Va.) facility. NBS responsibilities in the program include overall planning, design and performance of the experiment, and analysis of the resulting data. Airborne Instruments Laboratory (Cutler-Hammer, Inc.) is responsible for design and construction of the satellite as well as the rocket payloads. The project is under the technical management and sponsorship of the NASA Goddard Space Flight Center and is part of an international cooperative program for space research.

When man lands on the moon, one of his first needs will be for reliable means of communication between points on the moon's surface. Under the sponsorship of the Jet Propulsion Laboratory, an analysis was made of the factors affecting point-to-point radio communication on the moon. In order to specify suitable radio frequencies for use, assumptions were made regarding lunar conditions that affect propagation but are not yet precisely known. The data obtained were used to determine the power required for sample transmission distances and bandwidths.

By treating very short radio waves as light waves, the Bureau developed a cavity resonator technique for probing "millimeter waves"—a largely inaccessible region of the radio spectrum—and determining their lengths with great accuracy. These waves, which form a band of frequencies between microwaves and the infrared region of the spectrum, offer a promising tool for studying the properties of materials, such as superconductors, and for investigating the electron density of heavily ionized gases. However, because of their extremely short wavelengths, there has been no efficient way either to generate or to resonate them.

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AUTOMATIC DATA PROCESSING

The Bureau continued to serve the Government as a central research and development agency in automatic data processing and as a readily available information center for the solution of specific problems in this field. During 1962 services to other Federal agencies included assistance to the Weather Bureau in connection with the processing of data from the NIMBUS satellite series, a study for the National Aeronautics and Space Administration of automatic data processing requirements for satellite control calculations, assistance to the Bureau of Naval Weapons on problems relating to missile control and test range instrumentation, and studies of the feasibility of applying automatic data processing techniques to the operations of the Office of Technical Services, the Food and Drug Administration, and the Interstate Commerce Commission.

The Bureau contributed both computational techniques and facilities in a cooperative program of the Office of Civil Defense to assess the usefulness of large buildings throughout the Nation as fallout shelters. Purpose of the nationwide survey was to identify not only those buildings that can serve as fallout shelters as they stand but also those which can be modified for this purpose, and to help identify geographic areas in which there is need for more shelter. NBS involvement in the program was twofold. First, it developed the mathematical procedures and theoretical data necessary for estimating the protection factors of a wide variety of buildings. It then used these procedures to convert the field data on several hundred thousand actual structures throughout the country to protection factors through the use of high-speed electronic data processing. Other government agencies assisting in the survey were the Census Bureau, the Army Corps of Engineers, and the Navy Bureau of Yards and Docks.

A number of computer programs were developed for specific purposes. One of these instructs the computer by means of simple English sentences to carry out mathematical calculations or to perform a wide variety of numerical and statistical analyses of tabulated data. It thus makes the high-speed computer as accessible to the laboratory scientist as his desk calculator.

Another computer program developed during the year made possible automatic composition of the extensive tables of atomic transition probabilities. This program causes the computer to produce a magnetic tape written in the proper form to operate a photocomposition machine. The machine produces film positives from which printing plates can be made. In recent years the direct numerical print-outs of automatic computers sometimes have been published to avoid the possible introduction of errors when these outputs are handset in type. However, the direct print-outs are not comparable in appearance with hand-set material. The final published material obtained using the Bureau's method is of a quality comparable with that of hand-set material, and the probability of error is substantially reduced. In addition the time required for preparation of data for printing is decreased by approximately 50 percent, resulting in appreciably lower cost.

BUILDING RESEARCH STUDY

A special study of the role of the National Bureau of Standards in building research was completed during the year. The study was made by a committee of the National Academy of Sciences at the Bureau's request in accordance with a recommendation of the Academy's 1960 report to the Secretary of Commerce on the role of the Department in science and technology. The committee reviewed national needs for building research and identified subjects of research now being neglected. In its report (released in July 1962) it recommended a Federally coordinated, comprehensive attack on the many complex problems of the building industry. The report suggests the establishment of a National Institute of Building Research under the National Bureau of Standards as the mechanism for solving these problems. It recommends that the Bureau incorporate its long-standing building research activities into a program to stimulate and sustain a continuing effort in building research.

MEASUREMENT SERVICES

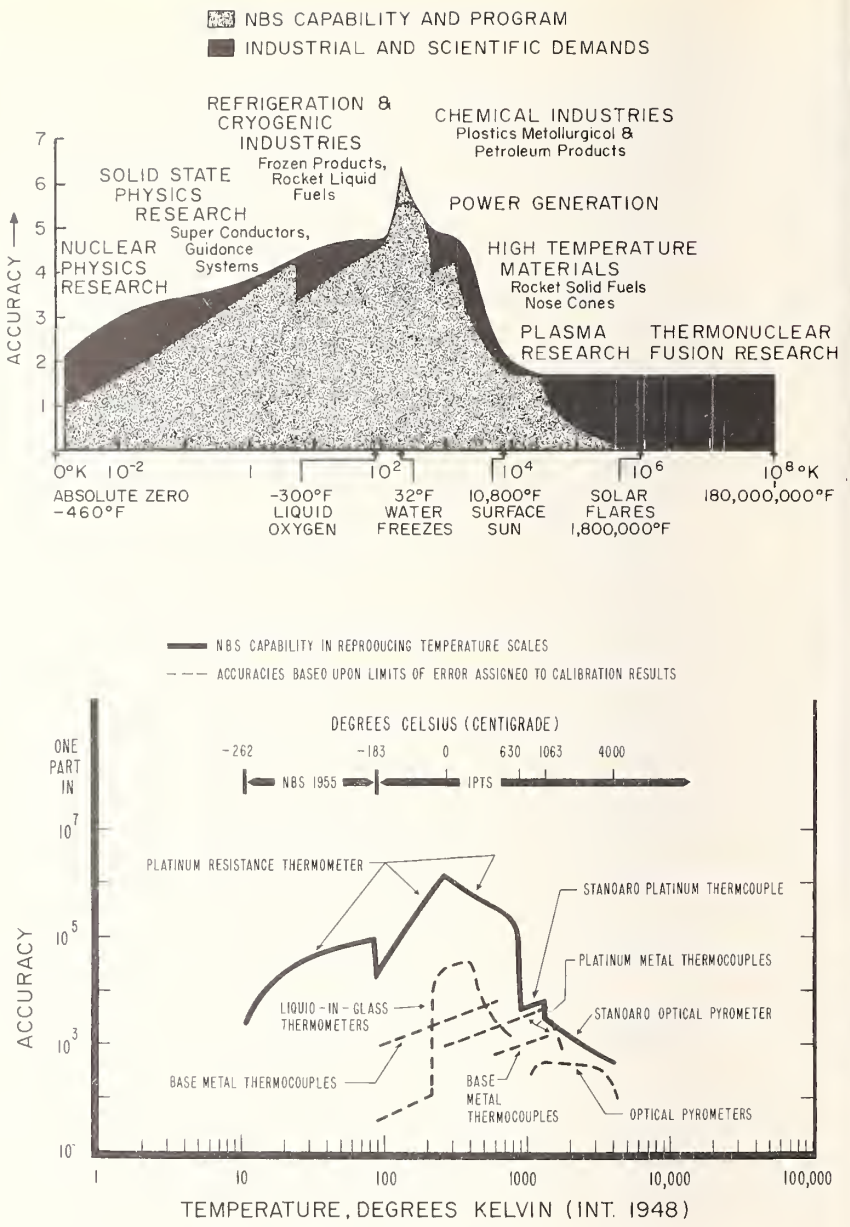
The demands made upon the Bureau for measurement services increased during the year, in terms both of additional services and refinements of existing services. This situation is to be expected, of course, in a dynamic and expanding science and technology. Fortunately, the importance of the measurement sciences as a foundation for technology is more widely recognized now than was the case several years ago. A supplemental appropriation of $1.5 million was made available to the Bureau in Fiscal Year 1962 to provide for a substantial effort on some of the problems pinpointed earlier by the survey of the Aerospace Industries Association. Major emphasis was given to problems in radio standards, temperature measurements, and atomic constants.

Statistical work has continued on the determination of the accuracies attainable in various measurement areas at NBS, and on the development of generalized techniques and procedures for intercomparisons of standards or measurement results to confirm continued accuracy of measurement standards.

A special effort has been made to prepare charts showing the ranges and corresponding accuracies of measurement and calibration capabilities of NBS. Such charts also provide a useful format for showing the measurement capabilities of other laboratories, or needs for extended ranges or accuracies in relation to Bureau services. Several of these charts are now being prepared for publication.

The year's calibration and testing activities are summarized in tables 1 and 2. A total of 138,712 calibrations and tests were performed for Government and industry; fees collected for these services totalled $3,378,820.

The Bureau's activities in standard materials compliment the program of precision calibration. Over 500 different standard materials are available for use in controlling chemical processes and maintaining the accuracy of apparatus and equipment. The primary purpose of the program is to help pro-



Top: Qualitative graph showing NBS capability in various regions of the temperature scale, compared with the most immediate accuracy demands of science and industry. Bottom: accuracies achieved in NBS calibration of specific temperature-measuring instruments.

vide a central basis for uniformity and accuracy of measurement. Emphasis is given to providing NBS Standard Materials (a) where attainment of needed accuracy of analysis or accuracy of measurement of characteristics is not economically or technically feasible elsewhere, and where such ac-

curacy is important to users widely, (b) where industrywide standards for commerce are needed from a disinterested supplier who is not otherwise available, and (c) where continuing availability of material from a common source is important to science or industry.

During the year, 66,048 samples were distributed to other laboratories (table 3). New standards issued during the year include: plutonium of extremely high purity—99.97 percent—developed in cooperation with the Atomic Energy Commission; cobalt 57, sodium 22, and zinc 65 radioactivity standards; a standard paper for increasing the accuracy of measuring the internal tearing strength of paper; and a zirconium alloy for calibrating the spectrochemical analysis of zirconium and zirconium-base alloys.

To meet the need for further information concerning thermal conductivity of building materials, a chromium-nickel alloy and a microcrystalline glass have been adopted as reproducible standards of thermal conductivity. It is hoped that work with these materials will allow accurate measurements to be made to as high as 1.000 °C. Other new standard samples made available during the year include metal samples with known gas content; specifically, of oxygen in titanium and titanium alloys.

The Bureau continued, insofar as possible, to restrict its calibration work to master standards and high-precision instruments, leaving the calibration of lower-echelon standards to other standards laboratories. Thus the Bureau no longer accepts for calibration, except under special circumstances, unsaturated standard cells. Certification of haemocytometer cover glasses and testing of reference fuel gas standards have been discontinued.

National Conference of Standards Laboratories. The Bureau has worked in close cooperation with the National Conference of Standards Laboratories since its inception in September 1961. This Conference and its continuing committees bring together representatives from military, commercial, and university standards laboratories, to promote cooperative action on common problems of management and operation of measurement standards and calibration laboratories. Several standards laboratory management workshops have been held by the Conference on Bureau grounds; the first national meeting of the NCSL was to be held at NBS Boulder in August 1962; and several Bureau staff members hold memberships on the general or special committees of the Conference.

A number of publications dealing with standards and calibrations were issued during the year. Among these were Miscellaneous Publication 241, which contains a descriptive listing of all NBS standard materials; Monograph 39, which describes calibration procedures for direct-current resistance apparatus; and Technical Note 121, *Precision Calibration of RF Vacuum Tube Voltmeters,* Handbook 77, *Precision Measurement and Calibration,* a 3-volume publication containing reprints of Bureau papers pertinent to the measurement field, underwent a second printing to meet a continuing demand for this information. A Standards and Calibration column was established in the *Technical News Bulletin* to keep readers aware of developments, both in and out of the Bureau, in these fields.

TABLE 1. *Summary of calibration services*

Area of Bureau activities	Representative items	Public		Government		Totals	
		Number of items	Fees	Number of items	Fees	Number of items	Fees
Electricity	Electrical instrument, standard cells, resistance, reactance and capacitance standards, d-c to 30 kc/s.	10,202	$183,765	2,292	$43,997	12,494	$227,762
Metrology	Light and color standards, photographic lenses, gage blocks and other length standards, refractive index standards, sieves, mass standards, track scales, capacity standards.	51,321	311,201	5,664	85,981	56,985	397,182
Heat	Resistance and liquid-in-glass thermometers, thermocouples, pyrometers.	6,152	144,253	697	28,817	6,849	173,070
Radiation Physics	Neutron sources and instruments, X-ray and gamma-ray protective materials and instruments, gamma-ray sources, alpha-ray sources, radioactive materials.	225	11,196	179	7,781	404	18,977
Mechanics	Acoustic instruments, proving rings, load cells, dynamometers, pressure standards, water current meters.	3,645	157,915	1,197	49,976	4,842	207,891
Building Research	Thermal conductivity	15	2,505	3	1,095	18	3,600
Radio Standards	Electrical and electronic instruments and standards in radio, ultra-high frequency microwave ranges.	1,699	126,867	1,466	925,672	3,165	1,052,539
Total		73,259	937,702	11,498	1,143,319	84,757	2,081,021

TABLE 2. *Summary of testing services*

Area of Bureau activities	Representative items	Public		Government		Totals	
		Number of items	Fees	Number of items	Fees	Number of items	Fees
Electricity	Dry cells, hearing aid batteries, storage batteries			546	$7,256	546	$7,256
Metrology	Lamps			4,317	49,000	4,317	49,000
Analytical and Inorganic Chemistry	Chemical analysis	18	$3,558	60	3,496	78	7,054
Mechanics	Mechanical devices			2,187	20,953	2,187	20,953
Organic and Fibrous Materials	Paper, textiles, rubber, leather and plastic products	5	74	6,170	174,374	6,175	174,448
Metallurgy	Metals and alloys	1	113	32	20,354	33	20,467
Mineral Products	Ceramic products, glass			13	1,950	13	1,950
Building Research	Building materials, air filters, fire extinguishers, heating and air conditioning equipment, paints and other surface coatings.	73	5,666	1,288	51,490	1,361	57,156
	Cement	3,259	117,350	21,052	685,343	24,311	802,693
	Concrete and concreting materials			14,934	156,722	14,934	156,722
Total		3,356	126,761	50,599	1,170,938	53,955	1,297,799

TABLE 3. *Standard samples issued*

Area of Bureau activities	Description of samples	Public		Government		Totals	
		Number of samples	Value	Number of samples	Value	Number of samples	Value
Metrology	Glass filters	75	$3,750	5	$250	80	$4,000
	Resolution test charts	8,415	1,683	703	141	9,118	1,824
	Calibrated glass spheres	86	817	21	200	107	1,017
	Photometric standards	341	16,995	62	2,759	403	19,754
	Spectrophotometric standards	64	5,352	12	1,310	76	6,662
	Color temperature standards	39	1,795	2	109	41	1,904
	Reflectance standards	258	4,229	19	300	277	4,529
	Opacity standards	102	3,098			102	3,098
	Gloss standards	207	3,580			207	3,580
	Signal glass limit standards	135	9,618	19	1,776	154	11,394
	Haze standards	90	1,279			90	1,279
	Radiance standards	123	34,290	34	9,560	157	43,850
	Irradiance standards	24	2,779	12	979	36	3,758
Radiation Physics	Radioactive samples	292	9,038	213	6,694	505	15,732
Chemistry	Hydrocarbon blends	206	2,472	9	108	215	2,580
	Hydrocarbon	813	26,139	95	2,805	908	28,944
	Cells	15	750	5	1,100	20	1,850
	Spectrographic	5,442	92,387	525	9,110	5,967	101,497
	Composition	21,290	110,805	1,528	7,458	22,818	118,263
	Uranium-isotopic	624	8,026	37	779	661	8,805
	Metal-organic material	542	5,420	32	320	574	5,740
	Sucrose and dextrose	369	1,439	53	203	422	1,642
	Labeled carbohydrates	7,739	8,277	1,722	2,130	9,461	10,407
	Cylinders of certified natural gas	90	6,750			90	6,750
	Standard benzoic acid thermometric cells	4	880	2	440	6	1,320
Mechanics	Viscosity oils	941	15,951	100	1,568	1,041	17,519
Polymers	Standard fading	621	8,079	66	383	687	8,462
	Reference paper	480	1,920	26	104	506	2,024
	Rubber	6,017	32,111	22	164	6,039	32,275
	Phosphor reference	54	162			54	162
Metallurgy	Unalloyed titanium	86	860	18	180	104	1,040
	Gas analysis	183	1,830	10	100	193	1,930
	Standard thickness samples for electroplated coatings	1,863	20,580	3	36	1,866	20,616
Building Research	Limestone slabs	29	725	1	25	30	750
	Surface flammability	24	192			24	192
	Paint pigments	83	249	2	6	85	255
	Cement	2,780	7,349	138	470	2,918	7,819
Atomic Physics	Radiation lamps	5	395	1	79	6	474
Total		60,551	452,051	5,497	51,646	66,048	503,697

COOPERATIVE ACTIVITIES

In order to bring the results of Bureau research and technical programs to bear on current problems of science and technology, NBS cooperates extensively with Federal, State, and local governments, national professional scientific societies and standardization groups, and many international bodies. Cooperation with other Federal agencies ranges from the supplying of technical information upon request to long-range projects undertaken through various scientific and technical committees. An important example of interagency cooperation is the development of government purchase specifications and test methods at the request of the General Services Administration. Cooperation with State and municipal governments is principally in the field of weights and measures. Although the Bureau itself does not have regulatory powers, it offers technical advice and consultation to local regulatory bodies and it calibrates and adjusts State standards of weights and measures.

Through the participation of Bureau staff members in the work of national professional societies and standardizing bodies, the Bureau plays an active role in the development of test methods and criteria, in the application of scientific discoveries, and in fundamental research programs of national scope. During the past year Bureau staff members held 1,250 committee memberships in 150 national groups such as the American Society for Testing and Materials, the American Standards Association, American Society of Mechanical Engineers, American Chemical Society, Institute of Radio Engineers, and Instrument Society of America. In many of these groups NBS staff members work with industry to provide codes and specifications, standard test methods, and standard data on the properties of engineering materials.

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

Sponsor	*Field of Activity*
American Dental Association	Dental research
American Electroplaters' Society	Galvanic effects associated with coating failure
American Society for Testing and Materials	Cement reference laboratory
American Standards Association	Codes, specifications, and standards
Asphalt Roofing Industry Bureau	Asphalt roofing research
Bone Char Research Project, Inc.	Studies of adsorption and adsorbents
NBS–Joint Committee on Chemical Analysis by Powder Diffraction Methods: ASTM, American Crystallographic Assoc., Institute of Physics (British), National Assoc. of Corrosion Engineers	Standard X-ray diffraction powder patterns

Sponsor	*Field of Activity*
National Science Foundation-National Research Council	Atomic physics
Porcelain Enamel Institute	Studies of metallic coatings

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

Donor	*Field of Activity*
American Iron and Steel Institute	Durability of steel pilings
American Iron and Steel Institute	Standard samples program
Corrosion Research Council of the Engineering Foundation	Reactions at metal surfaces and stress corrosion
Edward Orton, Jr., Ceramic Foundation	Research in clays
Expanded Shale, Clay and Slate Institute	Shale aggregate

International Activities. On an international basis, the Bureau represents the interest of the Government and American science in matters dealing with the establishment and maintenance of standards and establishment of values for physical constants. Most of this work is done through participation in a large number of international groups such as the International Bureau of Weights and Measures, the International Union of Pure and Applied Chemistry, International Scientific Radio Union, International Commission on Illumination, and International Organization for Standardization. Staff members attend a large number of international meetings during the year, and the Bureau frequently plays a major role in organizing international committees.

An important aspect of the Bureau's international activities is the contribution to the establishment or development of foreign standards laboratories. This is particularly important for newly developed countries where the experience of the Bureau and its personnel can be usefully applied toward a new activity. This type of aid takes two forms: the loan of Bureau experts to the countries interested in establishing new laboratories, and foreign specialists coming for training to the Bureau. During the past year, 187 trainees and guest workers from 48 countries came to NBS. In addition, 590 foreign scientists visited the Bureau from 54 countries.

There are NBS field stations located in several countries of the world, as part of the Bureau's radio propagation program. One of the most significant is the Jicamarca Observatory in Peru, set up in cooperation with the Instituto Geofisico de Huancayo for ground-based explorations of the upper atmosphere and outer space.

For the first time this year, the Bureau engaged in a program of granting funds to scientific institutions in certain foreign countries, in order to support scientific research supplementing the Bureau's own in-house research program. These grants are financed from local-currency funds accruing to the United States from the sale of surplus farm products; they are therefore

limited to countries where an excess balance of such funds has accumulated. The program has thus far operated in India, Israel, and Pakistan. Eleven grants were conferred during the first year, about 20 more were initiated and are being processed. and an additional 30 requests for support are under consideration.

Grants already in effect cover such topics as calculation of atomic properties of rare earth elements from their optical spectra, lifetime and line shape measurements of spectra of rare earth ions in crystals, study of molecular interactions by means of infrared spectroscopy and of the effects of adsorption on infrared spectra, theoretical and experimental investigations of the Moessbauer effect, studies of the excluded volume in multi-component polyelectrolyte systems and other investigations in statistical mechanics, X-ray crystallographic research in solid-state polymerization, separation of optical isomers by gas-liquid partition chromatography, and solution of boundary value problems on a digital computer.

In addition to the scientific results of these activities, the program has resulted in an increased interest among foreign scientists in the kinds of problems relevant to the Bureau's mission, in greater awareness among Bureau staff members of the scientific potential in other countries, and in intensified communications and exchanges of visits.

ADMINISTRATIVE ACTIVITIES

Several organizational changes were made during 1962 to strengthen various program areas and to accommodate changes in program orientation. As part of the Bureau's intensive efforts to improve its standards and measurement capabilities in the field of electronics, a Radio Standards Laboratory was established at Boulder. The new Laboratory, which replaces the former Radio Standards Division, includes two divisions, Radio Physics and Circuit Standards (see appendix 3.1). This will provide for subdivision of this rapidly expanding program while preserving unified direction.

More appropriate titles were selected for two divisions. Organic and Fibrous Materials was changed to Polymers Division, and a new section structure was established to reflect that division's increasing concern with the physical and chemical properties of polymers. Mineral Products became the Inorganic Solids Division, since this title is more descriptive of the division's current program. In addition, the section organization of the Metallurgy Division was realined to provide increased emphasis on the interpretation of properties of materials in terms of their structure.

A new position, Assistant to the Director for Weights and Measures Administration, was established with responsibility for administrative advisory services to officials of the States on weights and measures matters. Technical services to the States and business and industry in this area of measurement remains with the office of Weights and Measures, which has become a technical division of the Bureau.

In a significant effort to meet urgent demands for basic atomic data in support of space sciences, and to offset the growing shortage of scientists

Architect's rendering of the administration building now under construction at the new NBS laboratories in Gaithersburg, Maryland. (See p. 20.)

trained in atomic physics and astrophysics, the Bureau joined with the University of Colorado to establish the Joint Institute for Laboratory Astrophysics on the University campus at Boulder, Colo. (See p. 8.) The joint institute arrangement is an innovation in Government-university relationships, providing for the collaboration of university and government scientists in an institute which will undertake the training of scientists and students as well as providing a unique center for research in this highly specialized field.

During fiscal year 1962 funds obligated by the Bureau totaled $74,238,000. This included $29,082,000 for construction and facilities. Of the $38,764,000 devoted to research and development activities, $23,759,000 came from direct appropriations to the Bureau, and $15,005,000 from other government agencies and private sources. Calibration, testing, and other services amounted to an additional $6,392,000. A statement of financial data is contained in appendix 3.3.

By the end of the year, the total staff of the Bureau was about 4,000 persons. Approximately one-third of these employees were attached to the Boulder Laboratories. Additional information concerning the staff may be found in appendix 3.2.

Good progress was made during the year toward completion of the Bureau's new facilities near Gaithersburg, Md. Construction of Phase I, which was started in 1961, has moved forward as planned and should be completed during the next year. This includes the Boiler Plant, which will provide heat and cooling for all buildings presently planned for the site, and the Engineering Mechanics Laboratory, which will house the large force-measuring machines, some of which are urgently needed for more precise measurements of the very large forces involved in modern rocket development. Phase II of the construction was placed under contract in June 1962. It includes the Radiation Physics Laboratory, Administration

Building, Instrument Shops, Supply and Plant Building, and Service Building. During the year much effort was devoted to the detailed planning of the seven General Purpose Laboratories which will comprise Phase III, the heart of the Bureau's new facilities. In addition preparations for seeking bids on the National Bureau of Standards Nuclear Reactor were nearly completed.

PUBLICATIONS

Publications are a major end product of the Bureau's research effort. They are the principal means by which the results of NBS projects are made available to science and technology. The publications of the Bureau are therefore suggestive of the scope and level of its technical program. During the year these totaled 989 formally published papers and documents. In addition some 367 classified and unclassified reports were issued to other government agencies.

Among the major publications of the year was *Experimental Transition Probabilities for Spectral Lines of Seventy Elements* (NBS Mono. 53). This Monograph presents further data on the spectral lines tabulated in the two-volume *Tables of Spectral Line Intensities* (Mono. 32) published last year. For the present work, absolute transition probabilities for 25,000 lines were calculated, and the results are tabulated by spectrum.

Another major publication, and two-volume work, was *Chemistry of Cement* (Mono. 43). It contains complete texts of all papers given at the Fourth International Symposium on the Chemistry of Cement, held in Washington, D.C., in October 1960. The Monograph is one of the most complete reference works available on the subject, and presents the latest information in most of the fields of cement chemistry research.

Also notable among the year's many publications was *Weights and Measures Administration* (Handb. 82). This publication presents, in convenient handbook form, a comprehensive guide for the establishment and conduct of an effective weights and measures program, whether at the State level or for a smaller jurisdiction. *Structure Shielding Against Fallout Radiation from Nuclear Weapons* (Mono. 42), summarizes the results of a varied research program at NBS which developed engineering methods and data for solution of fallout shielding problems.

Of the 989 formal publications issued during the year, 160 were published in the *Journal of Research*, and 616 in the journals of professional and scientific societies. Also, 122 summary articles were presented in the Bureau's monthly *Technical News Bulletin*. In the nonperiodical series of publications, 91 papers were published: 19 in the Monograph series, 5 in the Handbook series, 3 in the Circular series, 6 in the Miscellaneous Publication series, 1 in the Applied Mathematics Series, and 57 in the Technical Note series.

Basic Radio Propagation Predictions, the Bureau's third periodical, which is published for a 1-month period 3 months in advance, presented radio propagation data needed for determining the best radiofrequencies to use in long-range radio communications.

A list of publications for the fiscal year, which includes several papers published in the previous year but not reported, is given in the appendix, section 3.7 (p. 187).

During the year, the Bureau participated in 29 scientific and technological exhibitions, with exhibits depicting the Bureau's research programs. Typical of the year's shows were: National Academy of Sciences, Washington, D.C.; Space Age Industries and Engineering Exposition, San Francisco, Calif.; International Conference on Spectroscopy, College Park, Md.; and American Standards Association, Houston, Tex.

The Bureau's motion picture program included 3,148 showings of NBS films to a total audience of 604,222, including educational television.

2. HIGHLIGHTS OF THE RESEARCH PROGRAM

The Bureau's technical program is carried out through organizational units called divisions. These are shown in appendix 3.1 in numerical order. A review of selected research and development programs is presented in this section under headings corresponding generally to these organization units but rearranged to bring together related types of activity.

2.1. PHYSICS, ELECTRONICS, AND MEASUREMENT STANDARDS

2.1.1. METROLOGY

The metrology laboratories of the Bureau maintain, develop, and disseminate standards for the commonly used physical quantities, including length, mass, volume, density, and angle, as well as light, color, radiation, refractive index, and other optical and photographic quantities. Although some measurements are made of quantities measured by the ancients, scientific techniques now used provide a considerably higher accuracy than they were able to obtain. For example, studies of the properties of a recently constructed gaseous laser indicate that the laser output is sufficiently coherent to theoretically permit measurements to wavelength precision over distances of 100 kilometers or more. Plans have been developed for using the laser to redetermine the speed of light with an accuracy consistent with future space requirements.

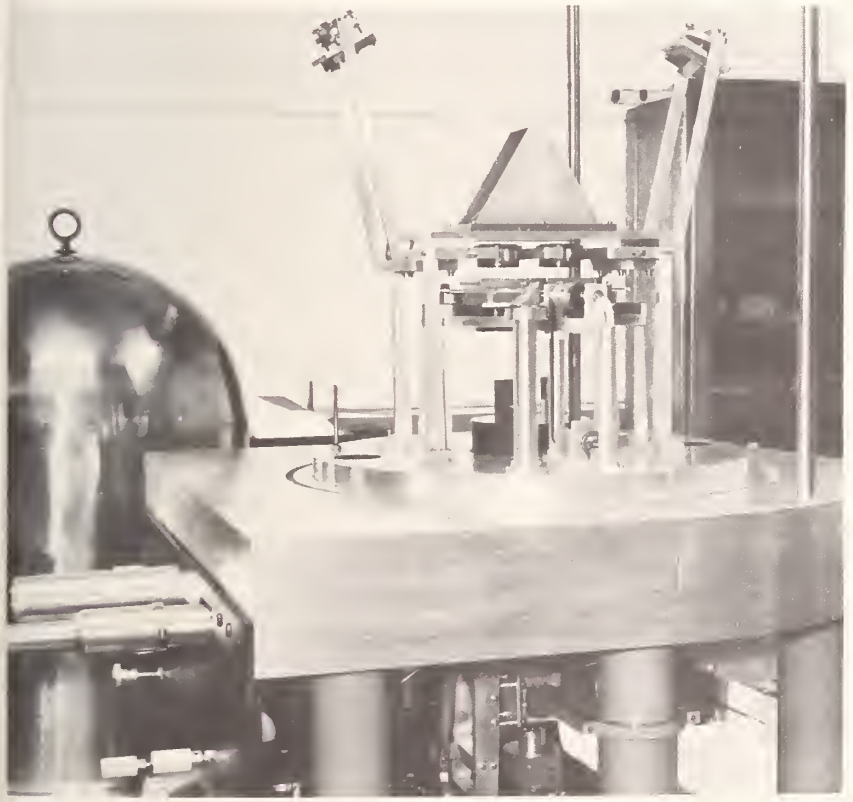
Industrial needs accentuate the problem of length measurements when the shapes of objects, such as gears, ball bearings, or other moving parts, are involved. To aid industry in meeting these needs, a gear metrology laboratory has been established—the first of its kind in the country—and master involutes were measured and compared with the standards of commercial gear laboratories. Methods were also developed for measuring diameters of master spheres up to 3 inches in diameter with a certified accuracy of two millionths of an inch. The need for extremely accurate spherical components

of missile guidance systems is responsible for a considerable portion of the demand for precise measurements of spheres.

Other developments having important industrial implications for economic growth and progress include the measurement of standards for surface finish by interferometric means, and the completion of an interferometer for measuring gage blocks to one ten-millionth of an inch.

An example of contribution to national scientific needs is the completion, in cooperation with investigators from outside of the Bureau, of a revision of the values of physical constants, such as electronic charge and Avagadro's number. This work is particularly timely because of the recent international adoption of a new scale for atomic masses based on the isotope carbon 12.

Photometric Units Internationally Intercompared. Lighting equipment (incandescent lamps, fluorescent lamps, and luminaires) made in this country is sold all over the world in competition with the products of other



Ultra-precise gage block interfermoter developed as part of a program to provide length calibrations to 1 part in 10 million. During operation, the aluminum bell jar (left background) covers the optics and working area of the instrument, and all manipulations are performed from a control panel removed far enough from the instrument to prevent the operator's body heat from affecting the measurements. **(See p. 26.)**

countries. To assure a fair competitive basis, the light output of this equipment must be evaluated in comparable terms. Hence, the various national photometric units must be in close agreement. Periodically, these national photometric units are intercompared at the International Bureau of Weights and Measures by means of photometric standards (incandescent lamps) from each nation. The latest international comparison showed only small deviations between the U.S. national standards and the average of the national laboratories of Canada, England, France, Eastern Germany, Western Germany, Japan, and Russia.

Slant Visibility Meter Developed. Application of measurements made by a slant visibility meter to airfield operations requires two assumptions: (1) Transmission of the atmosphere is uniform horizontally but may vary vertically; and (2) conditions are stable so that the visual range does not change significantly between the time an aircraft is cleared to land and the time the landing is made. However, experience has shown that under fog conditions the horizontal variations in transmission are as great as or greater than the vertical variations, and that conditions often change significantly within a very few minutes. Thus the accuracy or usefulness of such a meter is limited by natural conditions, and a complex instrument will have little more value than a much more simple instrument.

These factors were considered in the design of a simplified slant visibility meter for the Bureau of Naval Weapons. An instrument was developed that gives a clear indication of ceilings and the tops of fog layers which are below 700 feet for any visibility greater than 1/16 mile; gives a readily interpretable indication of whether the fog increases, decreases, or does not change with height; and, if the fog density changes with height, gives an indication of the rate of change.

Four-Filter Thermoelectric Colorimeter. To utilize the superior stability of the thermopile as a detector of heat, such a detector was substituted for the less stable photocell in a colorimeter used at the Bureau for calibration purposes. Four filters designed to convert the nonselective response of the thermopile into responses proportional to the color-matching functions of the average normal human eye were designed and built. The instrument provides a rapid means of measuring the color coordinates of the light filters used in color measurements, and, unlike photoelectric colorimeters, it probably will not require frequent recalibration.

Refractive Index Measurements Extended. Calibrated wavelength standards are available from the Bureau for making high-precision measurements of refractive index at discrete values of wavelength. However, refractive index over a range of wavelengths is often needed by users of optical materials. To provide an accurate means for interpolating the Bureau's measured values to the desired range, refractive index data were fitted to the classical Sellmeier formula relating wavelength to refractive index. A three-term Sellmeier equation containing six parameters was used. Three of the parameters enter the equation nonlinearly, precluding the use of a straightforward least-squares process. So an iterative least-squares procedure was

developed by means of a high-speed digital computer. A large number of refractive index measurements can now be fitted in only a few minutes with a precision consistent with the accuracy of the original measurements.

Fiber Optics. Although the principle of fiber optics has been studied for many years, only recently has any serious work been done toward marketing items utilizing this principle. As a result, the refractometry laboratory of the Bureau is being called upon to evaluate the image-producing qualities involved in fiber optics materials. Hence, methods are being developed to determine the resolution, numerical aperture, and transmittance of such materials.

Luminance Standards Developed for Photographic Exposure Meters. To obtain a good photograph, the exposure must be adjusted to the speed of the photographic material. This adjustment is accomplished by a photocell which either automatically adjusts stop size and exposure time or else provides the operator with information enabling him to do so. At the request of the photographic exposure-meter industry, acting through the American Standards Association, the Bureau developed luminance standards for the calibration of exposure meters. They take the form of an incandescent lamp combined with a blue glass to duplicate average sunlight, and a diffusing plate of white plastic. This combination of lamp, filter, and diffusing plate provides a 5-inch square of uniform luminance.

Absolute Measurement of Sphere Diameters. Interchangeability in industry requires the use of master spheres whose absolute sizes are known to a very high degree of accuracy, and a few sets of these master spheres having roundness deviations of less than 2 microinches and diameter tolerances of 20 microinches, were recently manufactured. Consequently, special fixtures were designed and built by the Bureau so that a sphere could be calibrated by placing it as a spacer between interferometer plates.

Fizeau interference fringes are produced when the plates are in the path of a collimated beam of light from either a mercury 198 or a cadmium lamp. The fringe fractions from selected visible radiations are read, and the plate separation at the points of contact with the sphere is determined by the method of excess fractions. Corrections are made for elastic deformation, for thermal expansion, for phase retardation of the light due to penetration and reflection at the base interference plate, for wavelength due to the effect of air temperature and pressure and water vapor pressure, and for an accessory block to give sphere diameter in its free state at 20 °C. Diameter measurements to an accuracy of 2 microinches were obtained on spheres up to 1⅝ inch diameter. The apparatus has a capacity of 3 inches.

An interferometer was also developed for measuring deviations from sphericity of small spheres. It consists primarily of a Koesters double-image prism having a portion of a sphere as its base, combined with a microscope objective of short focus and large normal aperture. The center of the sphere is placed at the point where the rays from the interferometer prism are focused by the objective. Straight-line interference fringes are observed over a relatively large area of the sphere surface when it is truly spherical.

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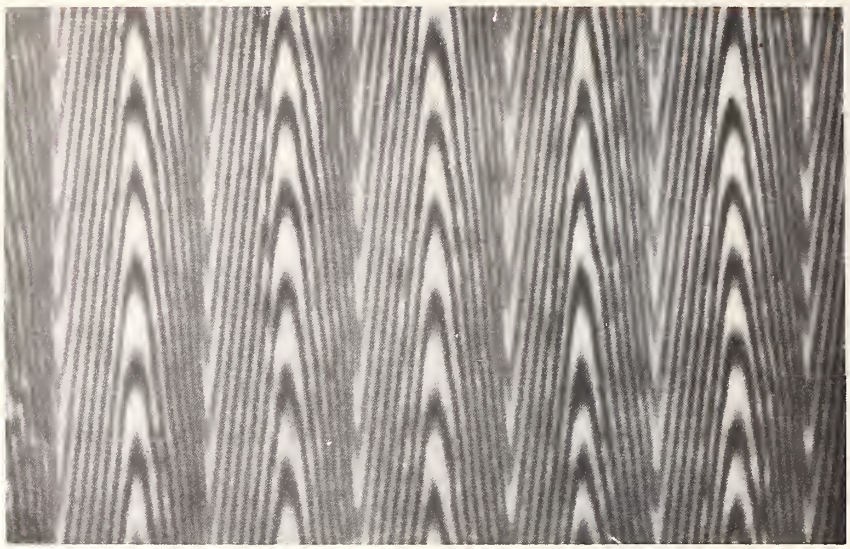


Photomicrograph of interference pattern of a surface roughness standard used for calibration of stylus-type roughness measuring instruments. The depth of the grooves averages 20 microinches. **(See p. 29.)**

Revised Length Calibration Equipment and Procedures. The intercomparison method of mechanical measurement for 0.01- to 0.09-inch gage blocks was developed to replace the accurate but costly interferometric method. For the first time gage blocks measured only by mechanical methods were certified to an accuracy of ± 2 microinches, equal to the accuracy of routine interferometric calibration. Plans are now under way to extend this service to the size range 0.1 to 1.0 inch.

Construction and preliminary testing of an ultra-precise gage block interferometer was completed during the year. This instrument provides absolute length measurements of gage blocks in terms of the wavelength of light. To achieve the uniform and constant temperature condition necessary for length measurements accurate to 1 part in 10 million, a polished aluminum bell jar is used to cover the optics and working area of the instrument. Unique features include an optical compensating device that modifies the observed measurement patterns to facilitate optimum precision of measurement, and a temperature-measuring system that provides a representative internal temperature measurement of the gage blocks under test.

Glass Bead Standard Samples. New standard samples of glass beads were prepared to provide a distribution of beads having specified diameters. These beads are used by the scientific and industrial community for routine calibration of sieves. The new sample, No. 1019, together with the two samples previously available, may be used to grade diameters from 50 to 2600 microns.

Gaseous Laser for Interferometry. A helium-neon optical maser with external confocal reflectors was constructed to study the mode patterns and

frequency distribution of laser output. Interference fringes of the 11,522.82-Angstroms (A) spectral line were observed in Fabry-Perot interferometers up to one meter in length. Analysis of the fringes showed that maser action occurs at five different infrared frequencies spaced by about 75 megacycles per second (Mc/s) (or 0.0033 A) within this spectral line. Radiofrequency beat notes between these frequencies were also observed. The beat note spectrum exhibited a splitting that varied between 0 and 20 kilocycles per second (kc/s), probably due to a "hole burning" effect previously suggested by others.

Gear Metrology Laboratory Established. Research in precision gear metrology, and the development and calibration of highly accurate dimensional masters for elements of gears and gear teeth, as well as master gears of improved design, are needed for the improved performance of gear trains. To fulfill these needs, a gear metrology laboratory was established, having temperature controlled closely at 20 °C and a relative humidity of less than 50 percent. Equipment for measuring certain elements of both small and large gears was installed. As a first step in this program, highly amplified charts of the involute form of a series of accurately made master involutes were made by means of a recording involute-form rolling instrument having amplifications up to 8000×. With one of these master involutes and accompanying charts for comparison purposes, a survey was made of the performance of involute checking instruments used by industrial plants throughout the country. Improvised high amplifications were applied to these instruments in place of the 500 to 1000× amplifications usually available. Agreement within about 50 microinches (or 1.2 microns) was found, but the comparisons pointed up the need for precision-calibrated master involutes in the various inspection departments of the plants.

Wave Front Shearing Interferometer. A prism type of wave front shearing interferometer was developed. The instrument measures the absolute shape of wave fronts that are produced by any optical element or combination of elements (reflectors or refractors). The magnitude of the aberration in the interferometer is found to be insignificant for beams smaller than an $f/3.5$ cone. If spherical entrance faces are used, this aberration can be reduced to zero for any size of beam.

In the construction of the device, a ray trace through the prism verified the observation that the two images of the wave front were rotated relative to each other slightly when the shearing action was produced by rotating one prism relative to the other. However, other means of producing shear were found in which no rotation of wave fronts occurred. For extreme accuracy this rotation is undesirable when testing large angle cones of light.

The fringes produced by the prism are nonlocalized, so the shape of the wave front at any position or distance from the lens is obtained by simply focusing the camera or other receiver on the desired location. Thus, the change in the shape of a wave front, and consequently the change in phase at the point of convergence, may be obtained by measuring the wave front shape before, during, and after it passes through the point or area of convergence.

It was recently found that the number of reference points that may be used (previously believed to be limited to only a few) is unlimited. Thus, a continuum of points may be approached and all details of the wave front obtained.

Standards of Mass and Weighing Techniques. An arresting mechanism was developed for knife-edge balances which requires only one moving part and permits all knives and flats in the system to remain in contact during the unloading and reloading process. The arrestment error associated with this device is a few parts in one billion, at the one-kilogram level.

No practical method has been available for hydrostatically weighing fractional-gram weights, due to uncertainties in the meniscus correction. However, the Cartesian diver, operating completely submerged, offered a possible solution. Hence, a crude closed-body Pyrex diver was blown and allowed to fall under constant pressure. It was loaded first with one, then with a second, 150-milligram weight, the two differing by about 15 micrograms in weight. The difference in fall rate, clearly visible to the naked eye, demonstrated the practicability of such a device for the hydrostatic weighing of small weights.

Experiments conducted in NBS shops showed that Hull's method of burnishing stainless steel to a high finish with a diamond tool was satisfactory for standard weights. The use of this process eliminates much of the time-consuming and costly polishing which weight manufacturers previously performed in order that weights would meet acceptable standards.

For a given material the surface-to-mass ratio of weights increases as their size decreases. It is desirable to minimize this ratio; however, fractional gram weights are usually constructed from sheet metal or wire which tends to increase this ratio. A method of melting fine wire and letting the surface tension of the liquid metal form a sphere—which has the most favorable ratio—was developed, and several platinum weights were constructed.

Recent experiments demonstrated that the passage of small amounts of a-c power through a knife-flat contact did not result in a measureable change in balance performance. A condenser plate was therefore attached to the beam of the NBS one-kilogram balance and energized through the knife edge. This device permitted mechanical manipulation of the beam by a small externally controlled variable electrostatic force, and eliminated most of the uncertainties of operation associated with mechanical members being brought into contact with the beam.

As a part of a continuing program for improving the precision of mass measurements and mass standards, a 200-milligram torsion fiber balance was put into service for calibrating weights 200 milligrams and smaller. It is an equal-arm balance in which torsion fibers (instead of the conventional fulcrum knife edge and plane) and suspension fibers (instead of the terminal knife edges and planes) are used. These fibers, made of fused silica, are fused to the beam, which is also made of fused-silica fibers fused together to form a one-piece unit. The free end of one of the torsion fibers is fixed to the case and the free end of the other torsion fiber is attached

to a rotatable graduated dial. The pans are suspended in wells from the suspension fibers. The position of the beam is indicated by a horizontal fiber seen as two parallel horizontal lines in the eyepiece of an optical system similar to that of a comparison microscope. With this system the balance is readable to 0.01 microgram.

To improve the usefulness of the torsion fiber balance as a calibration instrument, the illumination of the index fiber was improved and a loading platform was added at pan level. The platform can be moved in and out of the pan well with the well door open. To further facilitate handling of small weights, a binocular microscope is focused on the balance pan. With this arrangement, a standard deviation of a few hundredths of a microgram is attainable. To fully utilize the precision inherent in this balance, two sets of suitable national reference standards were made and carefully calibrated.

Surface Roughness Standards. Two types of surface roughness standards are used for the calibration of stylus-type roughness measuring instruments. One, a 2 × 3 inch rhodium-plated plaque, has a 150-degree triangular pattern, and the other, a similar plaque made of glass, has an

Diamond burnishing was shown to give the necessary high surface finish to standard weights. The process eliminates much of the time consuming and costly polishing previously necessary in production. **(See p. 28.)**

etched trapezoidal pattern. Slight deviations from the basic waveforms of these patterns recently caused difficulty in instrument calibration, so a reevaluation of the calibration techniques used was made.

The measuring force on the stylus was reduced to a point where no visible permanent deformation of the standard occurred, and the traversing velocity was reduced enough so that dynamic tracking effects were eliminated. Interferometric measurements on gage steps permitted investigation of the instrument magnification, linearity, and hysteresis.

A simple method was devised for the measurement of radius of curvature of the tracing stylus. Measurements of the average curvatures in the "corners" of the samples were made by microinterferometry, providing corrections for the differences between the locus of the stylus motion and the true waveform of the sample. Measurements were also made of the uncertainty in using a planimeter for the evaluation of roughness, and one of the triangular-wave-type standards was calibrated by the planimeter method for use as a master for calibration by comparison.

A series of comparisons of measurements on surface roughness standards was undertaken. A British manufacturer of surface roughness measuring equipment supplied samples, and measurements were compared with those of an Atomic Energy Commission laboratory. Average deviations from the mean values on four samples were very small, and further work with other laboratories is contemplated.

2.1.2. MECHANICS

The Bureau's work in mechanics is primarily in the development and improvement of methods of measurement of mechanical phenomena in solids, liquids, and gases; the establishment of required standards in mechanics and the relation of such standards to the prototype standards; the support of these activities by theoretical and experimental researches into mechanical phenomena; the determination of physical constants of particular importance in mechanics; and provision of assistance to other laboratories in relating their measurements to a common basis (or to established standards) by transfer standards, calibration services, and other means. Measurement areas include sound pressure and intensity, shock, vibration, force, strain, pressure, vacuum, viscosity, and rate of gas and liquid flow.

These measurement areas are of vital importance in the missile and space programs, which require great accuracies over widely extended ranges under extreme temperature environments. Special emphasis therefore is given to research directed toward meeting these needs.

Because of the increasing requirements for measuring mechanical quantities in defense industries and in government laboratories, and because of the requirements of missile and space projects, requests for calibration services continued to increase.

Considerable progress was made in the design of the special-purpose equipment to be housed in the Engineering Mechanics Laboratory now under

construction at Gaithersburg, Md. Detailed data necessary for the planning of the Sound Laboratory and the Fluid Mechanics Laboratory were developed for use in preliminary work on the design of these buildings. The availability of these facilities will make it possible to provide more comprehensive services in several of the measurement areas in mechanics.

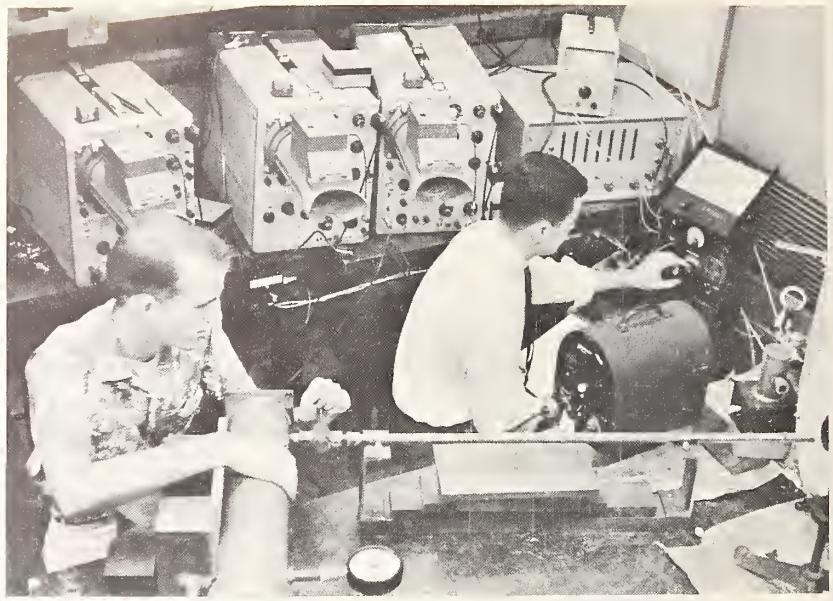
Infrasonic Waves in the Atmosphere and in the Earth. Infrasonic waves having fairly constant periods of about 6 seconds pass through the atmosphere of the Washington area. These waves—usually called microbaroms—come mainly from easterly directions and travel parallel to the ground. A mathematical analysis of the influence of ocean waves on the atmosphere shows that these might be the source of the infrasound. The impact of waves on a beach produces the familiar audible sounds of surf, and, in addition, the periodic arrival of the waves can generate infrasound of the same period in the atmosphere. Experiments are being planned to check the validity of this hypothesis.

The infrasound generated by geomagnetic storms comes mainly from northerly directions, possibly from the auroral zone in the Arctic. A new infrasonics station is being installed at the Bureau's Boulder (Colo.) Laboratories to obtain data that will supplement data from the Washington station. The two stations will show a directional effect that may make possible a decision as to whether or not these waves originate in the auroral zone.

The microbaroms in the atmosphere have their counterpart in the microseismic waves in the earth's crust, as these waves also have periods near 6 seconds. Three seismometers of a pattern developed at the Bureau are being installed at sites spaced far enough apart to allow determination of the propagation speed and direction of the microseisms. It seems unlikely either that the microbaroms cause microseisms, or vice versa. Whether or not they have a common origin is one question to be studied with the combined infrasonics and seismics stations.

Elastic Changes Caused by Static Loads. The nature—even the question of the existence—of the so-called Fitzgerald "resonances" in various crystalline materials has engendered much discussion and controversy in recent years. According to Fitzgerald's theory, certain static stresses, either residual (built-in) or due to external load, cause severe changes to occur in the dynamic elastic constants of these materials. Characteristic of these changes are sharp resonances and high internal friction at various frequencies in the range 100 to 5000 cycles per second (c/s). There is also a general loss of elastic stiffness over this range, particularly at the lower frequencies.

The implications of such effects in the fields of fatigue failure of machine and structural elements, particularly those associated with aircraft, are serious, as are also the fundamental solid-state problems raised. For this reason, the Bureau undertook measurements on quartz, fused silica, and polycrystalline aluminum. The technique used was designed to allow easy detection of these effects, provided that they actually are associated with the theory proposed to explain them or with any similar theory. No trace of the predicted effects on the elastic constants was found. This negative



Stress-strain characteristics of metals at high temperatures (up to 1,460 °F) were obtained by impacting cylindrical specimens in a furnace (barely seen at right) with projectiles impelled by an air gun (foreground). (See p. 35.)

result lends support to the conception that either the theoretical background employed by Fitzgerald to explain his results is not relevant to them, or that the observed resonances are artifactitious.

Acoustical Repulsion of Birds at Airports. The Fish and Wildlife Service is studying the use of acoustical stimuli to repel birds from airports. At airports near the ocean, the presence of sea gulls on or about the runways presents a great hazard to aircraft. In order that the acoustical signals used in this program may be accurately controlled, NBS is working with the Fish and Wildlife Service—giving technical advice on equipment and on its operation and calibration. As part of this study, scientists from these organizations made two field trips to a nearby area frequented by these birds. The scientists played at various sound levels previously recorded tape of the distress cries of sea gulls. At most of the sound levels, 10 seconds of signal was enough to repel the gulls out of sight. Generally, within an hour or two gulls would again be feeding at the site. It is not known at this time whether the same gulls returned or a new group of gulls flew in.

Reverberation-Chamber Technique for Calibration of Standard-Type Noise Sources. A new reverberation-chamber method of test was developed for the measurement of sound power output of noise sources in both 1 and ⅓ octave bands covering the frequency range 40 to 10,000 c/s. The development of the method required specialized calibration of the reverberation chamber and of all instrumentation over an extended frequency range.

The test method was developed primarily for the calibration of standard-type noise sources, which, by means of a substitution technique, are used in determining the acoustic power radiation of various types of noise sources in field environments. The substitution technique may substantially increase the accuracy of such measurements in field installations, where conditions depart drastically from the closely controlled ones in laboratories.

Field Measurements of Airborne and Impact Sound Insulation. Many nations throughout the world have had rather stringent noise-control requirements embodied in their national building codes for the past two decades. These requirements have served to restrain the growth of noise levels and to suppress the tendency toward inferior sound insulation often produced by modern building technology with its emphasis on economy and lightweight construction.

In the United States, the building codes contain no noise-control requirements. However, the FHA has recently taken positive action to incorporate noise-control requirements in its building requirements, which are presently undergoing revision.

A considerable amount of work bearing on the development of such requirements, closely coordinated with the FHA's activity, was undertaken at the Bureau. The work dealt with the most pressing noise-control requirement, that of developing impact sound insulation criteria. Reviews and analyses were made of numerous foreign publications and building codes pertaining to sound insulation in dwellings and of field measurements. A series of impact tests was conducted on more than 15 basic types of floor-ceiling structures for the collection of data essential to the establishment of noise-control criteria in building codes.

Pressure Measurement. Providing standards and measurement techniques over the range of pressures of current interest in science and industry is a formidable task, for these range from about 10^{-15} millimeters of mercury in the ultra-high vacuum range to about 2.5×10^{9} millimeters of mercury (about 50,000,000 pounds per square inch (psi)) in shock-wave measurements. At present, standards and techniques are adequate for only a few decades above and below atmospheric pressure (760 millimeters of mercury (mm Hg)). Work is in progress on methods of generating and measuring pressures to extend the range covered by adequate standards and techniques to both higher and lower pressures. Production and measurement of pressures at the extremes of the 24-decade range of interest involve great difficulty because of limitations of material properties, etc.

Advances were made at several levels of vacuum measurement, such as in the evaluation of McLeod and ion gages by means of the volume expansion technique. The first experimental model of one of the instruments being developed for the vacuum range was put into operation. This apparatus, which is known as an interferometer—oil-manometer, makes use of an interferometer for measuring the difference in height between the two surfaces of oil in a manometer. Preliminary results indicate that the sensitivity of the instrument is adequate to permit its use for measurement of pressures as low as 10^{-5} mm Hg.

In the range of high-pressure measurements, a new controlled-clearance piston gage was put into operation at pressures up to 120,000 psi. The gage is of an improved design with a piston 0.080 in. in diameter. Some idea of the performance of the instrument, which met all expectations, may be gained from the fact that the oil leaking past the freely rotating, unpacked piston would amount to only 1 cubic inch in 20 years at a pressure of 110,000 psi. Readings were reproducible to ± 1 psi at 100,000 psi. This piston gage is being used for a new determination of the freezing pressure of mercury at 0 °C and approximately 109,800 psi. These conditions are of considerable importance as presenting a fixed point for the calibration of other pressure-measuring instruments.

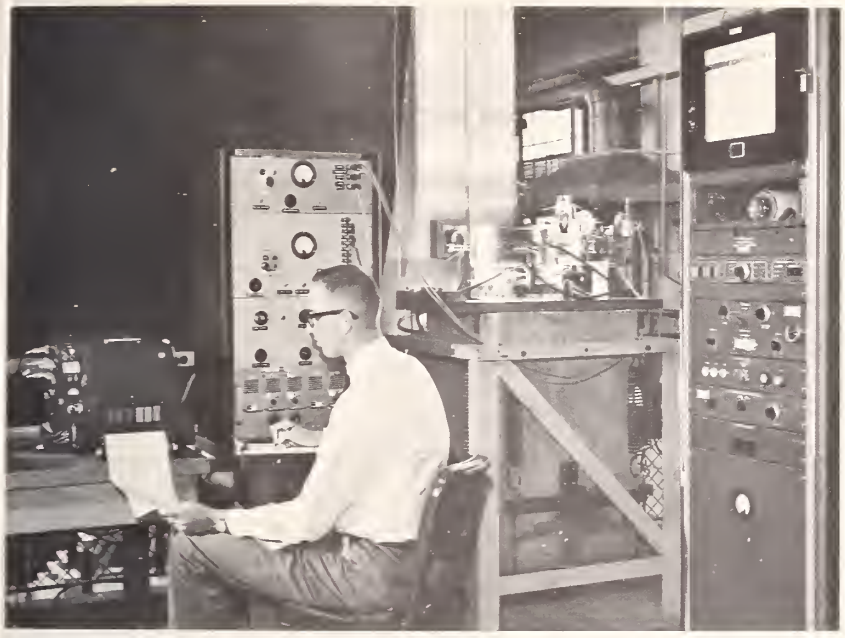
Ultra-high pressure measurement work continued with the multiple anvil devices capable of generating pressures in excess of 1,000,000 psi. Exploratory work was done on additional types of apparatus in an effort to evaluate transitions useful for fixed points at higher pressures. One of these is a "two-stage" modification of the tetrahedral device. This modification increased the pressure range of the apparatus while retaining its capability of generating high temperatures through internal heating.

Hydrodynamic Effect of Hydrophobic Materials. It is well known that water will not cling to certain materials when their surfaces are clean and no wetting agent has been added to the water. Such materials are termed hydrophobic or, since this is a surface effect, the surface may be called a hydrophobic surface. Questions have often arisen in regard to the hydrodynamic effect of this property, such as whether the friction between a fully submerged surface of this kind and the water is less than it would be for a wetted surface. An investigation conducted a few years ago with Teflon as the hydrophobic material showed no effect on the friction to flow through a tube.

In a recent investigation supported in part by the Office of Naval Research, another situation was studied in which a difference was found between the behavior of hydrophobic materials and wettable, or hydrophilic, materials. In this situation, the material in the form of a plate was moved in and out through a water surface. The hydrophobic material came out "dry," while the wettable material retained a film of water on its surface. An added force opposing the motion was found to be associated with the peeling off of the water from the hydrophobic surface when the plate was moving out, and an equal and opposite force, again opposing the motion, was associated with the replacement of water in contact with the surface when the plate was moving in. As soon as the plate started to move in or out, the force appeared and was independent of the rate of motion.

The forces that in this case—of the nonwettable property—affect the movement of a fluid are several times larger than those due to surface tension. While their action is of a different nature, the conditions under which they become significant are similar.

Culvert Hydraulics. For the past several years, the Bureau of Public Roads has sponsored an experimental investigation of culvert hydraulics.



Recording data on the performance of resistance-type strain gages when subjected to varying thermal and mechanical loads. Modern structures, especially missiles and space vehicles, must be designed to sustain high loads at high temperatures—environmental testing of such structures requires strain gages which will perform reliably under the same conditions. **(See p. 36.)**

A major portion of the study has been concerned with the factors controlling the hydraulic efficiency of pipe culvert inlets. However, since the design problems of box culverts are also of importance, recent emphasis has been directed toward the investigation of their flow characteristics. The box culvert is a culvert of rectangular or square cross section, frequently used in situations where pipe culverts would not be economical.

The development of improved inlet structures for box culverts is the principal goal, as it was for the pipe culverts. It has been shown that culvert inlets are sensitive to the ventilating effects of vortices over the inlet and are significantly affected by approach channel conditions. Consequently, it is difficult to define their performance with a single and unique discharge relationship. The investigation has furnished adequate methods of bounding the region of performance to be expected in the field. General design criteria for the utilization of susbtantially improved inlets, similar to those derived for pipe culverts, are under development.

High-Temperature Impact Tests. Techniques and equipment were developed for impacting cylindrical specimens at temperatures up to 1,460 °F with known instantaneous contact stresses up to 90,000 psi. In one method, an air gun accelerates an elongated bullet to strike an anvil bar to which strain gages are attached, which in turn enters a furnace and impacts a heated specimen. As the strain sensors remain substantially at room tempera-

ture, wire strain gages can be used on the anvil to yield impact stresses with an accuracy of 5 percent or better. The gage output is recorded continuously on oscilloscopes. The technique has been used for determining high-temperature stress-strain characteristics of metals at rates of straining up to 1,000 in./in./sec, and also for evaluating high-temperature instrumentation under impact conditions.

Spectrum Fatigue of Aircraft Structures. Under sponsorship of the Bureau of Naval Weapons, programed variable-amplitude fatigue tests were carried out on built-up aluminum alloy beam specimens using variations of an aircraft loads spectrum. The fatigue properties of the beam specimens were found to be similar, in several respects, to those of certain full-scale aircraft structures. The test results showed that none of the currently available theories of cumulative fatigue damage were adequate for the dual purpose of predicting spectrum fatigue life and evaluating the relative effects of individual load levels in the spectrum. However, the spectrum fatigue behavior of the specimens was consistent with the measured effects of preloading, periodic overloading, and periodic underloading.

Strain Gage Evaluation. Modern structures, especially missiles and space vehicles, must be designed to sustain high loads at elevated temperatures. Some of the more severe operating conditions involve transient loads applied simultaneously with intense heat. Strain gages capable of reliable operation under these conditions are needed to determine the capability of materials and structural configurations. In cooperation with the Bureau of Naval Weapons and Aeronautical Systems Division of the Air Force Systems Command, the Bureau developed equipment for evaluating the performance of various types of strain gages as they are subjected to rapid loading while being heated at 40 °F per second to temperatures as high as 1,500 °F.

High-Temperature Tests of Vibration Pickups. Modifications made in a commercial vibration calibrator and special heat sources permit tests and calibrations of vibration pickups at frequencies from 10 to 2,000 c/s and at temperatures up to 1,000 °F. A mounting table with a built-in heating element is isolated thermally from the shaft and driving coil of the moving element by a compact, circulating water, heat exchanger. This simulates the situation of a pickup mounted on a hot body and surrounded by relatively cool gas. For the condition of uniform temperature, a furnace with radiant heat sources is placed around the pickup. Studies of effects of temperature on sensitivity factors and measurements of temperature coefficients were made on selected devices for the Bureau of Naval Weapons.

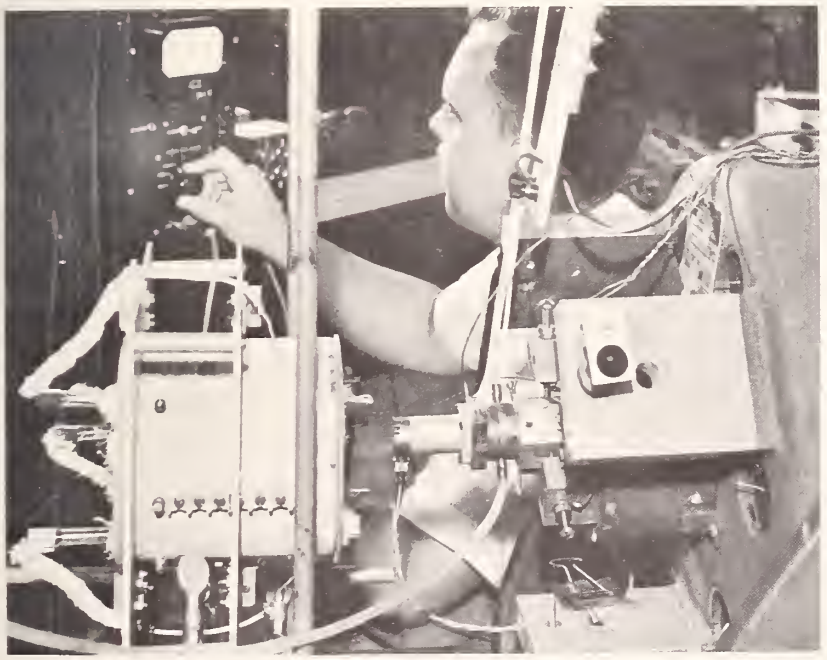
Rheology. Three independent techniques for the absolute measurement of viscosity are under development. Studies are being made of the inertial effects of a hollow sphere full of test fluid, the loading on a cylindrical crystal in torsional oscillation immersed in a test fluid, and an experimental technique to eliminate end effects in capillary flow. These studies should result in a check on present standards of viscosity, and possibly a convenient way of eliminating the need for standard viscosity samples. Some unusual methods for calculating nonlinear hydrodynamic effects are being developed.

These refer, in particular, to the nonlinear effects of inertia and of viscous heating.

Stress relaxation measurements were made on certain rubberlike polymers in simple extension. Concurrently, a simple nonlinear theory of viscoelastic solids was worked out. This theory, which is only second-order in a certain sense, seems to explain stress relaxation data over a surprisingly large range of deformation ratios and accounts for several phenomena previously attributed to *ad hoc* molecular mechanisms. A more crucial test of the theory will be undertaken with experiments on biaxial stress relaxation.

Hypersonic Combustion. Stabilization of combustion in hypersonic streams of air and fuel is a prerequisite to application of combustion to hypersonic propulsion. Research on stabilization and properties of combustion by detonation continued by observation of a hypervelocity missile in a stationary combustible gas. A detonation is regarded as a shock wave followed by combustion. Ignition delays for various fuels were determined from observed separation of shock and combustion waves at the front of the missile. Wave shape and position are being used in calculations to derive the structure and rate of heat release in the detonation wave.

Fluid Metering. In an attempt to attain increased accuracy in the calibration and application of instrumentation, the Bureau of Naval Weapons requested NBS to plan and conduct a Colloquium on Fluid Metering. Those



Final operational checkout for a velocity type vibration pickup prior to testing it at elevated temperatures. The pickup (center) will be heated in the furnace at left to determine the effects of high temperatures on its operating characteristics. **(See p. 36.)**

attending were engineers and senior technicians from Naval Air Stations and Naval laboratories. Speakers from industry, Naval laboratories, and NBS presented selected topics which included the theory and application of turbine, variable-area, positive displacement, and differential pressure flowmeters with both compressible and incompressible fluids. Calibration techniques were discussed and laboratory demonstrations were arranged to illustrate calibration procedures using liquids, LP gas, and air as the calibration fluids. Data work sessions were conducted to illustrate the application of existing codes, standards, and recommended procedures to specific problems encountered in fluid metering.

Calibration of transfer reference flowmeters for the fuel flow rate standardization program was continued. These meters are used by others in the aircraft industry to evaluate the accuracy of their calibration facilities. Other work included calibration of reference fuel control units for gas-turbine engines and a preliminary investigation into swirl or rotational flow and its influence on conventional flowmeters.

High-Temperature Thermocouples. At least three iridium-rhodium versus iridium thermocouples are in current use in various laboratories for measurement of high temperature. The alloy wires of these thermocouples contain 40, 50, and 60 percent iridium, and 60, 50, and 40 percent rhodium, respectively. Reference tables giving temperature-emf relationships up to 3,800 °F have been published for the 40 percent iridium-60 percent rhodium versus iridium thermocouple.

Observations have been completed on the 60 percent iridium-40 percent rhodium versus iridium thermocouple up to 3,900 °F, and reference tables for it are being compiled. Preliminary observations up to 3,900 °F have been taken on the 50 percent iridium-50 percent rhodium versus iridium thermocouple.

Stability Tests of a New Thermocouple. The Aeronautical Systems Division of the Air Force Systems Command sponsored evaluation tests of a new thermocouple known as Platinel II, which was developed by an industrial corporation for use in the temperature range somewhat above that of currently used base-metal thermocouples. Ten thermocouples from three lots of wire were heated in oxidizing atmospheres at various temperatures and for different lengths of time to determine the stability of their calibrations.

Some of the thermocouple wires were heated by passing an electric current through them; others were heated in a muffle furnace. With the exception of one sample, the thermocouple calibrations were fairly stable after being heated for 1,500 hours up to 2,200 °F. After heating at 2,300 °F, the deviations from the original calibration were quite large.

Twenty-four commercial-type Platinel II thermocouple probes were exposed to a thermal shock test. Most probes failed before completion of the specified duration; however, the test conditions are probably more severe than those encountered in most applications.

Catalytic Effects of Thermocouple Materials. Work to determine the catalytic effects of several of the commonly used thermocouple materials on gaseous mixtures containing combustible gases and oxygen has been completed. The work, sponsored by the Aeronautical Systems Division of the Air Force Systems Command, included experiments in low-velocity gas streams of prepared mixtures of hydrogen, carbon monoxide, propane, and methane in air. Experiments were also made in the more realistic gas flows from the burning of hydrocarbons in air. The composition, velocity, and temperature of these gases simulated those in gas exhausting from a conventional turbojet burner.

In all these experiments, gold, silver, Chromel, Alumel, and constantan were found to be noncatalytic. Platinum, palladium, iridium, and alloys containing these metals were found to catalyze the combustion of the unburned products. The use of base-metal thermocouples is therefore recommended where appreciable amounts of combustible gases and oxygen are present.

2.1.3. ELECTRICITY

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

Absolute Measurements. A new evaluation, in terms of the prototype standards of length and time, of the unit of resistance maintained at the National Bureau of Standards was completed. The evaluation was based on a nominally 1-picofarad symmetrical cross capacitor having a value that could be computed to high accuracy from its mechanical dimensions. The computable capacitor was used to establish the value of a 0.01-microfarad capacitor which then, through the medium of a frequency-dependent bridge, established the value of a 10,000-ohm resistor. A measurement of that resistor in terms of the unit maintained by the group of 1-ohm standard resistors currently used to maintain the National Bureau of Standards unit of resistance agreed with the value of the unit with a precision of approximately two parts in ten million. It is expected that a comparable precision will be attained in the repetition of these measurements. Such a result will greatly improve the Bureau's ability to check on maintenance of the unit of electrical resistance using a group of standard resistors.

In addition, repetitions of determinations of the gyromagnetic ratio of the proton in a field at the center of a solenoid gave the same value within one part in a million. As the field in the solenoid was computed from its

Highly stable shielded 100-megohm resistor designed and constructed for use in the very precise measurement of high voltages. (See p. 40.) Measurements can be made to within 20 parts per million.

dimensions and from a current determined with standard cells and standard resistors, as had been done a year previously, it may be concluded that the NBS unit of current did not change during the year. Since the other experiment showed that the unit of resistance maintained with standards did not change, this experiment shows that the NBS unit of electromotive force was also maintained without a signficant change by means of a group of saturated standard cells.

Precision Measurements at High Voltages. Direct voltages up to 100 kilovolts can now be measured to within 20 parts per million by using a highly stable, 100-megohm resistor of unusual design. The resistor is made up of 100 individually shielded 1-megohm resistors which are connected in series and arranged to form a vertical helix between a ground plate and a high-voltage electrode. Brass shields completely enclose each resistor and prevent formation of corona at the surface of the resistance coil, no matter how high the potential of the shield is above ground.

Standard instrument transformers for use at 350,000 volts can now be calibrated with an accuracy of 2 to 3 parts in 100,000 by employing a capacitance voltage-divider technique. This accuracy is significantly better than has been available previously even at lower voltages. A 1-picofarad, 3-terminal free-air capacitor is used. Its housing is an aluminum can 7 feet high and 7 feet in diameter. NBS measurement techniques and results have been compared with those of the National Research Council of Canada

through cooperative tests of a 350,000-volt transformer built for the Ontario Hydroelectric Power Commission. Agreement of test results between the two national laboratories has been within about 2 parts in 100,000 on transformer ratios ranging from 2,000/1 to 4,000/1, and over a voltage range from 100 to 350 kilovolts.

Rapid Calibration of Resistance Voltage Dividers. Because of scientific and technical advances in recent years, the standard resistance voltage divider ("volt box") with its self-calibrating feature has become part of the basic equipment of many standardizing laboratories. In the past, users have generally depended on NBS for calibration of this type of standard. With more widespread use of volt boxes, however, it becomes necessary to equip other qualified laboratories to perform this task.

To facilitate the gradual transfer of the calibration of standard volt boxes and the evaluation of their performance to other standardizing laboratories, the Bureau developed a method which permits the rapid calibration of standard volt boxes at their rated voltages. The technique employs a direct-reading ratio set and a group of standard resistors or their equivalent. All components are incorporated in a test console. The only external connections required are those to the d-c supply and standard volt box under test. Since most standardizing laboratories already have the necessary components, additional outlay for equipment is not required.

Vicious Cycle in Storage Batteries. Storage batteries may go into a "vicious cycle" during charging under constant potential maintained by a generator and suitable voltage regulator. Battery temperature invariably rises during charging, causing internal resistance to decrease. If this decrease is sufficient to more than offset the increasing counter-electromotive force, the charging current rises. As the current rises, so does the temperature—leading to "vicious cycling." Under these conditions, battery temperature becomes excessive and deleterious effects result.

A theoretical study showed that "vicious cycling" could be produced in any type of storage battery by limiting the heat transfer to the surroundings. It was found that the rate of increase in current is nearly linear, whereas that for temperature is logarithmic. The mechanism controlling the temperature-current relation is the activation overpotential for the overcharge reactions, namely, the electrolysis of water for which the overpotential depends on electrode material and condition. The theoretical predictions were checked by charging lead-acid and nickel-cadmium batteries in Dewar flasks at constant potential. Experimental and theoretical results agreed except for long charging periods, when heat losses to the surroundings became significant.

Electrolytic Conductance in Porous Media. Close-packed beds of spheres provide an easily obtained reproducible medium for studying the effect of capillary or pore size on electrolytic conductivity. For a rhombohedrally packed column of equally sized inert spheres, the fraction of space occupied by the spheres is 0.74. This value is independent of sphere size. Thus, if the electrical conductance of an electrolytic solution is meas-

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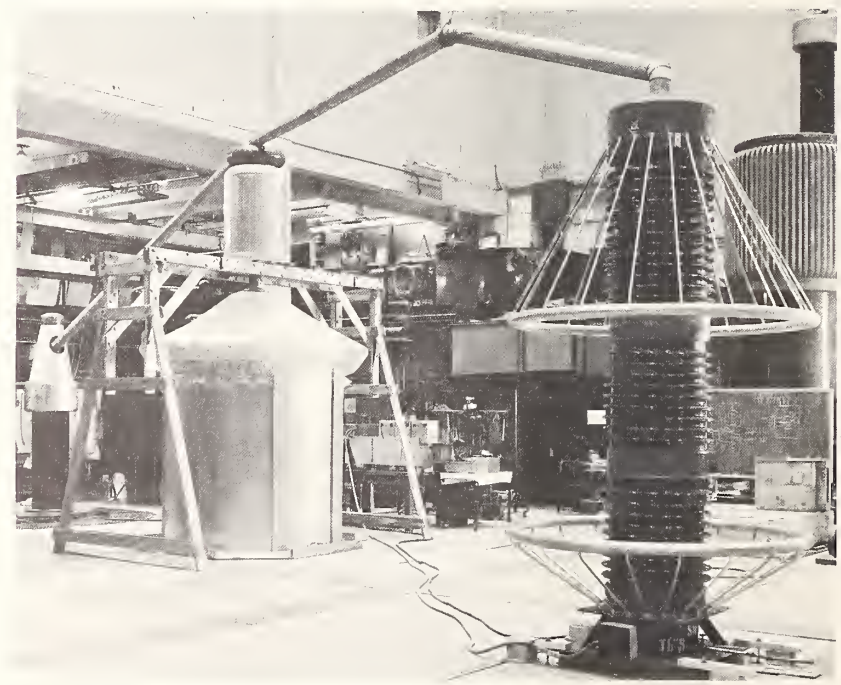
ured in a particular cell in the presence of spheres (beads) and then in their absence, the ratio of the conductances would be 0.26 if the change in volume were the only effect and the conductance of the beads themselves was negligible relative to that of the medium. With increasing dilution of the electrolytic solution, however, this ratio would be expected to increase because of surface conductance, electro-osmosis, and the increased importance of the conductance of the beads.

The Bureau checked these predictions using glass and plastic beads, 300 $\pm$50 microns in diameter, in aqueous solutions of potassium chloride and hydrochloric acid. For potassium chloride of concentrations 0.02 normal or greater, the conductance ratio was slightly less than 0.26, probably because the unequal size of the beads permitted tighter packing. Below 0.02 normal, however, the ratio steadily increased, reaching 0.31 at 0.002 normal after corrections were made for the conductance of the beads themselves (determined in distilled water). Thus surface conductance and electro-osmosis produce a 20 percent increase in the electrolytic conductance in porous media. For hydrochloric acid and plastic beads over the same concentration range, the conductance ratio is nearly constant at 0.24. This result indicates either that surface conductance and electro-osmosis are inoperative or that specific interaction occurs between the beads and the acid medium.



As part of an international comparison of voltage measurements, a Canadian 350,000-volt instrument transformer (foreground) was calibrated to an accuracy of a few parts in a hundred thousand using a new capacitive-divider technique. The 7-foot high, 1-picofarad capacitor to the left of the transformer was specially constructed for use in such calibrations. **(See p. 40.)**

Corrosion of Single Crystals of Silver in Molten Salt. In the presence of a temperature gradient, the corrosion rate of single crystals of silver in molten sodium chloride is independent of the crystallographic orientation of the silver, but extensive mass transfer of silver occurs. This transfer, resulting from dissolution and deposition of silver, occurs from the hot to the cold end of the crystal and results from a shift in the equilibrium between ionic and atomic silver from the ionic to the atomic state. In the absence of a temperature gradient, some effects due to crystal orientation occur, but no mass transfer of silver takes place. Spirals and square pits form on the [100] surface at dislocations in the interior of sub-grains in concentrations somewhat less than 10^6 per square centimeter. Some spirals and pits also form on [111] surfaces, but not [110] or [211] surfaces.

Microwave Absorption in Compressed Nondipolar Gases. As part of the systematic study of the dielectric behavior of compressed gases in the microwave region, measurements were made on a number of pure gases and mixtures which do not have permanent dipole moments and therefore do not produce ordinary microwave spectra. Significant loss was found in carbon dioxide, nitrogen, and ethylene. This loss is attributed to the existence of transient dipoles induced by molecular force fields during collisions. The losses observed have so far been confined to gases having permanent molecular electric quadrupole moments, for which the force field has a comparatively long range. These results are of interest in that they provide indirect information on the magnitude of the quadrupole moments, for which direct methods of measurement are not presently available, and on the dynamics of collisions. This mechanism of absorption can also have a very significant effect on planetary heat balance and on the interpretation of observations of the planets using radioastronomy. Venus is of particular interest in this respect because of its carbon dioxide atmosphere.

Magnetism. The nuclear magnetic resonance frequencies of various cobalt- and nickel-rich alloys were determined so that these values could be used in calculating the internal magnetic fields that exist at the cobalt and nickel nuclei for the various alloys. These results will provide information to be used in theoretical studies of the behavior of ferromagnetic alloys. For the cobalt-rich alloys, isotopically enriched Ni^{61} was used. This enriched nickel contained 99.9 percent of isotope 61 as compared with approximately 1.5 percent of isotope 61 found in ordinary nickel metal. The alloys were prepared in powder form, in which the largest particle size was 10 microns, and carefully annealed. A successful search was then made for the nuclear magnetic resonances of Co^{59} and Ni^{61}.

At the cobalt nucleus in the 99 percent and 1 percent Ni^{61} alloys, the same value of internal field was found as for the 100 percent cobalt metal ($-212{,}000$ gauss). The same value of magnetic field existed at the nickel nucleus for the pure nickel metal as for the 99 percent Ni–1 percent Co alloy ($-57{,}000$ gauss). The value of the magnetic field at the cobalt nucleus in the 99 percent Ni–1 percent Co alloy was found to be $-112{,}000$ gauss,

and the magnetic field at the nickel nucleus in the 99 percent Co–1 percent Ni alloy was found to be −170,000 gauss.

The calculated magnetic fields at the nickel nucleus are based on a value of a nuclear moment of Ni of 0.9 nuclear magneton instead of on the usually accepted value of 0.3. Several groups of investigators are presently attempting to remeasure this quantity.

A series of Os^{+4} complexes were prepared and measurements made of their magnetic susceptibilities. The paramagnetism of the osmium (IV) complexes was found to be independent of temperature and to increase as the osmium ions are separated. An equation was derived to describe the results. The results were shown to be in agreement with the intermediate coupling scheme, and values for the spin-orbit coupling constants and coulomb interactions were calculated to a relatively high degree of accuracy.

Absolute measurements of susceptibilities were made for more than a year on two compounds, $[CoHg(CNS)_4]$ and $(NH_4)_2OsCl_6$, which are being considered for standards of paramagnetic susceptibilities. These materials are performing in a very satisfactory manner. It is hoped that such standard materials will improve the accuracy with which equipment capable of making only relative measurements can be calibrated.

Deposition of silver on silver single crystal after exposure to molten sodium chloride in a silver crucible for 15 hours. Such studies have shed much light on electrolytic processes. **(See p. 43.)**

2.1.4. RADIO STANDARDS

The Bureau program in radio standards, centered at the Boulder Laboratories, plays an important part in the economy and defense of the country. As the electronic industry continues to expand, the role of this program becomes increasingly important. Its aim is to provide the central basis for the complete, consistent, uniform, and accurate measurement of physical quantities relating to radio science, and to assure international coordination in such measurements.

The results of this program include, for example, the determination of new theories which radio scientists can exploit, the invention and development of new instruments and measuring devices which the instruments industry can produce, the provision of accurate data on the properties of materials, the provision of calibration and broadcast services which furnish yardsticks for radio measurments to hundreds of industrial and military laboratories over the country, and consultation and instruction which assist in the solution of industrial and government research, development, operation and training problems.

With the continued rapid expansion of the electronics industry and the development of systems and space vehicles of increasing sophistication, increasing demands have been made on the Bureau to increase the scope of its radio standards and services. Since the requirements have increased more rapidly than standards could be supplied, some standards are necessarily lacking. This lack constitutes significant portion of what is referred to as a "measurement gap."

As an initial step in closing this part of the "gap," the radio standards program was expanded appreciably during the year, following the appropriation of supplemental funds. Based upon available information concerning measurement needs and apparent trends, a systematic plan is being developed for defining the expansion of effort required to meet these needs and as an aid in establishing the optimum program with available facilities. Efforts are also being intensified to find and use other effective ways to assist electronic laboratories in their use of the National standards. These ways include publications, sponsoring of conferences, conducting of courses, and participation in the National Conference of Standards Laboratories.

Radio Physics

In its program on radio physics, the Bureau conducts research concerning the interaction of electromagnetic fields with matter. Such studies have possible application to radio standards, frequency standards, time scales, atomic and aggregate properties of matter, and constants of nature. This research leads to the development and international coordination of certain national standards of measurement. The dissemination of such standards is accomplished by broadcast and calibration services, and results of the complete program are made known by publication and consultation.

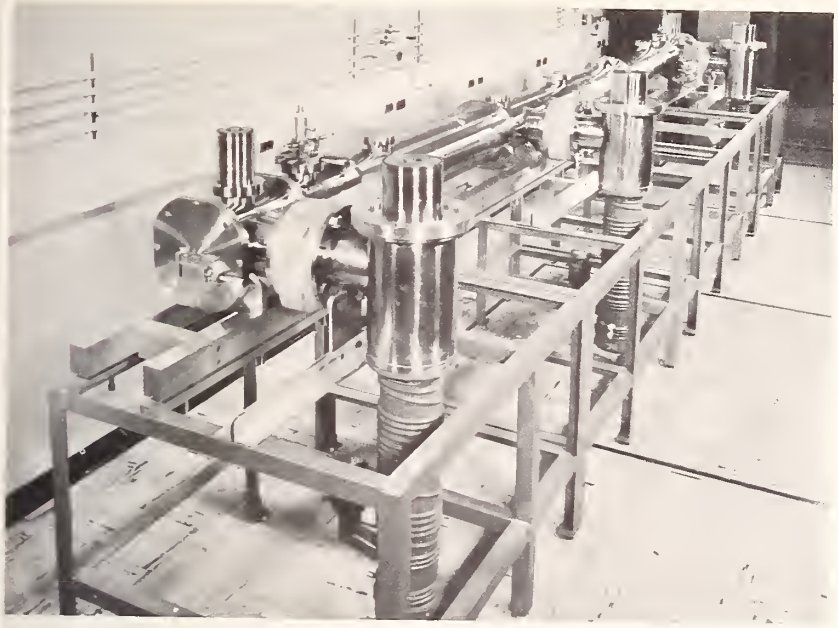
United States Frequency Standard. The United States Frequency Standard, whose present accuracy is better than one second in 3,000 years, has been modified to provide a complete multiplier chain and servosystem for controlling the frequency of a quartz oscillator with the cesium resonance frequency. This improvement will reduce the quartz spectral line width by a factor of one-half, thereby increasing the stability of the system. The performance of the servo system has been evaluated by observing frequency shifts as a function of many of the system parameters, such as gain, modulation frequency, bandwidth, phase shift and others. It was found by com-

parison with results of more direct manual methods of measurements that systematic errors were $0 \pm 3 \times 10^{-12}$. The servosystem approach to the problem of using cesium or thallium as a frequency standard permits the realization of greater precision than can be obtained with a manual method. At the same time, more meaningful long term averages of the frequency of the working standard may be obtained less tediously. Further, equipment to permit the simultaneous operation of two cesium beam machines in the servo mode has been constructed and initial performance tests have been made.

Atomic Time Scale. In order to use atomic frequency standards to measure time it is necessary to count the number of cycles which have occurred during the elapsed time. During the past year an apparatus which counts cycles directly has been built and is being improved. Another method of obtaining time is by a mathematical analysis of data pertaining to a number of continuously operating frequency standards. If the frequencies are measured at periodic intervals and plotted against the nominal value of the time, the exact time can be shown to be proportional to the area under the curve: that is, the integral of the frequency with respect to the nominal time evaluated from the beginning to the end of the desired interval. Considerable effort has been devoted to exploiting this method. The procedure was applied to several quartz oscillators, including the one which controls WWV. Data going back to 1957 are being studied. The purpose of this study was to test the consistency of various determinations of atomic time—to see whether it could live up to its expectation as the ultimate standard of time suitable for such critical activities as aerospace navigation, etc.

Ft. Collins Radio Station. For many years the Bureau has operated high-frequency standard frequency stations WWV at Greenbelt, Md., and WWVH at Maui, Hawaii. However, the accuracy attainable from the use of these high-frequency broadcasts is inadequate for many present-day satellite and missile programs. Experimental low frequency broadcasts from WWVL Sunset, Colo., at 20 kc/s and WWVB Boulder, Colo., at 60 kc/s have indicated that considerable improvement in accuracy can be obtained at these frequencies. Since October 28, 1961, the carrier frequency of WWVL has been automatically phase locked to the United States frequency working standard located in the Boulder Laboratories by a radio link. This arrangement has maintained the carrier stability as transmitted to about two parts in 10^{11}. The success of these experimental broadcasts provided technical justification for the construction of new facilities at Ft. Collins, Colo.

The Ft. Collins site was selected because it most nearly met all of the required technical conditions including that of exceptional ground conductivity. The installation will cover a land area of approximately 379 acres and the antenna system will be supported by eight steel towers approximately 400 feet in height, weighing about 60,000 pounds each. Transmitters presently under construction are of greatly increased power (7-kw



In addition to improving frequency measurements by modifying the existing cesium frequency standards, NBS has started construction of an entirely new cesium-beam device. This NBS III atomic frequency standard has an oscillating field separation of approximately 3 meters. **(See p. 45.)**

radiated power on 60 kc/s and 1-kw on 20 kc/s) and range in order that a more favorable signal-to-noise ratio may be achieved and thus a more reliable coverage during any given 24-hour period. The accuracy of the present system is analogous to a clock having the capability to maintain the time to within two seconds in 300 years. However, efforts are being exerted continually to improve this accuracy.

Fundamental Constants

Speed of Electromagnetic Radiation. The speed of electromagnetic radiation is being redetermined using a Michelson interferometer at 6-millimeter wavelength. Experimentally, this consists of a 2-foot square horn and a 5-foot square plane mirror which can be moved through a known distance of about one meter. The horn is excited by a klystron of very accurately known frequency. The wavelength in room air is measured by counting the number of minima in the signal leaving the interferometer as the mirror is moved. Corrections must be made for both refraction in the air and diffraction effects. The latter provide a serious difficulty and require extensive mathematical analysis. The apparatus was placed in operation during the past year, and a preliminary value agreeing with the accepted one within a few parts in a million has been obtained. It is expected that the experiment will be completed during the next year.

A more novel method for the redetermination of the speed of electromagnetic radiation employs gamma rays and the Mössbauer effect. This experiment is unusual in that it involves radiation traveling only in one direction over a path. A source and absorber are mounted on piezoelectric transducers which vibrate at a frequency of about 1000 Mc/s. The absorption goes through a maximum when the distance is such that the time necessary for the radiation to travel between the transducers is a whole number of periods of vibration. The time is also equal to the distance divided by the speed of propagation. The assembly of the apparatus is approaching completion, and it is hoped that a preliminary experiment will take place shortly. Ultimately, it is hoped that an accuracy of the order of one part in 10^7 can be achieved.

Fine Structure Measurements. The fine structure constant α, for which two previous measurements have given values containing significant differences, is also being remeasured. This constant is related to the charge of the electron, e, the speed of light, c, and Planck's constant, h, by means of the equation $\alpha=2\pi e^2/hc$. This direct connection with the other atomic constants is an indication of its importance.

A program to redetermine this constant by a microwave measurement of the fine structure of singly ionized helium has been started in the past year. This new measurement is expected to resolve the discrepancy between the two previously obtained values of α. The measurement will also be a test of the validity of the theory of the fine structure of hydrogenlike atoms. When the magnetic field is zero, the fine structure of singly ionized helium exhibits two resonances. The 14 Gc/s resonance, known as the "Lamb Shift," has been previously measured to within ± 4.5 Mc/s. The present experiment is intended to observe the other resonance at 161 Gc/s per second, which has not been observed by microwave methods.

Millimeter Waves. NBS, one of the first to construct and operate microwave Fabry-Perot interferometers with both flat and spherical mirrors, is vigorously exploring the operation of these devices in detail. It is expected that the present theory will be substantiated to a large degree and modified in some deails. Microwave engineering has been given a completely new type of resonator by this recent result from physical optics.

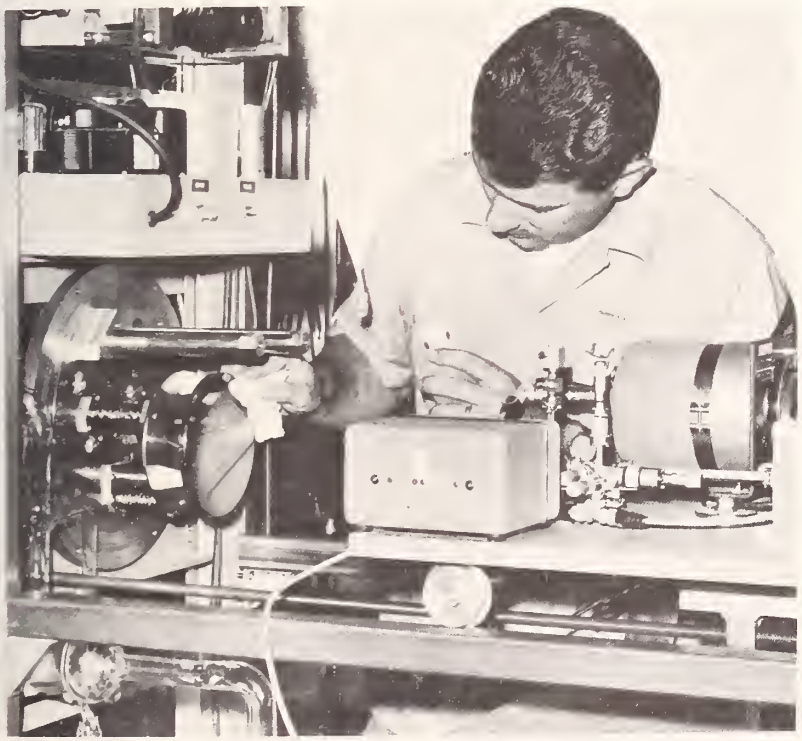
Attention is being devoted to the application of these resonators as refractometers and spectrometers. During the past year an absorption cell, using a parallel plate interferometer for the observation of Stark effects in molecular spectra, has been constructed. The Stark effect concerns the splitting of spectral lines by the application of electric fields, and provides an unexploited possibility of measuring d-c and low-frequency voltages to very high precision. It is expected that in the next few months preliminary experiments on the use of the Stark effect as a method of measuring voltage will be completed.

A very efficient method for transmitting millimeter wave power has been designed in which spherical mirrors are used as part of a periodically refocused transmission line. Alternatively, the mirrors may be replaced by

lenses, in which case the Goubau transmission line results. These are promising new methods for handling millimeter wave power, which suffers such prohibitive attenuation in conventional waveguide circuits. An experimental evaluation of these various new transmission techniques will be undertaken as part of the millimeter wave research activity.

Coherent Light. The extension of the realm of coherent radiation through the advent of the optical maser provides many opportunities for new methods of communication and for measurement of fundamental constants. Therefore it is necessary for the Bureau to develop competence in this field.

During the past year a pulsed ruby laser has been assembled at the Boulder Laboratories. This laser, powered by powerful xenon flash lamps, has a coherent light output at a wavelength of 6943 A which can be focused by means of an ordinary lens to provide a high-energy density of optical radiation, making feasible experiments that a few years ago were impossible. One such experiment now under investigation consists of irradiating certain organic crystals with the intense light of the ruby laser. These organic crystals have optical absorption bands at nearly twice the frequency of the ruby laser. In order that the crystals absorb photons from the laser beam one must have what is known as a two-photon process. The organic crystal excited through photon absorption decays back to the ground state via a 5000 A



The Stark effect—splitting of spectral lines by the application of electric fields—is being investigated as a means for measuring d-c and low-frequency voltages to very high precision. This experiment employs millimeter wave techniques which were developed at NBS. **(See p. 48.)**

fluorescent state. The detection of the two-photon process will be accomplished by observing the 5000 A emission line on spectrographic plates. The experiment should provide a better correlation between experiment and theory of two-photon processes.

In addition to this experiment two helium-neon gas masers are under construction, and it is expected that they will be placed in operation during the next year. They will be studied with regard to communication possibilities and with regard to use in new determinations of the velocity of light.

Radio Plasma Studies. A broad program designed to delve into the basic physics of plasmas, principally as related to the interaction of plasmas with electromagnetic radiation, is currently under way. A laboratory program in this field can be expected to yield valuable information concerning fundamental processes of the propagation of radio waves in the ionosphere and exosphere and in the transmission of signals through the plasma sheath surrounding a satellite. Moreover, such investigations are likely to lead to the development of new devices, such as mixers and harmonic generators, useful in the millimeter and submillimeter region.

Bounded Plasma Calculations. An important result of the past year's work has been the theoretical analysis of an experiment concerned with the propagation of a wave through an over-dense, highly magnetized bounded plasma. Carried out in cooperation with the Atomic Energy Research Establishment in Harwell, England, this work was predicated upon the so-called "whistler" plane wave mode derived in basic magneto-ionic theory. Complete analysis of the results, however, indicates frequency regions, both of propagation and of attenuation, that are not explained by the original "whistler" mode theory for unbounded plasma. The detailed bounded plasma solution not only predicts many "whistlerlike" modes, but also new sets of modes that are relatively nondispersive.

Reaction Rate Coefficients. Much of the work carried on in the plasma area is of particular interest to the upper atmospheric physicist. One task is concerned with determining atomic and molecular reaction rate coefficients, especially of gases associated with ionospheric phenomena. The present state-of-the-art is such that the known data constitutes only a small part of that which is required, and even that small fraction is subject to large uncertainities. Present work is concerned with refinement of microwave and optical plasma diagnostic tools, and with development of new techniques. Two such new techniques, which are particularly suited to investigating a far afterglow of a nitrogen discharge, are a microwave surface wave device using a helical structure, and an audio frequency technique involving the Hall effect. Optical and infrared spectroscopic techniques are being used on both carbon and nitrogen atoms and on such molecules as C_2, C_3, CH, CH_2, H_2, CN, and NO. The carbon processes are characteristic of comet tails and the others are evolved in upper atmospheric mechanisms. The particular aim of this work is to evaluate the probabilities of some of the transitions from the excited states of these species. In addition, the energy exchange processes involving these species are being investigated.

Plasma Waves. Plasma waves, or oscillations, are a function of such properties as electron density and temperature and consequently offer a possible key to determination of these parameters. Further, various instabilities that are preventing successfully controlled thermonuclear reactions are intimately related to these plasma waves. An experiment is currently under way in an attempt to generate such oscillations in the form of a longitudinal electro-acoustic wave and to compare the propagation constant and other properties of this wave with those predicted by theory. Most of the previous and present work is based upon various linear or at least linearized theories. While the most pressing need is for completion of these tasks, other future work involves the extension into the domain of non-linear phenomena. This includes the generation and detailed investigation of plasma "striations" and the use of an arc discharge as a means of harmonic generation in the millimeter wave region.

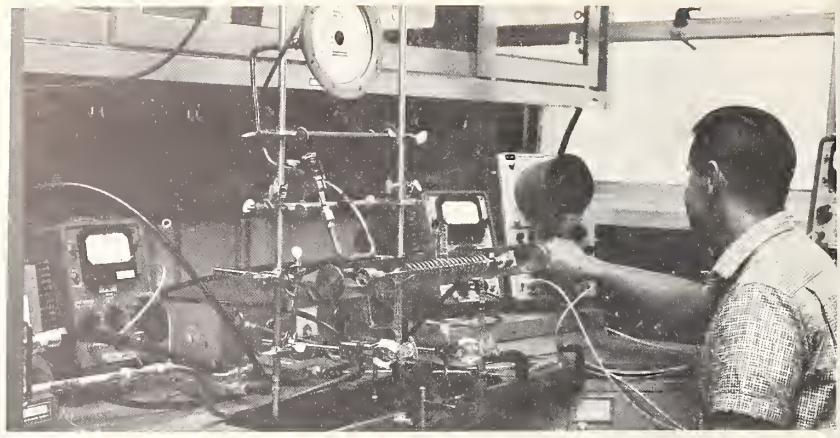
Particle-Plasma Interaction. Some exospheric and solor phenomena result from the interaction of beams of charged particles with plasma, particularly the generation of electromagnetic waves in space. During the past year a laboratory experiment has been set up to produce some of these effects—particularly to study the effect of the finite temperature on the evolving of "pass" and "stop" bands where none are predicted for zero temperature.

Radio and Microwave Materials. Investigations of the interaction of electromagnetic waves with materials are primarily directed toward advancing the present understanding of solid state phenomena as well as toward improving and developing standards and measuring techniques for determining material properties.

Studies of magnetic resonance phenomena using a recently completed spin resonance spectrometer resulted in the observation of interesting electron paramagnetic resonance spectra in amethyst, topaz, and aragonite crystals. Attention was concentrated on the amethyst spectrum and a serious attempt is being made to characterize the spectrum completely and to correlate it, if possible, with other known physical phenomena which take place in amethyst.

The synthesis of selected specimens for magnetic spin resonance work also received considerable emphasis during the year. In particular, a process was developed for growing single crystals of anhydrous sulfates such as copper or cobalt sulfate, which are of interest in studies of antiferromagnetic properties. Preliminary experiments also indicate the possibility of growing sizable single crystals of zinc sulfate, dense with paramagnetic ions. This work is in accord with the recommendation of the Aerospace Industry Association which emphasized the desirability for a concentrated effort on the study of materials of known composition and purity.

Several contributions were made in the continuing effort to obtain better measuring techniques for evaluating the properties of radio and microwave materials. For example, more accurate measurements of very small dielectric losses of material at microwave frequencies were made possible through



A new technique utilizing the interaction of a surface wave with a plasma is being used to investigate the ambipolar diffusion process, a fundamental loss mechanism in the plasma. Knowledge of the details of such processes is vital to a more complete understanding of plasma physics, and to its application to communication and energy generation. **(See p. 50.)**

the development of improved $TE_{0\,11}$ mode cavity employing a concentrated dielectric post. Research is also continuing in the development of better variable length re-entrant cavities for complex dielectric constant measurement in the region of a few hundred megacycles per second. Four-terminal techniques for making measurements in the kilocycle region were completed during the year.

Improved techniques were developed for measuring the reversible complex permeability spectra of ferrites with d-c fields applied parallel to the RF fields, including the development of variable length cavities for measurements of this type. This represents considerable improvement over previously used slotted lines. Facilities for paramagnetic resonance measurements on ferrite spheres at several frequencies ranging from L band through K band were completed, and work continues in evaluating the merit of tensor permeability data versus ordinary ferromagnetic resonance data at various microwave frequencies.

The effort in the area of conductivity phenomena was directed primarily toward a theoretical study of the electric current density produced by the action of an electromagnetic field in electron gas. This work included the case where a static magnetic field is applied to the electron gas, and although as yet the work is preliminary in nature initial efforts indicate promising results.

Applied Mathematics. Much of the effort in this field was devoted to analysis and computation as related to the diffraction correction for the determination of the velocity of light with a microwave Michelson interferometer. Neglecting the multiple reflections and assuming the mirror to be infinite, the correction is obtained from a two-dimensional integral over the weighted product of the complex vector, radiation, and receiving pat-

terns, which are given by two-dimensional Fourier transforms of the (complex vector) field in an aperture plane. Analysis and programing have been carried out for the fitting—with tests of statistical significance—and plotting of residuals of the rapidly varying aperture field, using a linear combination of products of generalizations of the Fresnel integral functions (each arising from an infinite slit with the illumination expressed by a term of a Fourier series). Exact expressions have been obtained for the Fourier transform of the basic functions, and approximate expressions for the needed diffraction correction integrals have been obtained and programed. The analysis and computations relating to the velocity of light measurements, including studies of minor effects such as mirror tilt, finite mirror, multiple reflections, variation of reflection with angle of incidence, aperture probe pattern, evanescent waves, and transverse aperture field component perpendicular to the nominal direction, will be published within the foreseeable future.

Microwave Spectral Tables. The primary aim of this project is the publication of a comprehensive set of tables of observed microwave line spectra, their intensities, and molecular constants derived therefrom. Present literature on microwave spectroscopy has grown to such an extent that the existing compilation contains only a small fraction of the available data, and some proposed work involving unstable molecules is impractical until and up-to-date catalog of information is available. Present activity involves the compilation of three volumes as follows: Volume 1—*Line Strengths of Asymmetric Rotors*, Volume 2—*Diatomic Molecules*, and Volume 3—*Hindered Rotors.*

Volume 1 contains a computation of the subject transition possibilities for $J=0$ to $J=30$. Volume 2 will contain tables of Casimir's function and of the hyperfine intensity splitting factor computed to I and J, for I and J half-integral as well as integral. Volume 3 will contain the microwave spectra of molecules undergoing internal rotation. Two additional volumes are scheduled for publication during the next year. They are: Volume 4—*Symmetric and Asymmetric Rotors*, and Volume 5—*Serial Frequency Listings (of Lines of all Atoms and Molecules)*.

Theoretical Physics. Studies in theoretical physics are conducted which contribute to basic aspects of the radio standards program. In addition to being end products in themselves, these studies occasionally provide key theoretical developments on which further work may be based, and form a basis for consultative services in both mathematics and physics.

Perturbation formulas, along with some of the underlying theory, were refined and applied to more problems. Specifically, finite conductivity calculations were made for half-round inductive obstacles in a rectangular waveguide. In the same vein, the general concepts of perturbation theory were restudied and some difficult points clarified. A particular point of interest was the realization that in many problems to which perturbation theory is applied the required power series expansions in the perturbation parameter may not be valid.

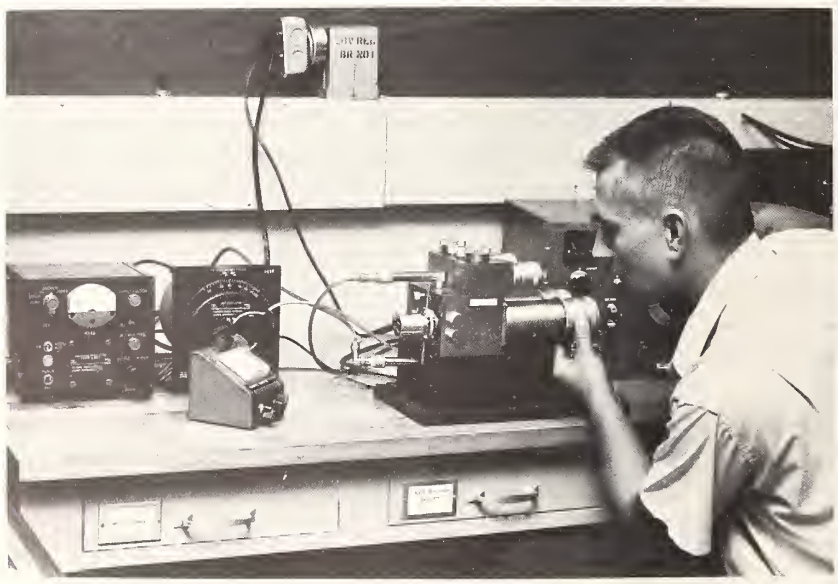
A good deal of work was performed in proposing expository notes on the advanced theory of waveguide junctions. Many known properties were formulated more clearly and some new results obtained.

A major work which was accomplished during the past year involved calculating the bound state energies of an exponentially-shielded Coulomb potential, which is identified with the Debye-Huckel potential in ionized gases. The perturbation treatment of this problem appears to give the most useful results obtained to date.

Circuit Standards

The Bureau's program in radio circuit standards includes basic research on physical principles and fundamental engineering techniques having applications in the field of precision electromagnetic measurements. This research leads to the establishment, maintenance, continued improvement, and international coordination of a comprehensive set of national standards and precision measurement techniques for fundamental electromagnetic qualities in radio circuits. Dissemination of measurement accuracy is accomplished in large part through calibration services, and information on precision electromagnetic measurements is disseminated widely through publication, consultation, conference papers, invited talks, committee work with the technical societies, individual visits to other laboratories, the NBS-Air Force Working Group visits to Air Force contractors, and through a Low Frequency Workshop for members of Department of Defense standards laboratories.

Low-Frequency Activities. The design has been substantially completed for new instrumentation for the rapid calibration of volt boxes. This



Measuring the impedence of a high-frequency resistance standard. The resistor is one of a new set, ranging from 1 ohm to 2 megohms, for use in the lower *rf* region. **(See p. 55.)**

equipment will incorporate a digitally programed analog computer. The elimination of hand computations and data handling will facilitate operation of the equipment and preparation of calibration results, and should eliminate several potential sources of error.

Investigation of inductive voltage dividers has led to the construction of a number of single-decade dividers having extremely small ratio errors (a few parts in a hundred million of input). Methods are being developed for using this type of divider to establish a ratio in a simple manner.

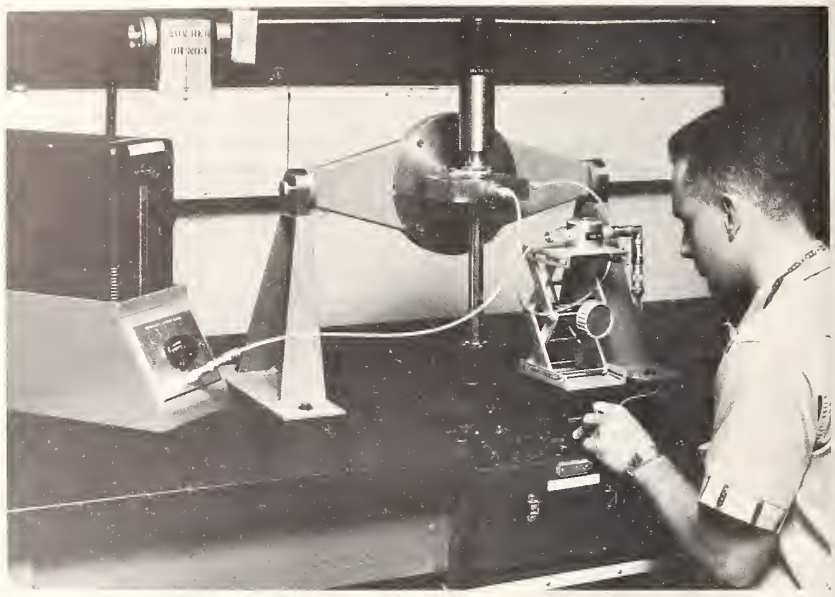
Repeated measurements on a group of six saturated standard cells at both NBS Boulder and NBS Washington indicate that calibrations of electromotive force of cells at the two laboratories agreed within 0.4 microvolt.

Comparisons of three Thomas-type 1-ohm resistors at both Boulder and Washington revealed a maximum change of only 0.1 microhm. Measurement agreement between the two sites also has been to this order of accuracy. This is better than the best certified calibration accuracy, so that resistance calibrations made at Boulder and at Washington have been nearly identical.

High-Frequency Activities. A significant addition to the NBS measurement capability was made in the field of pulse radiofrequency power, where no measurement capability has existed previously. In this new method the power level of a selected portion of the pulse is compared with a known amount of cw power at approximately the safe frequency. The measurement range extends from 0.25 watt to 10 kilowatts, with a limit of error of 3 percent. The pulse width may be as small as 0.5 microsecond, the minimum duty cycle is 0.0005, and the frequency range is 30 kc/s to 1000 Mc/s. This work will form the basis for a new calibration service.

On a project sponsored by the Naval Bureau of Ships, a special set of filter units covering the frequency range from 14 kc/s to 1000 Mc/s was developed and constructed for use in the measurement of spurious outputs of radio transmitters. These filters allow the measurements to be made with the transmitters operating into standard 50-ohm dummy loads, thus avoiding the interference that would be created if antennas were used during the measurements. Techniques were employed which made the characteristics of the filters independent of transmitter power level. The design achieved optimum bandwidths while providing less than 10-decibel (db) attenuation outside of the rejection band in the frequency range from 14 kc/s to 1000 Mc/s. The high sensitivity of the units permits the measurement of spurious signals as much as 145 decibels below the carrier level.

An experimental attenuator operating in the TM_{01} mode using cylindrical waveguide was constructed for investigation. A special two-stage input impedance matching unit, necessary to prevent the burnout of some of the capacitors due to high currents, was incorporated into the attenuator. The unit worked well and, for the minimum launching and pickup probe separation which could be used while maintaining a linearity of 0.001 db, produced a maximum output of 1.5 volts into a 50-ohm load. Preliminary measurements over the maximum range (120 db) of the experimental attenuator showed no evidence of the presence of the TE_{11} mode. The



Comparison of a 1-picofarad incremental capacitor with an accurate section of coaxial line. The accuracy of the high-frequency corrections to the 1-picofarad incremental derived standard has been improved. **(See p. 56.)**

measurement accuracy at the upper end of this range has not yet been determined.

This investigation was made necessary by the fact that the conductivity of the waveguide wall of waveguide-below-cutoff attenuators operating in TE_{11} mode is a limiting factor in the operation of this type of attenuator. Since this effective conductivity is difficult to measure accurately, it may not be possible to use this form of the attenuator as an accurate measurement standard for frequencies below 1 Mc/s. This effect is less serious in attenuators operating in TM_{01} mode (capacitive type). For successful use of this latter mode in a standard attenuator, the less rapidly attenuated TE_{11} mode must be adequately suppressed.

Several improvements were made in high frequency resistance standards. A new set of standards, ranging from 1 ohm to 2 megohms, was completed for use at the lower radiofrequencies. This set has metal film and solid wire cylindrical center conductors with linearly tapered outer conductors. A new type of resistor was developed which can be used at high frequency with 0.02 percent nominal accuracy and ± 10 parts per million per degree temperature coefficient. The use of photoconductors for adjustable resistance standards has proved successful in calibrating the residual reactance of resistance standards.

Improvements have been made in high-frequency capacitance standards by further analysis of losses through utilizing capacitors with different relationships between loss and capacitance, by use of mercury contacts rather than solid metal sliding contacts, and by analysis of losses from capacity

coupling through the bearings supporting the rotors of variable capacitors. The accuracy of the high-frequency corrections to the 1 picofarad (pf) incremental derived standard was improved by use of a new 1-pf fixed capacitor.

Coaxial line techniques were advanced by the development of a three-terminal method of evaluating discontinuities experimentally and by improvements in the mathematical analysis. A bead was developed for use in the NBS-Woods connector which makes possible the construction of transmission line standards.

Radiofrequency voltage calibration services were expanded to include 500, 700, and 1000 Mc/s. This was accomplished by using thermal voltage converters compensated so that their frequency response is uniform to within 1 percent over a 2 percent frequency range at each of the operating frequencies. The accuracy of RF voltage calibrations was improved by reduction of distortion in the sinusoidal voltage sources and by improving the long-time stability of the micropotentiometers to better than 0.1 percent.

The high-frequency impedance calibration service was considerably improved by the procurement and evaluation of two three-terminal bridges and associated standards. This service was further improved by additions of tapers and adapters to various connector types, by improvements in the system for calibrating the working standards against the standard 1-pf capacitor, and by addition of a six-terminal mount to connect as many as five impedance standards in parallel.

The calibration accuracy supplied for attenuators in field strength meters was improved from ± 0.8 db to ± 0.2 db over the frequency range 400 to 1,000 Mc/s. By comparing balanced voltages with the unbalanced voltage standards, dipole antenna measurement accuracy was improved to ± 5 percent (formerly $\pm 15\%$) over the 30 to 300 Mc/s range. Attenuation calibration services at spot frequencies from 1 to 300 Mc/s were improved to give an accuracy of ± 0.005 db. The range of attenuation measurement was increased by 10 db to a total of 150 db by addition of a new detection system.

Microwave Activities. When microwave instruments having rectangular waveguide inputs are calibrated, they are connected to NBS calibration equipment having rectangular waveguide outputs. The NBS waveguide is usually made to closer tolerances than commercially available waveguide, and in particular, the rectangular cross section of the waveguide has sharp, rather than rounded, corners.

When the calibrated microwave instruments are used in various applications, they often may be connected to apparatus having output waveguide with rounded corners. This difference between the measurement conditions during calibration and during use, while usually a small one, may produce significant errors which cannot be evaluated without a knowledge of the magnitude of the reflection at the junction of a waveguide having rounded corners with one having sharp corners.

During the past year this problem was investigated both analytically and experimentally, and data were obtained on the magnitude of the reflec-

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tion from such a junction as a function of the radius of the corner. A simple formula also was obtained which closely fitted the measured data.

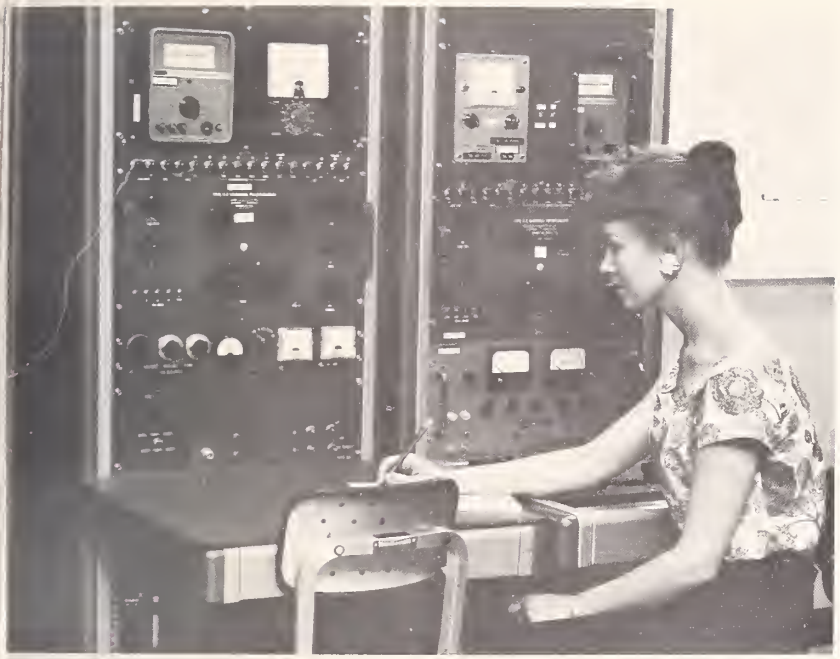
Since 1958 NBS has had a regular calibration service for microwave bolometer mounts for only one of the many waveguide sizes, WR90 (8.2 to 12.4 Gc/s). This calibration service is based principally upon the microcalorimeter, in which the efficiencies of bolometer mounts can be determined to an accuracy of 0.2 percent. Additional microcalorimeters have been constructed for WR62 (12.4 to 18.0 Gc/s) and WR42 (18.0 to 26.5 Gc/s) rectangular waveguide. The evaluation of errors in the microcalorimeter for WR62 waveguide and the design, construction, and evaluation of barretter mounts have been completed to form the basis of a calibration service in the WR62 rectangular waveguide.

The development of a microwave standard phase shifter for WR90 waveguide has been continued. A satisfactory sliding short-circuit has been produced. When the sliding short-circuit is used with a tuned single directional coupler, a signal is produced from the side arm of the coupler which has a nearly constant amplitude and a variable phase. The phase of the signal tracks the position of the sliding short-circuit and can be used to calibrate phase shifters. A preliminary error evaluation indicates that the phase of the signal in the side arm can be determined to an accuracy of better than 0.1 degree.

The pulse technique for horn gain calibrations has been developed to the extent that it gives results comparable with those obtained by unmodulated techniques. The pulse measurements are performed under regular laboratory conditions, while the unmodulated measurements were made in the small microwave enclosure currently available at the Boulder Laboratories. The pulse equipment is capable of resolving a 0.02-db change in a 2-nanosecond pulse while rejecting a 2-nanosecond pulse of comparable amplitude arriving at the detector only 4 nanoseconds later.

A calibration service for noise sources in WR90 (8.2 to 12.4 Gc/s) waveguide was initiated. This service represents the culmination of experimental and theoretical work in the past several years at NBS, and provides a useful service to the electronic industry. Measurements of excess noise ratio can be made to an accuracy of ± 0.1 db (± 250 °C effective noise temperature). The basis of the service was verified experimentally with the use of two different hot-body standards, one consisting of a gold waveguide section with silicon carbide as the load material, and the other consisting of a platinum-rhodium waveguide section with zinc titanate as the load material. The agreement between the average of measurements made with the two standard noise sources was 0.007 db. The oven developed for use with the standard maintains the temperature to within ± 0.3 °C at 1,000 °C, and the modified radiometer developed for the measurement is capable of 0.005 db resolution.

The calibration of a special cavity wavemeter in WR90 waveguide was performed with an accuracy of ± 0.0001 percent. This is more than ten times the calibration accuracy required for the usual device of this type and the full capabilities of the present calibration system were required for the



Significant advances were made in NBS measurement capabilities in the high-frequency power area. Here, a new self-balancing bolometer bridge is used for calibrating high-frequency power standards. **(See p. 55.)**

first time. An analysis of the rotary-vane attenuator has revealed that attenuators of this type are potentially capable of better resolution than the usual dial mechanisms provided; a rotary-vane attenuator was modified to demonstrate this. An improved procedure for the initial setting of the vane has been developed which provided a substantial increase in the overall accuracy of the dial readings. Also, improved models of fixed waveguide attenuators have resulted in greater stability and reduced reflection at the terminals.

2.1.5. HEAT

Heat measurements, standards, and related research play a most important role in modern science and technology. The Bureau discharges important responsibilities in these areas through the maintenance of the National standards for such heat measurements as thermal diffusivity, heat capacity, and heat of combustion. Internationally agreed upon temperature standards are maintained to assure a common scale upon which all temperature measurements are based. A strong research program aims to keep these standards adequate for the expanding scientific needs. In addition, supporting research on the physical properties of solids and gases at both low and high temperatures includes studies in low-temperature physics, statistical thermodynamics, high-temperature processes, high-pressure thermodynamics, and in various aspects of plasma physics.

Substantial advances have been made recently in thermometry at both high and low temperatures. An inexpensive analog computing device has been devised for the spectroscopic investigation of high current density arcs, and the acoustic resonator has been developed to the point of direct competition with the gas thermometer for primary thermometry at low temperatures. Combustion calorimetry employing fluorine as the oxidizing agent is leading to improved accuracy in the determination of the heat of formation of technologically important compounds. Noteworthy theoretical advances were made in the statistical mechanics of time-dependent phenomena. Nuclear cross sections are being determined using oriented nuclear targets at very low temperatures. Experimental and theoretical work on the special properties of perturbed spectral lines has resulted in a new approach to the determination of molecular lifetimes. A new program in molecular spectroscopy has as its aim the precise determination of the spectroscopic properties of simple radicals and molecules.

Analog Computer for Plasma Thermometry. An inexpensive analog computing device has been developed which greatly improves the efficiency of spectroscopic investigations of cylindrically symmetric sources. The immediate application of this instrument will be the determination of spectral line widths and intensities in high current density arcs. Such information can often be used for determining electron densities and temperatures. It is expected that the principles of this computer also will find application in other fields where "side-on" measurements must be made of inhomogeneous objects possessing cylindrical symmetry.

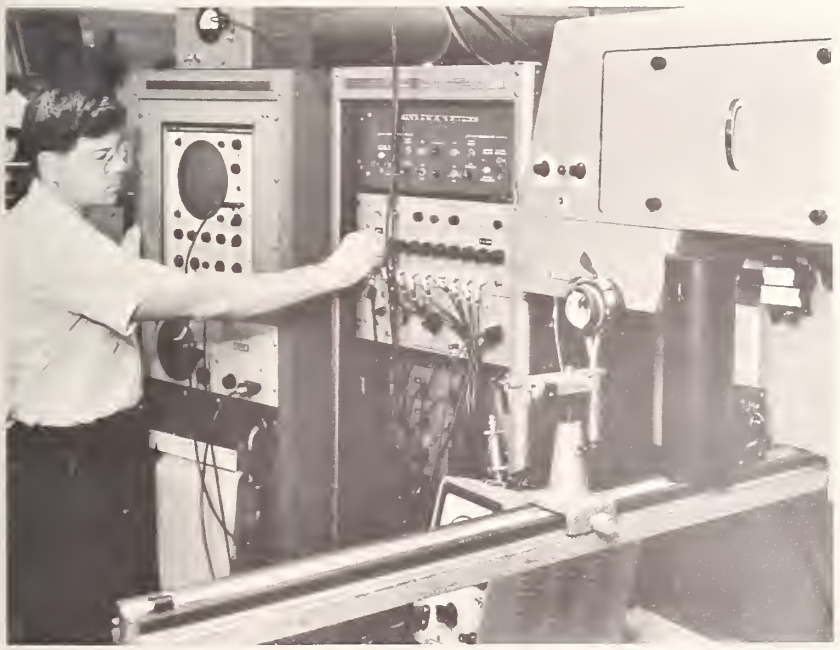
In the determination of temperatures and other physical parameters in cylindrically symmetric arcs, spectroscopic observations are usually carried out on a small cross section of the arc midway between the electrodes and in a direction perpendicular to the axis of the arc. Such "side-on" measurements include contributions from the outer, cooler regions of the discharge as well as from the hot core. In order to separate the contributions of the different radial zones and to obtain the true radial characteristics of the arc, rather extensive data handling and calculations are required. High-speed digital computers have been employed for this analysis, but a significant time delay (days) persists between the recording of the "side-on" observations and the availability of the true radial characteristics. By using the recently developed analog device, this conversion is performed, with an estimated accuracy of within 5 percent, in the laboratory as the data are obtained.

The operating principle of the new instrument involves scanning repeatedly an image of the arc cross section across the entrance slit of the spectrometer by means of a rapidly rotating prism. The waveform of the resulting train of photomultiplier current pulses is then Fourier analyzed and the Fourier coefficients reassembled by the computer to give the desired recorder signal. In conjunction with a spectrometer scanning in wavelength, it is possible to record directly the spectrum appropriate to whatever radial distance has been dialed into the computer, just as if the arc were a homogeneous unit

volume of gas with the properties prevailing at that particular radial distance.

Fluorine Combustion Calorimetry. The thermodynamic quantity called heat of formation is used to predict chemical equilibria and to estimate heats in such chemical reactions as the oxidation of rocket fuels. Values of heats of formation are usually obtained from combustion experiments in calorimeters, using oxygen as an oxidizer. Since in many cases it is impossible to obtain complete combustion using oxygen, calorimeters have been developed which use fluorine instead of oxygen. The principal advantage of fluorine is that the fluorides resulting from combusion are more volatile than the oxides, allowing better contact of the fluorine with the sample for more complete combusion. Using the special sample preparation technique of mixing aluminum powder with finely divided Teflon, it was found possible to obtain combustion of better than 99 percent of the aluminum. The heat of formation of aluminum fluoride has been determined to be −357.1 kilocalories per mole, and the same technique is now being employed to determine the heats of formation of other metal fluorides and borides.

In view of the increasing importance of fluorine compounds in both national defense and in industry, a compilation was made of the heats of formation of inorganic fluorine compounds, and of organic fluorine compounds containing one carbon atom per molecule. This survey, covering the literature from 1949 to 1961, lists heats of formation obtained from 625 references.



Spectroscopic measurement of extremely high temperatures is a useful but very complex technique. This inexpensive analog computing device was developed to improve the efficiency of NBS investigations of high-temperature arcs. **(See p. 60.)**

Gaseous Heat Transfer at Low Temperatures. Experimenters in the low-temperature field frequently encounter a very large undesired gaseous heat transfer associated with tubes leading to the low-temperature region. This heat transfer, which may be as large as 100 to 1,000 times normal heat conduction, is apparently caused by a gas vibration which can be simultaneously detected in the tube. The transfer, for which no completely acceptable mechanism is known, has often been reduced by empirical change of the mechanical configuration in the apparatus.

It has been found possible to eliminate essentially all of this vibrational heat transfer in one apparatus with a simple device used as an appendage to each tube where the tube is accessible at room temperature. The device consists of a tubular constriction leading to a chamber whose minimum size is partially determined by the size of the constriction. While the device has proved extremely useful, the data obtained in the present investigation indicate that additional systematic experiments are needed to understand this phenomenon better.

Nuclear Reactions with Oriented Nuclei. Experiments were initiated on the measurement of nuclear cross sections using oriented nuclear targets. This interdisciplinary program (see p. 74) was aimed initially at measuring the (γ,n) cross section for the nucleus Ho^{165} in the region of the giant resonance. A cryostat incorporating a He^3 refrigerator was built for attaining temperatures just below 0.3 °K, where the nuclear alinement, f_2, is about 0.27. The cryostat was of special construction so that the incoming photon beam would need to traverse only thin aluminum windows before reaching the target. The target consisted of a single crystal of holmium ethyl sulfate, or in some occasions a single crystal of holmium metal, weighing about 7 grams. The design was such that operation could continue with the nuclei oriented for many hours, and provision was also made for both rotating the specimen and lifting it up out of the photon beam. The cryostat was made portable so that after it had been built and tested it could be moved easily to the betatron. This work could possibly be extended to other types of nuclear reactions, e.g., photo-pion production, elastic and inelastic neutron scattering, etc.

Low-Temperature Thermometry. Primary thermometry experimentation in the region of 1.5 to 20 °K has led to the development of an acoustical interferometer for measuring the velocity of sound in helium gas. Measurements thus far completed indicate that the acoustically determined values of temperature are within 0.003 and 0.010 °K respectively of the temperatures associated with the liquid helium (at 2 °K) and hydrogen (at 20 °K) vapor pressure scales, and the reproducibilities appear to be ± 0.002 and ± 0.007 °K, respectively.

The acoustical thermometry offers the advantage of eliminating some of the more serious concerns that are inherent in conventional thermometry, i.e., dead space corrections, gas absorption, and required accuracies of pressure and volume determinations. While these results should be considered as preliminary in a precise thermometry program, they do indicate that primary thermometry based on the velocity of sound in helium gas is com-

petitive with primary isotherm and gas thermometry in the region below 20 °K.

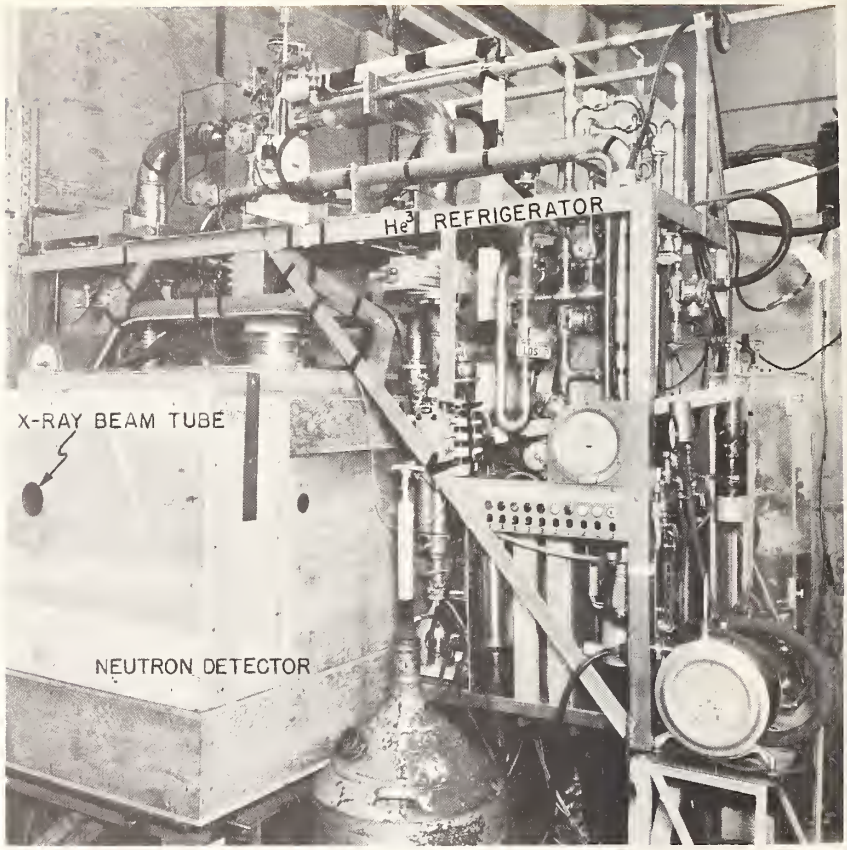
Steady-State Measurements of Molecular Lifetimes. Several problems of current astrophysical interest require for their solution knowledge of the radiative and collisional lifetimes of certain simple molecules and molecular ions in their excited states. Information of this sort, combined with measured spectral intensity distributions of such luminous gaseous systems as comets and the terrestrial upper atmophere, would permit deduction of the physical properties and conditions of excitation of these remote systems.

Laboratory measurements of molecular lifetimes are ordinarily performed by timing the fluorescent decay of a pulse-excited gaseous sample. An alternative approach now being investigated, capable of achieving much better sensitivity and spectral resolution, employs a continuous but selective excitation technique. The molecular lifetimes are determined from an analysis of the spectral intensity distribution of the fluorescent light. The analysis depends on the special properties of perturbed spectral lines, and so is applicable only to molecular spectra which exhibit these perturbations. Examples, however, include the spectra of such important cometary and upper atmosphere molecules as CN, N_2^+, and CO^+, for which lifetime information is at present fragmentary.

Recently a complete intensity analysis has been made on the CN fluorescence spectrum emitted by the active nitrogen flame—the luminous chemical reaction between active nitrogen and a carbonaceous vapor. The chemical excitation process in this emission source has the selective nature required for lifetime determinations, and the intensity analysis has yielded valuable new information on radiative and collisional lifetimes of the CN molecule. Similar measurements on N_2^+ and CO^+ require the development of appropriate emission sources.

Thermodynamic Tables. The mechanized computation of thermodynamic and related tables of physical data has progressed significantly during the year. Calculations have been completed for two monographs, one being a detailed presentation of Tables of Einstein Functions (NBS Monograph 49). These functions are useful to research workers in such fields as spectroscopy and molecular structure, low-temperature calorimetry, and the measurement of electrical and thermodynamic properties of crystals. The other work, Ideal Gas Thermodynamic Functions for Atoms and Atomic Ions, presents tables from 100 to 10,000 °K for 73 elements and their unipositive ions. These tables have important application in a wide variety of fields ranging from the chemical industry, aerodynamic, jet and rocket propulsion, to research in high-temperature phenomena, plasmas, nuclear energy, and space. Publication of this work is planned for late in 1962.

Mechanization of thermodynamic calculations has produced general-purpose computer programs which have application outside the thermodynamics field. A second generation general-purpose computer program, OMNITAB, was developed for the Bureau's electronic digital computer which makes the



Complex of equipment used to measure nuclear cross-sections with oriented nuclear targets. The plywood box houses a neutron detector and the sample; the plumbing is part of a He^3 refrigerator which maintains the sample at 0.3 °K. **(See p. 62.)**

high-speed computer as accessible to the laboratory scientist as his desk calculator. The program instructs the computer, via simple English sentences, to carry out calculations involving elementary, transcendental, and algebraic functions, or to perform a wide variety of numerical and statistical analyses of tabulated data. Although the program was designed largely for relatively small calculations of a nonrepetitive type, the language, logic, and operating feature are such as to make it highly efficient for more extensive calculations such as tabulations for two or more arguments, and the numerical evaluation of complicated integrals.

Kinetic Theory of Dense Gases. An analysis of the assumption, which is universally understood to underlie the kinetic theory of gases, that the N-particle distribution functions are in some sense functionals of the single particle distribution function, has been made. This analysis gives, on the one hand, an explicit expression for all orders of density and, on the other hand, a series of correction terms depending on initial circumstances, as well as

the single particle distribution function, which show in some detail how a system of distribution functions obeying a functional assumption develops from an arbitrary system of distribution functions. This work clarifies the theory of time-dependent phenomena in gases and has future applications in the theory of chemical reactions in gases and in quantum transport phenomena.

A study was also made of the structure of the HO_2 radical by the LCAO–MO–SCF (Linear Combination of Atomic Orbitals—Molecular Orbital—Self-Consistent Field) methods. Based on computations using the 7090 computer and an analysis of correlations of molecular states with those of the combined and separated atoms. the work has developed a new idea of the structure of the HO_2 radical. Instead of the linear shape customarily assumed, the work showed an isosceles triangle configuration is most likely. This new idea of the structure may yield information by which this elusive radical so well known in chemical kinetics will be finally observed by physical means.

Pair-Distribution Function in Dense Gases. A two-year investigation of the equation of state of simple gases and liquids, using the newly developed diagram summation methods in equilibrium statistical mechanics, has been completed. A complicated nonlinear integral equation for the pair distribution function also has been completed. The results these computations gave are in very good qualitative and good quantitative agreement with experimental results on liquid and gaseous argon. In particular, the critical constants are given by the theory to within 10 percent. The investigation shows that this method is a good first approximation and that successive terms of the formal development can be used to give more and more accurate computation of the equation of state of simple fluids. The equation was solved also for the theoretically interesting case of the hard sphere gas and shows no evidence of a phase transfer to a solid state.

2.1.6. ATOMIC PHYSICS

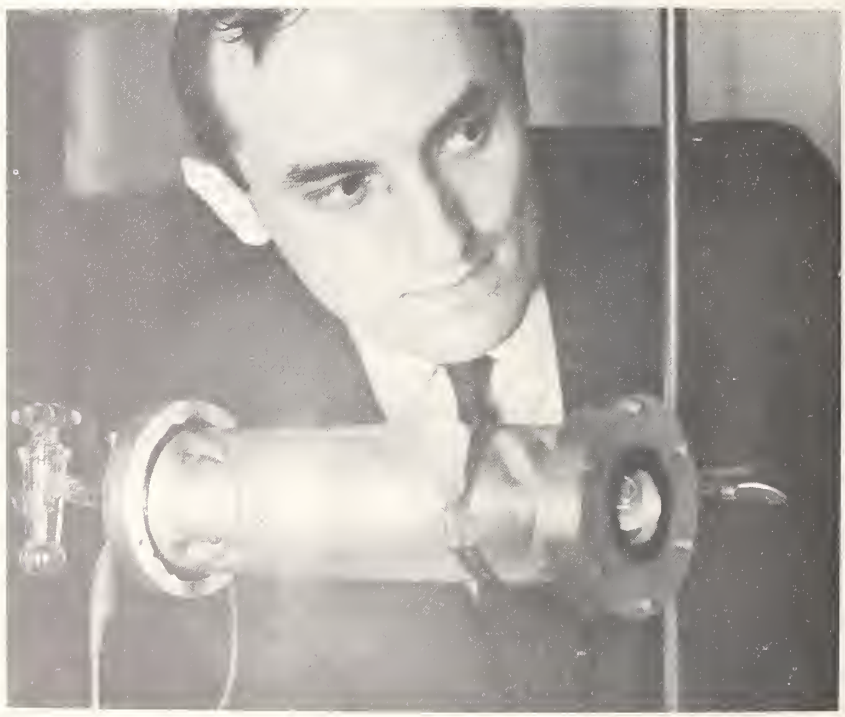
The emphasis in atomic physics research has continued to be on the accurate determination of atomic constants and the detailed properties of atoms. Valuable contributions are being made to the national effort in space and plasma research and to the national materials program. Significant progress has been made in determining and cataloging data on atomic transition probabilities and in gaining a better detailed understanding of the more complex atoms through exhaustive analyses of their spectra. More precise information on atomic collision cross sections has also been obtained. The continuing effort expended in studying these fundamental atomic properties is yielding the data necessary for a detailed understanding of stellar atmospheres and hot plasmas.

Laboratory Astrophysics.

Atomic Energy Levels. Information concerning the various discrete energy levels within an atom can be obtained from the study of spectrograms

on which spectra of atoms in different states of ionization can be separated. Such spectrograms are especially needed for the interpretation of the complex spectra of rare-earth elements of the lanthanide group. For this reason, emphasis centered on the development of sources that will produce such spectrograms. One such source is a pulsed-arc type of discharge which produces self-reversed lines in selected first and second spectra of rare-earth elements. These lines represent transitions to the ground or nearby states of the atom. Interpretation of these spectra led to the determination of the ground states of terbium I and uranium II.

Cerium spectra from 3300 to 4400 Angstroms (A) were observed using various sources, and some 300 lines of cerium III between 840 and 2000 A were measured. A general description of praeseodymium I and II spectra is nearing completion. An intensive study of the energy levels and atomic structure of these atoms is under way. Theoretical prediction of the positions of unknown energy levels of praeseodymium III has aided in the classification of about 1,600 lines and the derivation of the ionization potential. Investigation of tantalum II was completed. A new description of thulium spectra is being determined. The analysis of ytterbium II was essentially completed, and a similar study of ytterbium I is in progress. Conclusion of the analysis of the spectrum of bromine I leaves this element with one of



Pulsed arc light source which produces numerous self-reversed lines in the spectra of rare-earth elements. Self-reversal greatly simplifies the interpretation of these complex spectra. **(See p. 65.)**

the best known atomic spectra descriptions. The energy levels were determined from observations from 1060 to 23,750 A and the ionization potential was established.

Theoretical research paralleled the laboratory investigations. A Fortran code was written which instructs the 7090 computer to calculate two-electron interaction integrals from orbitals given in analytic form. With the aid of this code, second-order perturbations can be evaluated with minimum effort.

An Ultraviolet Multiplet Table, NBS Circular 488, was published. Section 3 parallels Volume III of *Atomic Energy Levels*, including selected spectra of the elements molybdenum through lanthanum and hafnium through radium. Finding lists of sections 1 through 3 constitute sections 4 and 5.

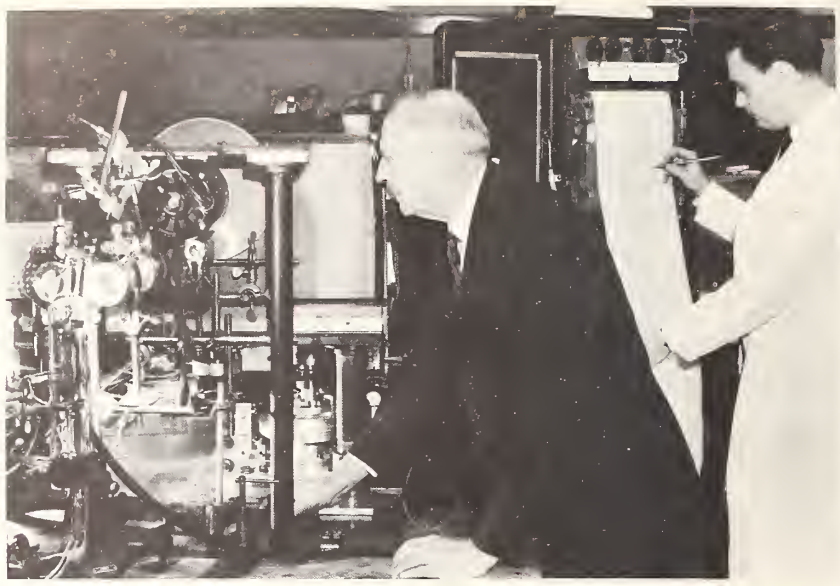
Transition Probabilities. Experimental transition probabilities on an approximately absolute scale have been derived for the 25,000 classified lines listed in NBS Monograph 32. In this Monograph, the relative intensities of 39,000 lines of wavelengths between 2000 and 9000 A of 70 elements are presented on a calibrated scale of radiant power. In the conversion of the intensity values to transition probabilities, f-values were obtained. A critical analysis of the chromium I f-values yielded a normalization factor for the reduction to absolute values that agrees well with those factors derived independently for 20 elements. These data will be used to derive solar curves of growth and to make abundance determinations for additional elements.

More precise transition probabilities for some neutral oxygen lines in the visible region of the spectrum were determined in a wall-stabilized arc. In another arc experiment, the profiles of Balmer lines were studied and compared with those obtained using line-broadening theory. The agreement is excellent and makes possible the application of line broadening to the diagnostics of dense plasmas.

A magnetically driven shock tube was put into operation, and temperatures of about 30,000 °K were obtained behind the shock fronts. Measurements of relative transition probabilities for lines of singly ionized oxygen are presently being made. Calculations of transition probabilities of lines of neutral helium and the lithium I sequence are in progress. This work is sponsored in part by the Office of Naval Research and the Advanced Research Projects Agency.

The Data Center on Atomic Transition Probabilities and Collision Cross Sections, under the sponsorship of the Office of Naval Research and the Advanced Research Projects Agency, completed a general bibliography of all known publications on atomic transition probabilities, published as NBS Monograph 50. All the available data on the ten lightest elements were critically analyzed and the "best" values are being tabulated.

Collision Cross Sections. Photodetachment of negative iodine ions has been observed in a crossed-beam experiment. The apparatus used was essentially similar to that of previous photodetachment experiments. Good "effective" resolution was obtained close to threshold, but an independent



Measurement of the infrared absorption spectra of gases reveals details of molecular structure. This high-resolution grating spectrometer was developed especially for these studies. (See p. 69.)

determination of the behavior of the cross section as a function of wavelength could not be made. A step-function cross section, shown by Berry and coworkers to approximate closely the true cross-section behavior, was used to provide an upper energy limit to the electron affinity shown to be close to the actual value.

A unique method for studying rates of certain types of ionic reactions important in gases at atmospheric pressures was developed in connection with a study of mobilities of ions in gases in the presence of uniform electric fields. The measured mobilities of ions are used to distinguish among species, and the relative populations of various species are found to depend on the elapsed time following production of the ions in an electrical discharge. Elaborate timing techniques permit measurements of the rates at which ions are converted from one species to another.

Far Ultraviolet Radiation Physics. A new group was created at NBS in September 1961 with the support of the National Aeronautics and Space Administration. This group is responsible for research activities in the area of far ultraviolet radiation physics—the absolute measurement of far ultraviolet radiation and the use of this radiation for physical experiments. A program investigating the usefulness of thermal detectors as absolute standards and another concerned with the physical mechanisms operative in flash discharge light sources are fully instrumented and under way. The group also calculated in detail the characteristics of the far ultraviolet radiation theoretically expected from the radially accelerated electrons in the NBS 180-Mev synchrotron. These calculations show that the highly

polarized continuum emitted by these electrons has a unique application in physical experiments. The radiation is also a potential primary standard of radiant flux.

Infrared Spectroscopy of Gases. Measurements of the absorption spectra of several gases led to several important results. The high-resolution absorption spectrum of acetylene-d_1 was studied in the 1,900 to 3,400 cm^{-1} region, and the ground state and equilibrium bond distances of the acetylene molecule were calculated.

The combination band $\nu_2+\nu_6$ of ethane was reexamined in order to resolve a discrepancy in the ground-state rotational constants obtained in earlier infrared and Raman studies.

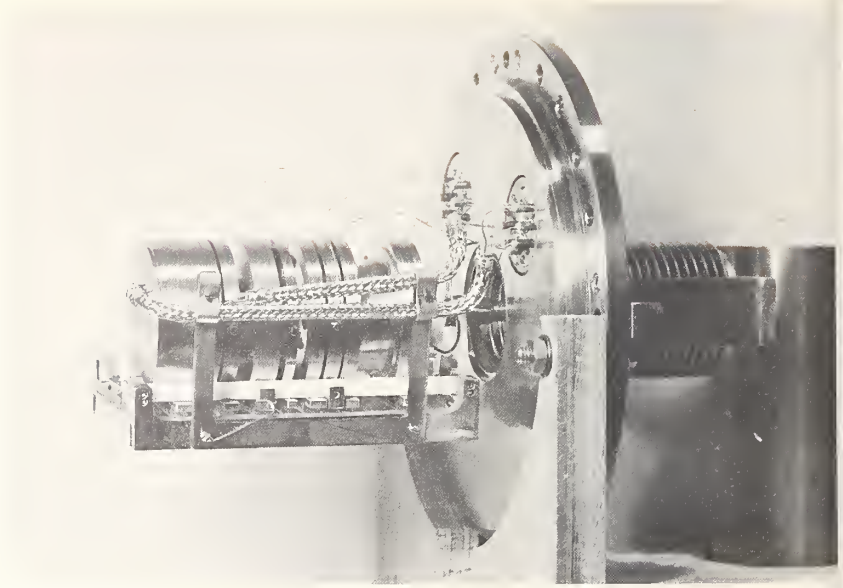
Infrared Reference Standards. A report was issued on the calibration of spectrometers from 16 to 65 microns. A number of the rotational lines of water vapor were measured for the calibration in this region, but the final values are based on the measurements of the rotational structure as found in the near infrared as well as the measurements in the far infrared region. Work is now in progress to continue the measurements to 200 microns. Also, the rotational lines of HCl were observed in the region from 30 to 150 microns and found to be useful for reference standards.

Electron Scattering. Most substances that absorb energy from electrons do so mainly by interaction with the atomic electrons or with those free electrons in metals which take part in electrical conduction. An exception to this behavior that is of considerable interest has been discovered in the loss spectrum of polystyrene. A prominent feature in this spectrum is a loss due to a resonance in the benzene ring. This loss is an unusual case of a collective interaction of limited extent.

Biological Constant Studied. An important constant in biological radiation physics is the average energy loss per inelastic event, which in electron sterilization is closely related to the dosage necessary for complete bacterial kills. This constant is also related to radiation damage in biological tissue. In collaboration with the Biophysics Department of Yale University, a study of electron interaction with tissue-equivalent materials was completed. The results of this study, besides illuminating the overall nature of electron scattering, showed that the value of this biological constant had been greatly overestimated.

Electron Optics. Being a young branch of science, electron optics has proceeded in a nonrigorous manner and many much-used devices are only partially understood. As part of a continuing effort to improve the situation, the Bureau for the first time undertook a systematic treatment of energy analyzers of the retarding type and of the effects of space charge in deflection analyzers. Systematic procedures were developed for designing electron guns for low-energy beams. These developments open the way for greatly improved experiments of physical interest.

Solid-State Physics. Increased emphasis was placed on the capabilities for growing single crystals of oxide semiconductors and insulators used in solid-state studies at NBS. Single crystals grown by the flame fusion



Inside of an electron optical bench which is used for testing electron optical components. It was set up at NBS to test a retarding field analyzer. (See p. 69.)

technique at high temperatures ~1800 °C (TiO_2, ruby, sapphire), from the melt at rather low temperatures ~200 °C (ammonium sulfate), and from solutions (silver iodide, lithium trihydrogen selenite) are now available for the many and varied investigations of the solid state. The defect structure and mechanisms of bonding for most of these materials were investigated by electron spin resonance, nuclear magnetic resonance, and pure quadrupole resonance techniques.

Through studies of the electronic transport properties of rutile, understanding of the energy levels and conduction mechanisms was appreciably advanced. The possible role of polarons and limitations of conventional polaron theory were pointed out. This has stimulated theorists to explore this difficult field further. Improved methods of preparing homogeneous samples of reduced rutile permitted the Hall coefficient to be measured at lower temperatures (~2 °K) than had previously been possible. New phenomena were revealed in this material which were interpreted as impurity level conduction. Analysis of data near room temperature also suggests that the energy-band structure of reduced rutile may be more complicated than previously considered.

Optical absorption studies on rutile doped with most of the transition metals were carried out over the range 0.1 to 3.0 electron volts at room temperature, and in a few cases at liquid helium temperatures. The data obtained give new evidence for absorption by the excitation and ionization of the added impurities (doping material). A theoretical calculation of the energy-level system for the case of vanadium-doped rutile showed that

a reasonable explanation of the observed spectrum requires considerable electronic bonding between the vanadium and the surrounding oxygen ions.

Theoretical investigations of the equation of state indicate that Gruneisen's equation is more general than usually believed and applies when the heat capacity is a function of T/θ, where T is the absolute temperature and θ is a function of the volume. When this condition applies to the liquid phase, only a minor additional assumption is necessary to derive the Simon melting equation.

Lasers. The advent of the laser has made possible for the first time an experiment to check on the frequency ratio of the fundamental and second harmonic generation in piezoelectric crystals in the optical range. The 6°43 Å output of a ruby laser was used as the light source. The accuracy of the experiments was determined by the resolution of the grating spectrograph, the line width of the laser radiation, and the imperfection of the piezoelectric crystals, which in the best case was ± 3 parts per million. Within this accuracy, the second harmonic generated in the piezoelectric crystals was found to be exactly twice the fundamental radiation.

Early predictions based upon the power level of the ruby laser and the coupling constant for the production of the second harmonic suggested an accompanying d-c polarization effect in the piezoelectric crystal of the order of 0.1 millivolt across the crystal. After unsuccessful attempts to measure this effect, the coupling constant was investigated and measured to be some two orders of magnitude smaller than was predicted. New attempts to measure the d-c polarization will be made with more powerful lasers.

2.1.7. RADIATION PHYSICS

The increasing application of atomic and nuclear technology to industrial, medical, and defense activities has resulted in an expansion of the demands placed upon radiation research. Industrial uses of radiation have brought about a growing need for improved standards and dosimetry at high dose levels and high energies. Medical users increasingly turn to higher energies and call for improved determination of both source output and absorbed dose. Research workers interested in the effects of radiation on various materials have need for more information in their field. The Bureau has attempted to meet these increasing demands with its radiation research program.

The research of the Bureau is directed toward obtaining basic experimental and theoretical data concerning the interactions of radiation with nuclei, atoms, and molecules, as well as with bulk matter; the investigation, development, and improvement of radiation sources and standards; and the development of improved techniques and instruments for the detection and measurement of these radiations.

Radioactivity Standards. The growing use of radioactive materials for industrial and medical applications, in addition to their utility in scientific research, has created an ever-increasing demand for a greater variety of standards and greater accuracy in existing standards. Effort to meet this

demand resulted in completion of the following projects during the past year: (1) Development of chlorine 36 and calcium 45 beta-ray solution standards; (2) development of a cobalt 57 radioactivity standard; (3) development of an yttrium 88 point-source gamma-ray standard to supplement the existing gamma-ray "kit"; (4) restandardization of the hydrogen 3 beta-ray solution standard by gas counting; and (5) participation in five international intercomparisons involving four different radionuclides.

Radiation Theory. The broad long-term program in radiation theory continued, emphasizing the following areas: The evaluation and systematic tabulation of elementary cross sections for the interaction of high-energy radiation (gamma-rays, neutrons, and charged particles) with matter; the penetration and diffusion of radiation in extended media due to multiple interactions; and the application of radiation transport theory to shielding problems such as those arising in the context of Civil Defense.

Cross Sections. An exact quantitative theory has been developed which allows the evaluation of gamma-ray polarization from measured angular distributions of electron-positron pairs. Work is also in progress on the evaluation of the pair production and bremsstrahlung cross sections in the second Born approximation, and on the large-angle inelastic scattering of electrons from nuclei, taking into account nuclear transitions. This research has been supported in part by the Office of Naval Research.

Penetration and Diffusion. The deep penetration of electrons has been studied in an approximation assuming that all scattering angles are small and neglecting fluctuations in energy loss. A computer program for determining the electron flux without making these approximations is in an advanced state of development. The transport of electrons and positrons in bounded media has been investigated by a technique combining analytical and random sampling methods, and results have been obtained for the reflection and transmission by foils, and for energy dissipation in semi-infinite media. The slowing-down spectrum of neutrons has been studied by a numerical method which allows one to take into account all the available information about neutron cross sections, in spite of their irregular and highly complicated nature.

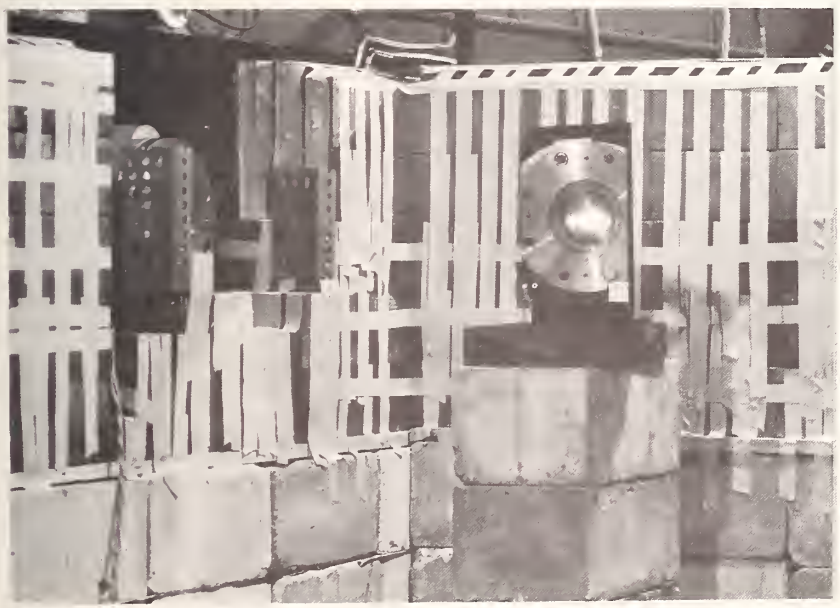
Shielding Engineering for Civil Defense. This program is sponsored by the Office of Civil Defense (DOD) and by the Defense Atomic Support Agency, and proceeds on various levels. The foundations and basic input data for radiation shielding engineering, derived from the theory of gamma-ray penetration and diffusion, have been published in NBS Monograph 42. Using these results, a practical shielding manual was prepared, in collaboration with staff members of the Office of Civil Defense, for engineers and architects concerned with protection against radiation from fallout. A simple survey guide to evaluate quickly the protective characteristics of various types of buildings was also prepared. This survey guide has been programed for the NBS electronic computer, and the program is being used on a large scale in the National Shelter Survey currently undertaken by the Office of Civil Defense. (See p. 115.)

Linear Accelerator. Progress continues in the design and construction of the NBS linear accelerator. Tests of the first prototype accelerator section have been valuable in fixing the final production phases of the new machine. Completion of the accelerator is expected in the fall of 1963 and installation in the new laboratory at Gaithersburg in the spring of 1964. Research with the accelerator will meet the increasing need for basic data and physical measurement technique developments in the uses of intense, high-energy electron beams in radiography, radiology, nuclear physics research, and radiation processing of materials.

Two investigations initiated during the past year will allow definition of the ultimate performance of the NBS linear accelerator facility as well as other comparable facilities around the country.

(1) The theory of heavily beam-loaded linear accelerators has been poorly understood. The traveling-wave linear accelerator waveguide is essentially a band pass filter with a pass band of only a few megacycles per second. The consequences of this fact are usually ignored in calculations of the behavior of linear electron accelerators. During the past year, the theory of linear electron accelerator operation has been extended to include these dispersive effects.

(2) The second investigation related to the development and handling of an accurately-defined high-intensity electron beam is the production of a well-collimated beam of krypton ions. This ion beam will have a magnetic



A viewing port has been installed in the NBS 100-Mev synchrotron to study the visible and ultraviolet light radiated by high-energy electrons moving in a circular orbit. The port can just be seen through the opening in the lead shielding wall at the left of the picture. The mirror located to the right gives a front view of the port and the visible synchrotron light. **(See p. 74.)**

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rigidity of 250 Mev/c (where c is the speed of light) per elementary charge and will simulate the momentum of 250-Mev electron beam. Thus, the optical properties of a magnetic beam deflection system or of experimental magnetic spectrometers can be measured in a small laboratory without requiring the use of the large accelerator facility to produce the test beam of electrons. The ion beam is accelerated by a 400-kilovolt Van de Graaff accelerator. Preliminary measurements show that the position of the center of the ion beam can be determined with an accuracy of better than ± 0.05 mm.

An investigation has been also made of the properties desired in a spectrometer for elastic and inelastic electron scattering. Calculations show that the resolutions obtained with the double-focusing ($n=\frac{1}{2}$) 180° deflection magnets often used can be substantially improved by reducing the deflection to the "magic angle" of 169.8°.

High-Energy Radiation. In order to extend the general utility of the 180-Mev electron synchrotron for radiation-physics research as well as atomic spectroscopy, a new accelerator tube was designed, built, and installed during the past year. This tube permits the study and application of the ultraviolet and visible light (100 to 500 A wavelength) radiated by high-energy electrons in a circular orbit. This experimental arrangement is unique in that the light produced is available in a vacuum, is intense, has a reasonably well-known spectrum, and is polarized.

During the last five years, the Bureau has actively investigated the interaction of high-energy photons with nuclei known to have large deformations (i.e., nuclei with large quadrupole moments). Studies were made of both the scattering and the absorption of photons by these nuclei. The analysis of these data indicated that such nuclei probably had a large intrinsic tensor polarizability. During the last year this facet of the polarizability of the holmium nucleus was confirmed directly in an experiment that showed that the nuclear absorption cross section in the giant resonance energy region depended upon the orientation of the nucleus with respect to a beam of photons. This represented the first direct experimental verification of the theoretical prediction that nuclei with large deformations should have large intrinsic tensor polarizabilities. Nuclear alinement was produced by cooling single crystals of either holmium metal or holmium ethylsulfate to 0.3 °K by means of a He^3 refrigerator. (See p. 62.) The refrigerator and a neutron detector were designed such that the yield of photoneutrons produced by an X-ray beam from the NBS 50 Mev betatron coulld be measured as a function of the orientation of the holmium nuclei with respect to the X-rav beam axis. This experiment represented the first successful attempt to study a nuclear reaction using a target of orientated nuclei in the beam from an accelerator. The use of such targets offers new possibilities for studies of nuclear structure.

Ionization Dosimetry. Radiation effects on materials are most closely correlated with the radiation absorbed in the material. One of the factors needed to determine this absorbed energy from ionization measurements is the average energy required to produce an ion pair in gas (W). For alpha

particle radiation, two different methods of determining W have been used over the past few decades. One of these methods depends upon the fast collection, and the other upon the slow collection of the ionization produced in the gas. Different laboratories in the past have obtained differences of as much as 5 or 6 percent between the two methods. An investigation and intercomparison of the two methods has been undertaken at NBS. It was found that when the electronic instrumentation was carefully calibrated and the effects of the chamber geometry were taken into account, the agreement was within the experimental error of a few tenths of a percent.

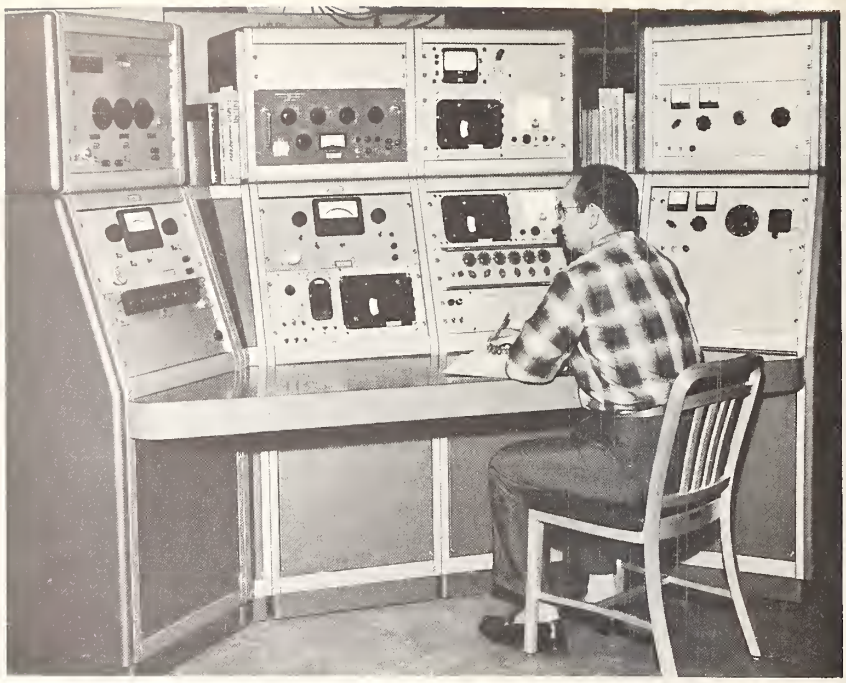
Large Ionization Chamber. The development of a large ionization chamber for the rapid and accurate determination of the total energy transported by a high-energy X-ray beam was completed during the past year. Two experimental methods have been used to calibrate this chamber with an accuracy to within 2 percent in X-ray beams with peak photon energies between 6 and 170 Mev and energy fluxes of 4 milliwatts. A description of the chamber, its calibration, construction, drawings, plus additional information about the variation of this calibration with changing experimental conditions, has been published in NBS Monograph 48. The calibration has been experimentally transferred to betatron laboratories in France, Germany, Switzerland, and Yugoslavia.

Cavity Corrections. Collimated-beam gamma-ray ranges are calibrated at NBS using a cavity ionization chamber whose characteristics have been carefully investigated. The use of a cavity chamber for measurement in terms of roentgens requires corrections for various physical factors, most of which must be obtained experimentally. Recent investigations have indicated that the end walls of cylindrical chambers, under some circumstances, do not contribute uniformly to the electron flux in the cavity. Tests to determine the magnitude of the effect have been carried out with cylindrical chambers of various dimensions as well as with spherical chambers. Results indicate that the effect of orientation of cylindrical chambers may be as large as 2 percent.

Scattering Measurements. Measurements have been made to determine the intensity and energy of scattered radiation from large cesium 137 sources such as are used for instrument calibration and radiation treatment. Though the investigation was based on a source and geometry that approximate that of the 2,000-curie installation at the Bureau, it goes beyond this in determining the effect of both thicker and thinner sources, of the source capsule, and of the head and collimator.

The measurements indicate the influence of source size and collimator geometry on the beam spectra. These data are of value in the design of source assemblies for instrument calibration. In addition, the information provided on the energy spectra of the radiation from cesium teletherapy units is useful in correlating physical data from different sources.

Photographic Dosimetry. The main emphasis of the Bureau's work in photographic dosimetry has been on the extension and refinement of knowledge basic to the photographic process and of concern in the photo-



New control console increases efficiency in precise international comparison of primary X-ray standards and routine calibration of laboratory and clinical instruments. **(See p. 77.)**

graphic measurement of radiation. Current effort involves the extension of the useful range of photographic dosimetry to exposures of 1 milliroentgen or less of cobalt 60 gamma-rays, without introducing rate dependence. Post-exposure to infrared radiation, treatment of the films with thallium and silver nitrate or thallium sulfate before and after exposure, as well as addition of salicylic acid, sodium hydroxide, or sodium thiosulfate to the conventional X-ray developer, showed promise. Work was continued on extending the photographic process to dosimetry of X- and gamma-ray exposures in the range from 1000 to 10,000 roentgens. Sugar and 6-nitrobenzimidazole were used as development retarders. Also, various silver solvents were investigated in their action of removing the image from grain surfaces, thus freeing the internal image for development. The methods were tried on three widely used dosimeter films. Internal development with X-ray developer, to which a small quantity of buffered potassium thiosulfate (hypo) was added, proved most effective. With this method, a 5,000-r cobalt 60 gamma-ray exposure could be determined with a precision to within 5 percent with two types of film and an exposure of 10,000 r with comparable accuracy with a third type of film. A disadvantage in the method is that a certain amount of rate dependence is introduced. However, internal development with hypo reduces the film's energy dependence in the 15- to 50-kev region.

A detailed study was performed of the energy dependence of the response of X-ray film in the region of medical diagnostic X-rays and of means for influencing it by the use of absorbers and electron emitters. Above the silver *K*-absorption edge, tinfoil in contact with the film surfaces was found useful. In order to investigate the influence of rubidium below this edge, the feasibility of pressing rubidium sulfate powder into thin plaques as electron emitters is being investigated.

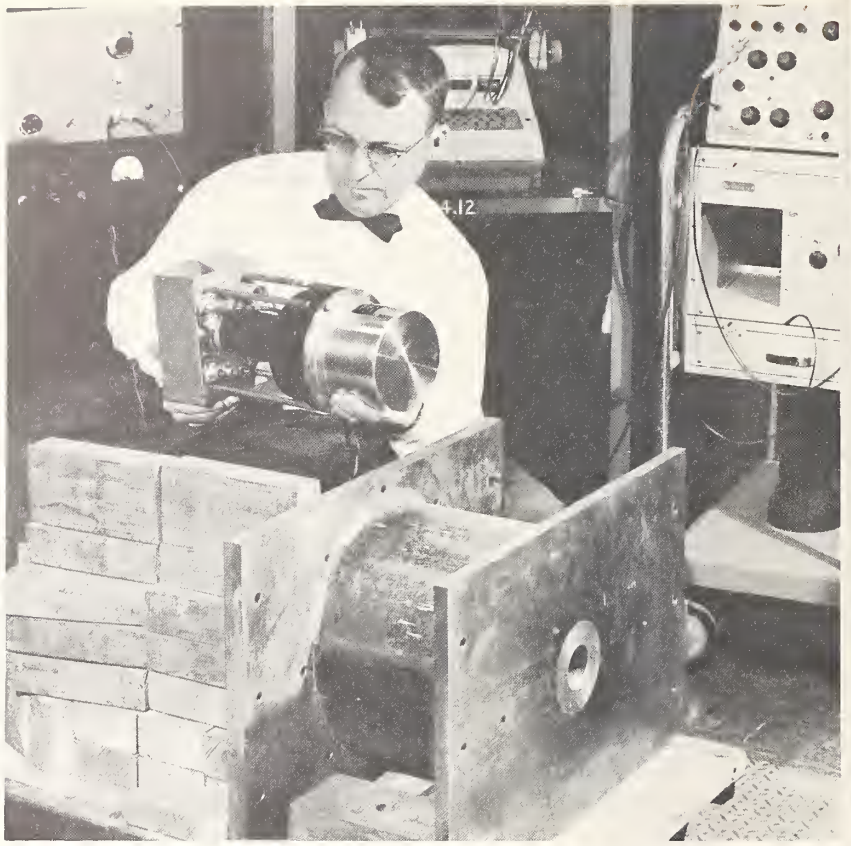
Solid-State Dosimetry. An investigation was made of the response to X-rays of silicon radiation detector cells of the diffused *p-n* junction type which are now widely used for charged particle energy spectroscopy. It was expected that such cells should be more sensitive to X-rays than silicon solar cells, previously investigated, because of their larger charge collecting volume and higher resistance.

The investigation has shown that it is possible to use silicon radiation detector cells as photodiodes for X-rays, especially for relative measurements of high dose rates when large voltage signals are required. For small dose rates of the order of a few roentgens per minute, these cells are preferably to be used as photovoltaic cells, thus eliminating the dark current which at higher voltages becomes unstable and at small dose rates reaches values larger than the photocurrent.

The photovoltaic current measured with low-energy X-rays was found to be proportional to exposure dose rate of values up to approximately 5000 r/min, and linear response could be preserved with load resistances much larger than those which could be used with silicon solar cells. The photovoltaic current per unit surface area was approximately three times, and the photo-emf approximately a hundred times, larger than measured values of silicon solar cells. The energy dependence of the photo-response to X-rays measured under conditions approaching electronic equilibrium was found to be similar to that measured on silicon solar cells

Nucleonic Instrumentation. A new control console has been designed and constructed for use in precise international comparison of primary X-ray standards and routine calibration of laboratory and clinical instruments. This console, which makes possible high accuracy with minimum effort, includes equipment for automatic regulation of the X-ray tube voltage and current to maintain constant X-ray output. Instruments are also included for the accurate measurement of minute ionization currents by determining the time required to accumulate a known charge on a standard capacitor. Auxiliary equipment supplies stable voltages to the ionization chambers, provides temperature measurements, and permits control of the X-ray shutter.

Neutron Physics. Standard radioactive neutron sources are widely used to produce known thermal and fast neutron fluxes, for neutron instrument calibration, and for calibration of film badges and neutron survey meters used in neutron radiation protection. The national standard radium-beryllium (γ,n) source has been absolutely calibrated by a new method involving the use of a manganese sulfate bath filled with heavy water. Most



Detector used in measuring scattered radiation from cesium 137 sources such as are used for instrument calibration and radiation treatment. The detector assembly is mounted behind the 12-inch-thick lead colimator in the foreground. **(See p. 75.)**

absolute measurements of neutron source strength have been made in baths of light water with either calibrated thermal neutron detectors or manganous sulfate in solution as the detector. In a light water bath many of the neutrons are captured by the hydrogen in the bath and, as a result, a large correction must be made for these neutrons which escape detection. In the present experiment, hydrogen (mass 1) is largely eliminated and nearly all of the neutrons are captured in the manganese 55. When a neutron is captured by the manganese, radioactive manganese 56 is produced and this is absolutely counted by beta-gamma coincidence counting. The water of the bath was about 94 percent heavy and 6 percent light water, and a correction was made for the neutrons captured by the small amount of light water present. The uncertainty of the new value is about 1 percent, a considerable improvement over previous measurements.

Radiation Protection Recommendations. Research on the fundamental properties of radiation and on radiation standards has placed the Bureau in a unique position to translate the latest information in these

fields into practical recommendations for radiation protection, quantities, and units. The Bureau has assisted in the dissemination of this information by publishing as NBS Handbooks the recommendations of the National Committee on Radiation Protection and Measurements (NCRP) and the International Commission on Radiological Units and Measurements (ICRU). During the last year, three new handbooks have been published. These include: NBS Handbook 79, *Stopping Powers for Use with Cavity Chambers;* NBS Handbook 80, *A Manual of Radioactivity Procedures;* and NCRP Report No. 29, *Exposure to Radiation in an Emergency* (University of Chicago Press). A number of handbooks are presently in preparation, including a series which will comprise the 1962 report of the International Commission on Radiological Units and Measurements. Staff members participate actively in this work, as well as in the work of the International Commission on Radiological Protection and the Federal Radiation Council. The recommendations of these groups represent the latest scientific thinking in the broad area of radiation protection, measurement, quantities, and units.

International Standards. In October 1960 the General Conference of Weights and Measures approved the extension of the work of the International Bureau into the area of ionizing radiation. A working group was set up to make recommendations on immediate and long-range programs for this area, a laboratory design for this work, laboratory equipment, and staffing. Members of the Bureau staff involved in neutron measurements, radioactivity measurements, and X- and gamma-ray measurements were invited to participate in this effort. During a meeting held early in 1961, this group considered the entire program and made recommendations. The staff of the International Bureau of Weights and Measures is now in the process of implementing these recommendations.

During the past year, two sets of X-ray transfer instruments were prepared and calibrated. These will be placed on loan to the International Bureau of Weights and Measures for an indefinite period. The cavity chambers, the diaphragm, and the capacitors of these transfer instruments may be calibrated at a national laboratory by comparison with the standards of that laboratory. The ratio of the calibrations obtained at different laboratories is then a measure of the relative values obtained by the national standards.

Such an indirect intercomparison has just been completed between the National Research Council, Canada, and the NBS. The ratios obtained for the cavity chamber at the two laboratories may be compared with the results of a direct intercomparison of the national standards themselves. The two sets of intercomparisons differed by a maximum of 0.5 percent with a mean deviation of about 0.3 percent. Thus, it appears that transfer instruments can be used for international intercomparisons instead of the direct comparison of national standards. There is considerable advantage in the use of such transfer instruments as they weigh only a few pounds even in their shipping container, whereas the national standards themselves weigh many hundreds of pounds.

2.2. CHEMISTRY AND PROPERTIES OF MATERIALS

2.2.1. ANALYTICAL AND INORGANIC CHEMISTRY

In response to the general demand for more detailed knowledge on the properties of materials, the Bureau carries out an extensive program of research in the areas of preparation, purification, and characterization. Under this program, new and improved methods of measuring chemical properties, composition, and behavior of substances are developed; standard reference materials of known composition or properties are prepared; fundamental investigations of chemical phenomena on which the behavior of chemical systems is based are carried out; and technical and advisory services in specialized areas of modern chemistry are provided.

Special investigations carried out during the year include studies of the preparation and stability of inorganic compounds, new and improved methods of purification and separation of chemical substances, and the development of criteria for measuring purity and chemical constants of pure materials. New programs were initiated in X-ray diffraction, atomic absorption, electron-spin resonance, and high-temperature purification processes.

Plutonium Standard Issued. High-purity plutonium for use as a standard reference material has been prepared and analyzed in cooperation with the U.S. Atomic Energy Commission. Considerable expansion of atomic energy use has underlined the need for standard materials on which to base measurements of high precision and accuracy. The plutonium chemical standard can be utilized as a comparison standard for all plutonium chemical analyses. It is issued as NBS Standard Sample 949, and is available to persons licensed to possess special nuclear materials.

Atomic Weight of Chlorine. The atomic weight of chlorine has been redetermined by coulometric analysis to be $35.45273 \left\{\begin{matrix}\pm 0.00092 \\ 0.00097\end{matrix}\right\}$. (See p. 90.) This electrochemical method employs the precise relationship that exists between the amount of electricity used in an electrolysis and the amount of chemical reaction produced. Modification of the electrolyte cell developed in previous coulometric work, and improved techniques in sample handling and end-point determination, have resulted in analyses having a standard deviation of five parts in 100,000.

Trace Level Analysis. Methods for determining trace level impurities in copper-, iron-, and zirconium-base alloys were developed. Adaption and extension of existing methods as well as the development of new procedures, such as the ion-exchange spectrographic approach for hafnium in zirconium-base alloys (parts per million), were employed.

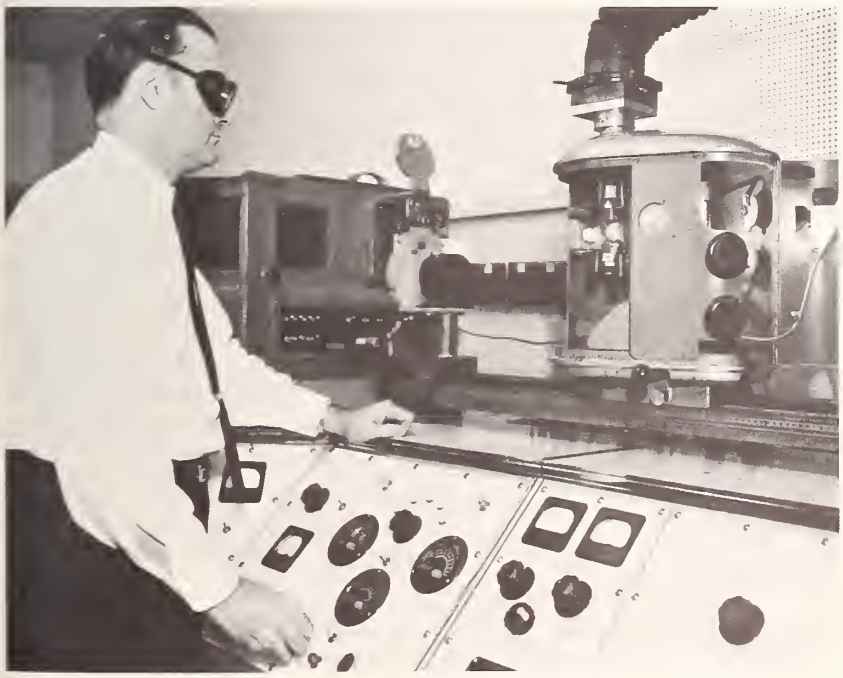
The anion-exchange process developed for zirconium in hafnium metal was expanded to cover zirconium up to 80 percent in oxide or metal. This procedure should be useful in following the fractionation of hafnium from

zirconium to prepare nuclear-grade hafnium as well as in inspecting the final product.

Uranium Analysis Standard. Single-crystal uranyl nitrate hexahydrate is being studied as a primary analytical standard for uranium analysis. Contrary to expectations, the crystals have been found to exhibit weight changes at relative humidities at which they should have been stable; no region of moisture stability has been found. The reason for this unexpected behavior is still under investigation.

Water Determination in Commercial Products. Investigation of methods for determining water content in various materials, including agricultural products, has been initiated recently. The Office of Weights and Measures is particularly interested in this program for the possibility of developing and calibrating a device for determining moisture content in grains. The States are looking to the Bureau for such a device, as they do for the development and calibration of other measuring equipment. A gas-chromatographic method appears especially promising and is being studied intensively.

Determining Transition Probabilities Using the Gas-Stabilized Arc. Transition probabilities are of basic importance to studies of excitation of spectra in analytical and basic spectroscopic research and in astrophysics. A gas-stabilized arc giving accurate intensity and temperature measurements has provided particularly uniform conditions for the excitation of elements



Experimental observations of spectral line intensities made with this spectrograph formed the basis for a catalog of 39,000 spectral lines for 70 elements. **(See p. 67.)**

introduced in solution form. The arc was demonstrated to be an especially useful tool in the accurate measurement of spectral line intensities for the spectrum of iron. The ease with which mixed solutions may be introduced into the arc permits the measurement of transition probabilities for two or more elements on the same scale. Knowing the absolute transition probability of one of these elements allows the possibility of placing all measurements on the aboslute scale.

X-Ray Analysis of Noble Metal Alloys. The application of X-ray spectrometry to the analysis of gold alloys was investigated to establish the value of the method as a substitute for tedious chemical or assay methods. Procedures were established to determine the alloying elements in the gold alloy—gold, platinum, palladium, silver, copper, and zinc. Precisions were found to lie between 1 and 2 percent of the amounts present. The spectrometric procedure with a single-channel X-ray spectrometer required 5 man-hours as compared to 3 man-weeks for chemical analysis. A similar procedure is under investigation for the analysis of silver-base alloys.

Trace Element Standard Samples. Attention is being given to means for extending the certification on present standard samples to include more trace elements (parts per million), and to develop new standards for high-purity metals. These standards will provide certified values for more than 25 chemical elements, many at concentrations of a few parts per million or less.

As a beginning on trace element standards, two sets of three samples each of zirconium and zirconium alloy (98 Zr–2 Sn) have been prepared in cooperation with the Atomic Energy Commission and the Bureau of Mines. Zirconium is used for structural members in atomic power units and the presence of even trace amounts of neutron absorbers causes deleterious effects. Three of the standards have been issued by the Bureau with tentative concentration values for the more common impurities; the standards issued are two for the analysis of zirconium metal and one for Zircalloy.

A reference sample of selected platinum wire of highest purity has been prepared with the cooperation of interested outside laboratories. This sample and another containing added impurities in the range 1 to 10 parts per million will serve in research for extending and improving several methods of trace analysis.

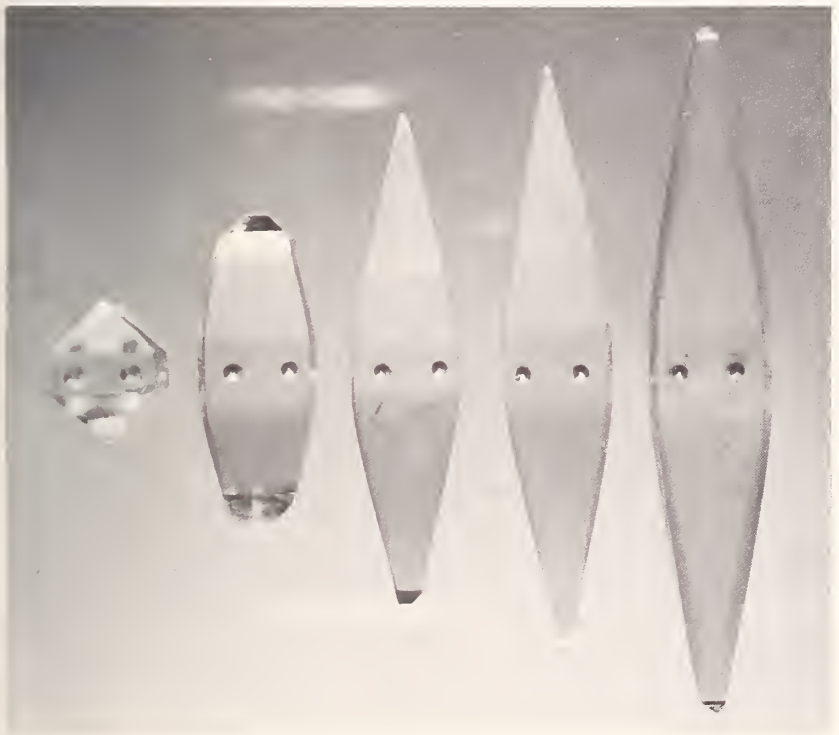
Test Mixture for Fractionating Columns Developed. A test mixture has been developed for use in evaluating high-efficiency fractionating columns. The test material consists of two isomers of heptane; 2,3-dimethylpentane, and 2-methylhexane. Because this mixture has a low relative volatility and each of its components can be easily identified, improved calibration and evaluation of high-efficiency fractionating columns will be possible. The difference between the boiling points of 2,3-dimethylpentane and 2-methylhexane is 0.268 °C, providing narrow limits within which the test column may separate substances by fractional distillation. The refractive index difference between the two components is nearly twice that of test mixtures used in evaluating columns of medium efficiency. This property

permits the use of a differential refractometer for identifying the separation point of each of the heptane isomers.

Improvements in Liquid-Solid Chromatography. Closer control of variables in liquid-solid chromatography has resulted in an improved and more efficient system. For example, by recording the temperature of a thermistor placed in a selected position of a column of adsorbant, the progress of the effluent front may be followed, since the thermistor senses a function of the heat of adsorption. The temperature generated bears a relationship to the adsorbability of each of a series of compounds. This may allow a reasonable prediction of their separability in an infinitely long column.

Relatively constant pressure throughout the column is desirable in order to avoid certain unwanted results, such as vaporization of the liquid. Better results are also obtained by pumping the starting material through the column, rather than using gas pressure.

Dielectric Constant Change. The dielectric constant of a liquid changes with temperature, primarily due to a change in density. As the material begins to freeze there is a very large change in dielectric constant until the sample is frozen. An investigation of this property as a func-



Single crystals are often used to investigate the fundamental properties of materials. This set of ammonium dihydrogen phosphate crystals, grown from solutions containing chromic ion, represents various stages of growth from the seed (left) to the final crystal. The tapered prism faces of the crystals are contaminated with chromium. **(See p. 84.)**

tion of time and temperature is being conducted and may offer a convenient means for determination of purity.

X-Ray Diffraction. Crystalline ozone and two forms of solid ammonia have been used to derive simple and direct information on the molecular geometry of crystals. The radial distribution functory, which can be derived for any phase from the powder X–ray diffraction intensities, has been tested. Rather serious errors tend to accumulate, which indicates that only the best obtainable data are likely to yield useful results. This study indicates care should be taken when using the radial distribution method for amorphous solids for which other conventional crystallographic methods are not available.

Internal Crystal Study. Large single crystals can be examined by conventional X–ray diffraction procedures only at their surface or by destructive sectioning. A new method for studying the perfection of large single crystals has been shown to be feasible. It employs high-voltage (up to 250 kilovolts) X–rays collimated and scattered coherently by the crystals. The technique is analogous to the Laue method of X–ray crystallographic photography in which the interior crystal structure is examined.

Crystal Growth. To provide means for measuring and controlling the supersaturation of aqueous solutions of inorganic salts during the growth of large single crystals, a method based on the electrolytic conductivity of solutions in the saturation region was developed. The conductance, measured by means of a cell immersed in the growth bath, has been found to be most sensitive to small changes in temperature and concentration near saturation. By using precise measurements and curve-fitting procedures, empirical formulas have been developed for the specific conductance of ammonium dihydrogen phosphate solutions.

2.2.2. PHYSICAL CHEMISTRY

The Bureau's program of basic research in physical chemistry covers a broad spectrum of theoretical and experimental activities. The primary objective of this program is to develop an understanding of the molecular basis of bulk properties and macroscopic processes. Particular emphasis is placed on precise determinations of structural parameters of stable and transient molecular species and descriptions of elementary molecular processes in well-characterized systems. Considerable effort is directed to the design and development of special techniques and instrumentation and to the evaluation of theoretical models of molecular structure and processes.

The following examples of research conducted during the year illustrate the scope of the physical chemistry program: Studies on synthesis of labeled carbohydrates, isotope effects, and conformations of sugars; spectroscopic determinations of structural constants of free radicals and simple organic molecules; analysis of elementary processes in flames; investigations of radiolysis and vacuum ultraviolet photolysis of organic molecules; precise measurements of heats of reaction and formation; studies of chemical reac-

tions and ionization processes at crystal surfaces; determinations of atomic weights; and measurements of nuclear spin-spin interactions.

Significant progress was made in the following areas: Development of special mass spectrometric instrumentation required for studies of the kinetics of ion decompositions and of photoionization processes, the construction of a microwave spectrometer for operation at high temperatures, and the design and construction of a calorimeter for precise measurements of heats of solution.

Precision Calorimetry. Recent calorimetric investigations have involved measurements of the heats of solution and liquid-phase reactions of beryllium compounds. The solution calorimeter currently in use consists of a 500-milliliter vacuum-jacketed glass vessel fitted with a 100-ohm glass-enclosed heating coil, stirrer, and an assembly used to introduce the sample into the calorimeter fluid. Temperature changes in the calorimeter are measured by a platinum resistance thermometer. Uniform stirring is achieved by a glass screw-type impeller driven by a synchronous motor. Measurements have recently been completed for the Advanced Research Projects Agency on the heats of solution of metallic beryllium and beryllium hydride in dilute hydrochloric acid. Additional measurements on the heat of solution of anhydrous beryllium chloride are currently in progress.

Measurements have also been made on the heat of solution of sulfur dioxide in water. These data have been combined with measurements made at the University of Lund, Sweden, on the heat of reaction of sulfurous acid with bromine to yield a value for the heat of formation of aqueous hydrobromic acid.

Other measurements have been completed recently on the heats of formation of lithium, ammonium, and sodium perchlorates. These values are based on the heats of reaction of the salts with potassium chloride solutions, and the heat of formation of potassium borohydride.

Reactions of Hydrogen Atoms. Hydrogen atoms react with unsaturated hydrocarbons down to liquid nitrogen temperatures. In a technique developed at the Bureau to study these reactions, hydrogen atoms are generated in the gas phase and react with a condensed film of the unsaturate (olefin) diluted in an inert matrix. The matrix in which the olefins are deposited has a marked effect on the rate of the reaction. This was shown to be the result of a diffusion-limiting process. The reaction occurs on the surface and is maintained by a flow of olefin molecules from the interior of the film. If the matrix does not permit ready diffusion of the olefin molecules, reaction does not occur after the surface molecules have been exhausted. These researches may be expected to shed some light on the question of the possibility of reactions occurring in interstellar space between hydrogen atoms and cometary particles.

Ionization Processes at Surfaces. The importance of surface ionizing processes for ion-propulsion systems has been recognized. A basic study of some of these processes has been undertaken to determine the mean life-

Solution calorimeter used in precise measurements of heats of solution and liquid phase reactions. Recent studies have concentrated on beryllium compounds. **(See p. 85.)**

time of ions on refractory metal surfaces. This was done by directing a molecular beam of cesium against a heated tungsten ribbon. Cesium ions resulting from the process were collected. The variation in the temporal intensity of the collected ion beam was analyzed in terms of the adsorbed lifetime of the cesium atoms on the surface. The results have shown that binding force between the cesium and tungsten is essentially electrostatic in nature. Gases adsorbed on the tungsten surface reduce the mean lifetime of the cesium ion and decrease the desorption energy.

Field Emission Microscopy. Field electron emission studies of molecules adsorbed on tantalum surfaces have been made. The technique permits observation of surface phenomena on an almost molecular scale. Studies of carbon monoxide on tantalum showed that carbon monoxide is dissociated. Both carbon and oxygen on tantalum were separately investigated. It was demonstrated that oxygen is held to the surface by very strong bonds, while work with carbon on tantalum confirmed that tantalum carbide is extremely stable. The carbide phase forms precipitates which are

deposited around the cube face planes and, at somewhat elevated temperatures, cluster preferentially along certain zones of the tantalum crystal.

Conformational Analysis. Study of the shape or conformation of molecules of cyclic organic compounds has become a subject of paramount importance for correlating chemical and physical properties. The first attempt to correlate reaction rates with ring conformation was made 25 years ago at the Bureau. Recent work has established that differences in rates of oxidation of aldoses with bromine, studied earlier, can be ascribed to differences in the conformational stability of the pyranose ring. The rate of oxidation for an aldose depends largely on the energy required to change the conformation of the ring, in the ground state, to that of a transition state wherein the ring oxygen and carbon atoms 1, 2, and 5 lie in a plane.

Work was begun on the determination of free-energy differences between the various conformations for each of several aldoses, and also of free-energy differences between the various aldoses in a given conformation. Correlations of structure with infrared absorption spectra were made for a series of sugars and glycosides.

Isotope Effects. Isotope effects (differences in the behavior of isotopically labeled and nonlabeled molecules) frequently lead to serious errors in chemical and biological research in which the isotopes are used as tracers. On the other hand, isotope effects (particularly of tritium and carbon 14) provide an extremely important tool for determining how organic chemical reactions take place. Methods previously devised at the Bureau for measuring isotope effects have been used for studying a variety of reactions of aldoses labeled with carbon 14 and tritium. These include: (1) oxidation reactions; (2) rearrangement (isomerication) reactions; (3) formation (as well as recrystallization) of phenylhydrazones.

The isotope effect, k^*/k, for the oxidation of aldoses-1-t to lactones was found to range from 0.12 to 0.69 and to depend on whether the oxidation takes place directly, or whether it is preceded by a rate-determining isomerization.

Higher Ketoses. In the past few years there has been a growing realization of the fact that higher ketoses (seven-carbon or more) play important roles in biological systems; presumably, these materials are formed by condensation of smaller units. It has recently been found at the Bureau that a variety of higher sugars can be formed, in vitro, by aldol condensations. In the synthesis, the carbon chain of the aldose is extended by three carbons with the production of new asymmetric centers at carbons 3 and 4. Thus, condensation of 2,4-ethylidene-D-erythrose with dihydroxyacetone gave four heptuloses. Three of the heptuloses were separated in pure condition and their structures were determined; the fourth was identified chromatographically. The procedure provides a means for preparing higher ketoses of biological interest.

Molecular Isomerism. A number of molecules which exhibit rotational isomerism have been studied by the techniques of microwave spectroscopy.

These molecules are capable of existing in two or more distinct geometric forms which interconvert so rapidly that they cannot be separated. The high resolution obtainable in the microwave spectral region permits detailed study of the individual isomers in the mixture. Useful information has been obtained in this way on *n*-propyl chloride and on several butadiene derivatives. In particular, the frequency of the torsional oscillation about the carbon-carbon single bond in butadiene-type compounds has been accurately measured for the first time.

Low-Temperature Spectroscopy. Recent research has provided the first definite evidence that hydrogen halide molecules trapped in solid rare-gas matrices do in fact rotate almost freely. The evidence is based on the observation of the fundamental rotation-vibration bands of a hydrogen halide, e.g., hydrogen chloride, with grating dispersion as a function of temperature over the range 4 to 20 °K. Other spectral features that were detected have been tentatively attributed to rotationless vibrational transitions and are being studied with the expectation that they may provide a novel and important approach to the measurement of intermolecular forces in molecular crystals.

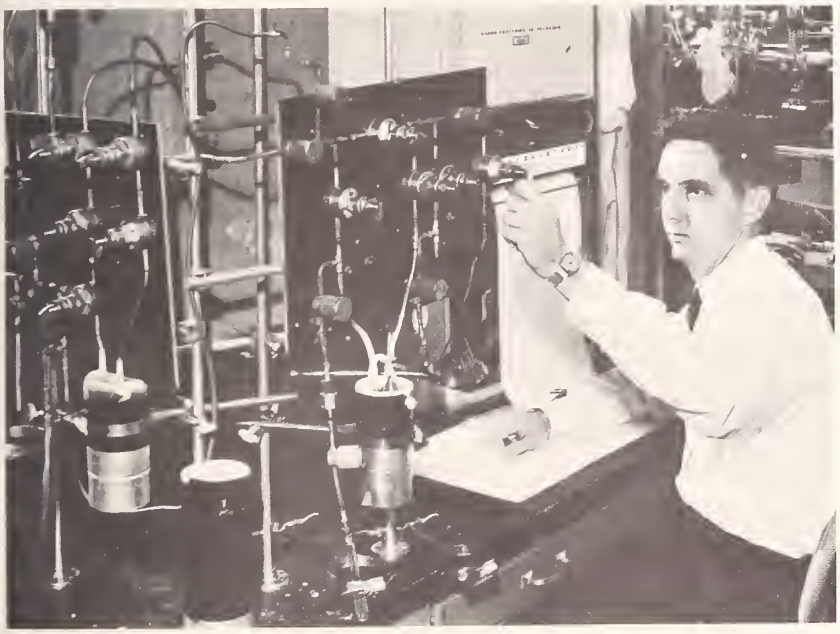
Collision and Ion-Decomposition Processes. A retarding-potential technique has been developed for use with time-of-flight (TOF) mass spectrometers. Many ionic processes which were formerly difficult to study can be easily observed with the new method. In a linear, pulsed TOF mass spectrometer, ions of a particular mass travel down a field-free drift tube in a focused bunch, and give a sharp-pulse electrical signal when they strike a detector at the end of the tube. If events occur in flight (grazing collisions with residual gas molecules in the tube, or spontaneous ion dissociation, for example), the products (neutral species and small fragment ions) generally travel along with the group of ions and arrive at the detector at about the same time. Thus a single pulse, or mass peak, may actually be composite. By application of a retarding field near the end of the drift tube, the mass peak can be separated into its components: Neutral species are not affected by the field and their arrival time does not change; unaltered ions are retarded but still focused as pulses arriving after the neutrals; fragment ions, being lighter, are retarded still more and can be separated as a third component. This technique provides a way of detecting charge exchange, collision-induced dissociation, and spontaneous ion dissociation during the time of flight. It is expected to be particularly useful in making surveys of polyatomic ion decomposition and in measuring kinetic energies of charged and neutral fragments.

Collisional Energy Transfer. Collision processes involving transfer of energy play an important role in determining the structure and properties of shock waves encountered in supersonic flight and missile reentry; also in determining the efficiency of rocket combustion. A knowledge of rates of exchange of energy in molecular collisions is particularly important in interpreting temperature measurements on hot, nonequilibrium gases such as rocket exhausts.

A prime objective is to carry out the experimental isolation of selected energy-transfer processes for spectroscopic study, as free as possible from extraneous environmental complications. Following this mode of attack, probabilities for exchange of known quanta of energy in single molecular collisions have been obtained for the OH radical, an important reactant in flames, and for nitric oxide, a gas important in atmospheric phenomena.

Statistical treatment developed for interpreting the laboratory data can be extended to the fluorescence of diatomic molecules in comet heads. This fluorescence is responsible for most of the observed luminosity of comets, from which comet "temperatures" have been estimated in the past. The new treatment takes account of the random nature of successive absorption and emission of light (in the region of the comet nucleus) by the molecules under solor illumination. It shows that comet "temperature" deduced in some cases may have no physical significance at all, and provides for the first time a statistical interpretation of the fluorescence observed.

Vacuum Ultraviolet Photochemistry. In order to understand the nature of the chemical events attending the absorption of light by hydrocarbon molecules, the Bureau is engaged in studying the photochemistry of hydrocarbons in the vacuum ultraviolet region of the electromagnetic spectrum. During the past year it has been discovered that when propane absorbs a quantum of energy at 1470 Angstroms, the most probable result is that a molecule of hydrogen is expelled, both atoms having been attached originally



Chromatographic purification of materials to be used in vacuum ultraviolet photochemistry. The Bureau is systematically charting the many chemical reactions triggered by absorption of light by hydrocarbon molecules. (See p. 89.)

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to the central carbon atom. Another highly probable process is the molecular elimination of methane. Photolysis of cyclopropane and isobutane have also been studied. The techniques employed involve labeling the hydrocarbons with deuterium in specific positions.

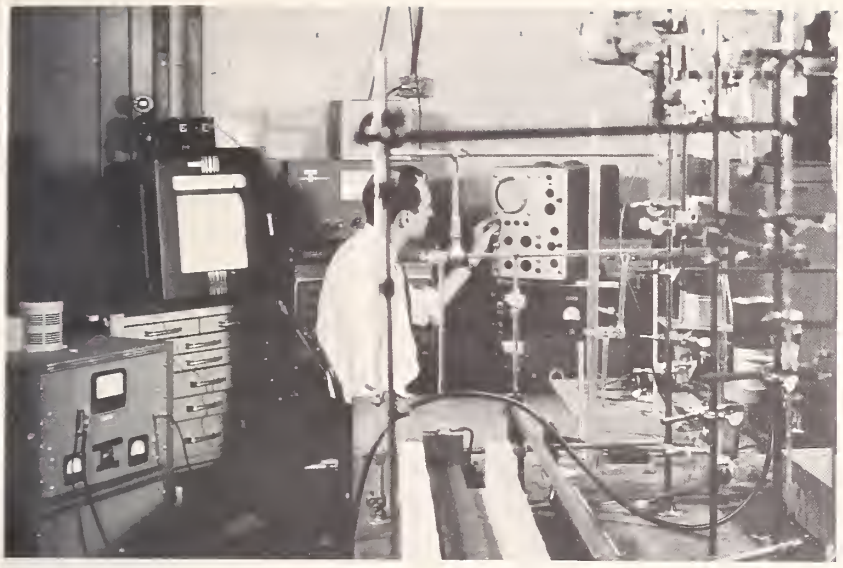
New techniques in vacuum ultraviolet photochemistry currently being used are high-temperature photochemistry and photochemistry in the ionizing region (argon resonance line). The former is being used to explore the chemistry of carbenes formed in the primary photochemical process, while the investigations involving the argon resonance lamp permit studies to be made in the overlap region between photochemistry and radiation chemistry.

Radiolysis of Simple Hydrocarbons. Deuterium-labeled compounds are used to determine the nature of the chemical processes occurring as a result of the absorption of ionizing radiation by simple hydrocarbons. Processes in which hydrogen and methane are eliminated as molecules from the parent hydrocarbon have been observed. Work on the radiolysis of propane and isobutane has been completed and studies on *n*-butane and neopentane will be made. Complicating factors, such as free-radical and ion-molecule reactions, are controlled by irradiating specifically deuterium-labeled hydrocarbons in the presence of scavengers. Using this technique, the isomerization of alkyl ions has been demonstrated and the kinetics of the transfer of hydride ions to the ethyl ion are being studied.

New methods of investigating ion-molecule reactions include radiolysis in an applied electric field. It is possible by this means to sweep out the ions and electrons formed by the ionizing radiation and to alter the product distribution substantially. This work is partly sponsored by the Atomic Energy Commission.

Isotopic Abundance Ratio Determined. Natural chlorine consists of two isotopes of mass numbers 35 and 37 in relative abundance of about three to one. The atomic weight of this element together with that of silver forms a basis for the determination of atomic weights of many of the elements. The isotopic abundance ratio of chlorine was determined by the Bureau with the cooperation of the Atomic Energy Commission, using 60° surface emission mass spectrometers with a 12-inch radius of curvature. The instruments were calibrated with synthetic mixtures made from separated chlorine isotopes (see p. 80) leading to an absolute value for the natural chlorine abundance ratio of $Cl^{35}/Cl^{37}=3.1272\ \left\{\begin{matrix}+0.0079\\-0.0082\end{matrix}\right\}^{*}$. This value, combined with accurately known atomic masses led to a new atomic weight value of $35.45273\left\{\begin{matrix}+0.00092\\-0.00097\end{matrix}\right\}^{*}$. Using the chemically determined combining weight ratios for chlorine and silver, the present atomic weight supports the physical determination of the silver atomic weight which was done earlier at the Bureau.

*The quantities in brackets are estimated limits to the uncertainties in the reported value arising from known sources of error, both random and systematic.



The high resolution and sensitivity of the microwave spectrometer reveals many fine details of molecular structure. Recent studies have been made of molecules which exhibit rotational isomerism. **(See p. 87.)**

Thermodynamic Reviews. The program on compilation and critical evaluation of data on the chemical thermodynamic properties of chemical substances has continued under partial AEC support. A review of all of the available data on the heat capacities and heats of solution and dilution of univalent electrolytes in aqueous solution has been completed and the data assembled in tabular form. A review of the entropies of a number of aqueous ions has also been completed. These reviews have been carried out in order to establish some of the basic thermodynamic values needed for a systematic self-consistent tabulation of the heats and free energies of formation of chemical substances.

2.2.3. INORGANIC SOLIDS

The importance of obtaining a better understanding of the physical properties of inorganic nonmetallic materials has been accentuated by the rapid development of space technology. Materials are now required which must meet extreme environmental conditions such as high temperatures in corrosive atmospheres or very low temperatures under constant irradiation. One of the promising classes of materials for use under these extreme conditions is the metallic oxides. Thus, as part of the research on inorganic solids, the Bureau is seeking to develop new techniques of preparing and measuring fundamental parameters of well-characterized specimens of these materials. In addition, research is continuing on other materials of specific interest to industry and the scientific community. Such research includes working on crystal growth, determining crystal structures and imperfections in solids,

studying high-temperature reaction kinetics at solid-gas interfaces, and investigating the properties of glass.

Vaporization of Refractory Substances. Investigations continued on vapor pressures, rates of vaporization, and associated thermodynamic and kinetic properties of refractory elements and compounds. In this program, the vapor pressure of ruthenium was measured and its heat of vaporization determined. Similar measurements were started on osmium. At the request of the Defense Department, the application of a mass spectrometer to study the high-temperature vaporization of selected light-element compounds was continued; modifying the apparatus has increased its reliability and accuracy.

Major emphasis was placed on the study of the beryllium-oxygen-fluorine (Be-O-F) system in the temperature range 900 to 2,000 °C. The thermodynamic goal of this work is to measure all of the gaseous and solid-gas equilibria at different temperatures. Results so far show several vapor species of beryllium fluoride (BeF_2), some of them resulting from the presence of water in the condensed material. The existence of these species is also, however, of interest. The study of this system is complicated by the widely different volatilities of BeO and BeF_2. A new double-oven experiment, designed to investigate the system, is currently being evaluated.

New Microbalance Required to Study Refractory Substances. The rate of vaporization of refractory substances is of interest to the National Aeronautics and Space Administration, which requires such data to select suitable substances for the development of thermionic heat engines. The necessity of making measurements under much higher vacuum conditions than are usually employed has required construction of a new microbalance apparatus which can obtain a vacuum of 1×10^{-9} torr without bakeout. This apparatus will be used initially to measure the rates of vaporization of the nitride and borides of tantalum, and of selected faces of ultra-high purity tungsten single crystals.

Studies of Alumina. An arc-image furnace was used to study the high-temperature vaporization of solid and liquid alumina in vacuum and in the presence of other gases. Such studies indicate that liquid alumina dissolves water vapor and that the water vapor (or an alumina-water reaction product), being less soluble in solid alumina than in liquid alumina, vigorously boils out of solutions when the molten substance solidifies. When liquid alumina evaporates in vacuum, it deposits as a transparent, amorphous film of aluminum oxide. The characteristics of this film and the crystallographic course of its thermal transformation to alpha-alumina were investigated. The rate of sublimation of alumina in vacuum was also measured by a microbalance technique and a novel method of heating by radiofrequency induction. These measurements indicated that the rate of free evaporation of alumina is not significantly less than the rate at which it is transported in an equilibrium vapor.

Plasma Torch Used in Crystal Growth. An adaptation of the Verneuil process for growing crystals, utilizing the inductively-coupled radiofrequency plasma torch was successfully applied in recent studies of stabilized

zirconium, chromium, aluminum, and titanium oxides. The process has three distinct advantages over related techniques: (1) the maximum temperature obtainable is sufficient to melt materials having melting points up to approximately 3,300 °C; (2) the ambient atmosphere can be controlled to a greater degree than in an oxyhydrogen torch; and (3) no contamination problem is encountered from electrode erosion of the type found in direct current plasma torch arrangements.

Research is continuing to improve certain aspects of plasma torch operation, such as thermal gradient control and feed delivery, and to solve the problem of containing plasmas having an extremely high heat content. Major efforts are being directed toward evaluating the chemical and crystalline perfection of plasma-grown crystals, and toward producing hydrogen-free rutile. Also efforts are being made to grow other high-melting-point oxide crystals using the plasma torch technique.

Rare Gas Crystals and Vapor "Snakes." Studies of crystal growth were carried out using the rare gases argon and krypton. As atoms of

Fibrous silica grown in a study of the structural relationship of the amorphous forms of silica to each other and to the crystalline forms. The exact nature of this form of silica is now being investigated. **(See p. 94.)**

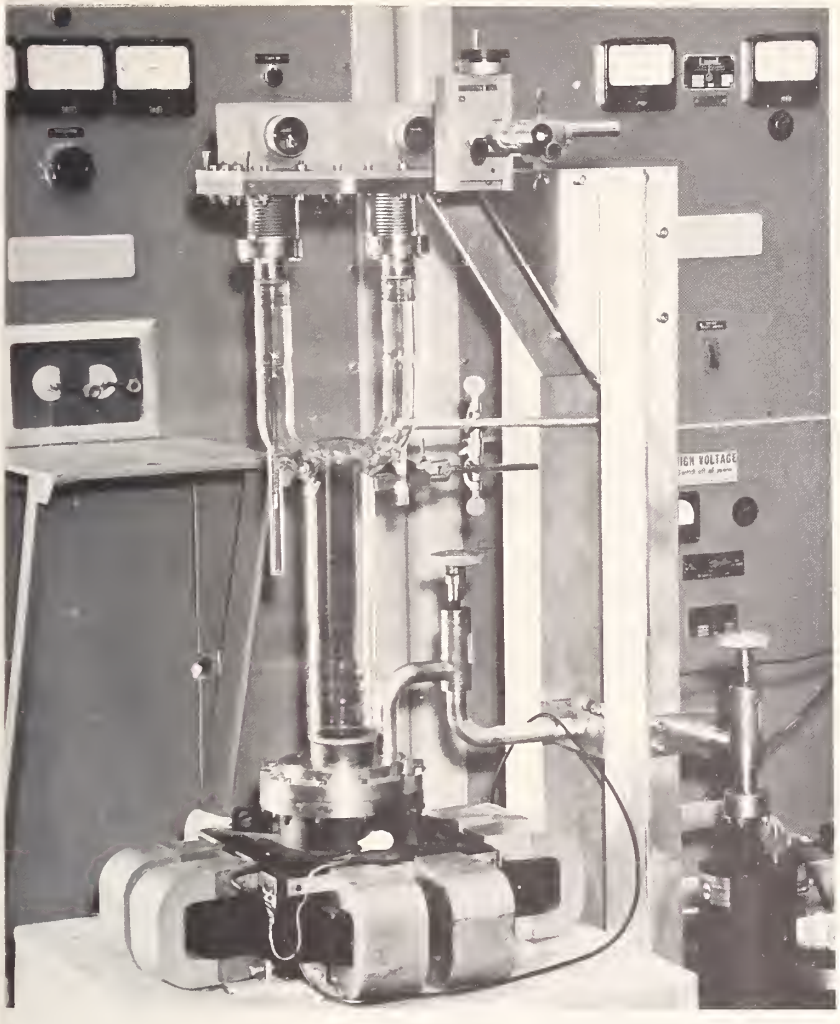
these gases exert only very weak forces, theoretical analyses of their crystalline states are relatively easy to determine. Idealized assumptions which loosely apply in the case of metals and more complicated polar molecules, often closely approximate the rare gas–solid situation. Extensive work has been done on applying crystal growth theory to rare gases, but so far there has been a dearth of experimental data because large single crystals are difficult to prepare.

Since temperatures at which the rare gases melt are much lower than are those of most other substances whose crystals have been studied, and since the properties of rare gases are so unusual, other techniques were recently adapted which produced striking results. For example, cooling the melt under certain conditions resulted in the formation of a long, snakelike cylinder of vapor with a solid sheath wall. The cylinder travels through the melt and bends as it hits a solid of any kind, hence the name, vapor "snake." These studies proved useful in examining such phenomena as plastic crystals, and dendritic growth and grain boundaries. Other work is now under way on the connection of vapor snakes to supercooling and to crystal growth rate.

Fibrous Form Found in Silica. Three-fourths of the existing solid matter of the earth consists of silica, the combination of silicon and oxygen. Pure silica is found in many different crystalline modifications and as an amorphous substance in a variety of forms such as gel and glass. However, precise structural information on silica, especially regarding its amorphous forms, is very incomplete. In studying the structural relation of amorphous forms of silica to each other and to the crystalline forms, silica formations were grown by directing a preheated mixture of nitrogen, silicon tetrafluoride, and water vapor against an electrically heated platinum target. Experimental conditions could be produced under which the deposition of silica on the target occurred in the form of round fibers or whiskers. The silica thus produced has certain attributes of silica glass, such as low refractive index and optical isotropy, yet its shape suggests a higher degree of molecular order than is generally assumed for glass or other amorphous formations.

Polymorphic Transition at High Pressure. The arrangement of atoms or molecules in crystalline solids, as determined by X-ray diffraction, is of fundamental importance in understanding the interatomic and intermolecular forces which ultimately determine the properties of matter. Although most solids exist in only a single structure under normal conditions, temperature or pressure changes often transform the ordinary structure into a new stable structure by a process known as polymorphic transition, or, more simply, transition.

In previous Bureau work, an instrument using diamonds was constructed to permit spectroscopic studies of solids to pressures of at least 50,000 atmospheres (750,000 pounds per square inch); it was recently modified to permit routine X-ray diffraction studies of solids at pressures as high as 70,000 atmospheres. In this device, X-rays transverse two diamond anvils and a



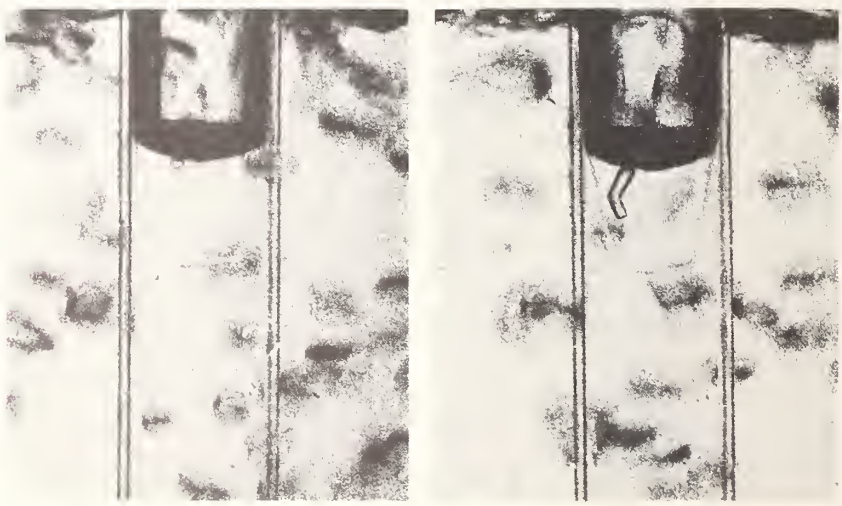
Rate of vaporization of refractory substances at extremely high temperatures and low pressures can be measured with this newly constructed vacuum microbalance. Such data is needed for predicting the behavior of refractories in thermionic engines and the other extreme environments. **(See p. 92.)**

thin film of material squeezed between flat surfaces of the diamond anvils. The diamonds are forced together by hydraulic pressure to produce a pressure on the solid film. On passing through the film of solid, the X-ray beam is diffracted and the diffraction pattern is recorded photographically as a series of rings or arcs. Knowledge of the diameters of the rings or arcs permits calculation of the interatomic spacing of the atoms in the solid. Since the diamond surface areas are very small (approximately 1×10^{-4} square inches), rather small forces on the diamonds are capable of producing extremely high pressures. Structures and atomic spacings were determined with this device for many high-pressure phases of metals and salts.

Properties of Silver Iodide Studied. The physical properties of silver iodide crystals were extensively investigated with respect to their structures and imperfections. A marked change of intensity after extended exposure to light was found for several lines in an X-ray powder diffraction pattern. This change apparently indicates a decreased crystal perfection involving lattice distortion and the separation of colloidal silver particles. A number of chemicals were found which would inhibit this process with varying degrees of effectiveness. The shapes of the ice crystals nucleated could be correlated with the process, supporting a theory of epitaxial growth.

The structure of the hexagonal phase of silver iodide was redetermined from precise single crystal X-ray diffraction data. The refinement was performed by a least-squares reduction on an electronic computer. The results showed virtually no deviation from an ideal wurtzite-type structure, but a much greater thermal motion for the silver than for the iodine atoms. The oscillation was only slightly anisotropic for both atoms. This program was sponsored by the National Science Foundation.

Symmetry of Crystals Under Strain. A study of the symmetry of crystals resulted in a scheme for reducing the 32 crystallographic point groups to subgroups by homogeneous strain. It might be supposed that the point group of a crystal could be lowered to any of its subgroups by such strain, but this is not so. Only those subgroups can be reached which require a change of crystal system and which preserve the centrosymmetric or noncentrosymmetric properties of crystals. For example, the piezoelectric coefficients of point group $\bar{4}3m$ can be changed to those of point group $3m$ by homogeneous strain, but a crystal with point group $m3m$ cannot have the coefficients appropriate to $3m$, even though $3m$ is a subgroup of $m3m$.



"Vapor snake" growing in crystallizing argon. Starting with a bubble at the surface of the melt (left) the snake grows downward as a vapor-filled solid sheath (right). This unusual phenomenon is shedding much light on the fundamental crystallization processes in the rare gases. **(See p. 93.)**

The scheme developed in this study was applied in internal friction experiments on crystals, and rules were formulated for predicting the splitting of a set of equivalent positions in an unstrained crystal into inequivalent subsets in strained crystals. Large strains are known to exist in the neighborhood of dislocations, and point defects in such neighborhoods should have a decided preference for one subset when splitting exists. This preferred distribution may help to make dislocations easier to observe.

2.2.4. METALLURGY

Metallurgical research is directed primarily toward increasing our understanding of the properties of metals, in order to encourage the optimum use of existing metals and alloys and to stimulate the development of new ones having desirable properties. Broad programs of fundamental and applied research are conducted which attempt to relate the macroscopic properties of metals and alloys to their known structure. Crystal structure and the role of dislocations and point defects are of primary importance, although in some cases more gross structural features such as grain size, shape, and distribution are investigated. The electronic structure of metals and alloys is investigated to obtain basic knowledge of the cohesion of metals. Important phenomena in metallurgy such as diffusion, crystal growth, fatigue, plastic deformation, and corrosion are studied intensively, and explanations in terms of atomic mechanisms are developed.

The metallurgy laboratories also provide advisory services to other Government agencies, particularly in connection with the investigation of service failures of transportation equipment. Participation in the Bureau's standard samples program by the development of specific standards of gases in metals is another activity.

Method Developed for Slack-Quenching Steels. The best combination of high strength and ductility of structural steels is usually obtained by complete hardening and tempering. Although it is known that complete hardening (slack quenching) without tempering results in an inferior combination of strength and ductility, quantitative evaluation of its deleterious effect has not been possible because no means have been available for completely controlling the amount of slack quenching. Such means were developed during the year and the effect of slack quenching upon the mechanical properties of certain selected steels is being studied.

Metal Fatigue Phenomenon. Under certain circumstances gas is evolved at the surface of metal specimens undergoing repeated stressing. This observation, first made at the Bureau several years ago, was investigated further in recent work sponsored by the National Aeronautics and Space Administration. Gas evolution can be readily detected under a piece of transparent pressure-sensitive tape that has been applied to a specimen before fatigue testing. The gas forms bubbles under the tape as the specimen is stressed.

In the present study, analysis with a mass spectrometer indicated that the gas was hydrogen, probably resulting from surface reactions associated with

fatigue damage and crack propagation. Experiments are now under way to attempt to use this phenomenon as a tool to learn more about the nature of fatigue failure in metals.

Gage Block Stability. Observations of gage block materials and treatments that show promise of fulfilling the target requirement for dimensional stability of 0.1 microinch per year are continuing. This extremely minute tolerance (it may be visualized by the fact that this is the amount of change that would be caused in a 1-inch length of steel by a temperature change of 0.01 °C) is being met by five materials or treatments. In addition, these blocks have all other characteristics that are considered necessary for gage blocks. Studies are now in progress to establish the nature and kinetics of some of the less understood processes causing instability in some of the additional materials under investigation.

Stainless Steel Diagram Completed. Hardenable stainless steel containing approximately 16 percent chromium and 2 percent nickel is widely used in applications requiring high strength and corrosion resistance. However, its constitution diagram had never been established. Because such a diagram is necessary to a basic understanding of the steel, various analyses of the material were conducted during the year to provide the necessary data for constructing the diagram. Its recent completion provides useful information on the several phases present.

Tensile Properties of Nickel-Aluminum Alloy. The effects of temperature on the tensile deformation of an age-hardenable alloy containing 94 percent nickel and 4¼ percent aluminum were evaluated. As this is a metastable alloy, its tensile properties were influenced markedly by prior aging and by precipitation-hardening during deformation. Mechanical properties such as hardness, ductility, and strength were found to be affected both by the number of active slip systems present in the system and by the nature and distribution of the precipitation, principally Ni_3Al.

Electronprobe Microanalyzer Completed. An electronprobe microanalyzer was completed and put into service. With this instrument a quantitative chemical analysis *in situ* may be performed at a one-micron level of spatial resolution. Characteristic X-rays emitted from the one-micron spot undergoing bombardment are collected and measured with the aid of two focusing spectrometers. A light optical system centered on the electron-beam axis permits the spot being irradiated to be observed directly.

The superconducting phase, Nb_3Sn, of the niobium-tin system, recently found to resist fields of 188 kilogauss at liquid helium temperatures, was identified with the aid of this microanalyzer. Identification of the other phases present, Nb_4Sn, Nb_2Sn, and Nb_2Sn_3, by the same technique permitted the construction of a new constitution diagram of the system. Microstructures such as impurities in silver grain boundaries, columnar nitride grains in a nitrided titanium-aluminum-vanadium alloy, and impurities in uranium-palladium alloys were also successfully investigated and analyzed with the newly constructed instrument.

Computer Produces Quantitative Metallographic Data. The physical and mechanical properties of metallic objects, as considered in engineering applications, bear only an indirect relationship to the physical and chemical properties of metallic atoms. Qualitative information on the sizes and shapes of the individual crystalline metal grains and on the manner in which different varieties of grains are fitted together is supplied by micrographic inspection of metallic specimens. The Bureau is now obtaining corresponding quantitative data by feeding photomicrographs directly to an electronic computer which reads the micrographs, performs the desired measurements, produces descriptions of the individual grains, provides statistical tabulations, and plots the distributions of the various geometrical parameters.

Standards Produced for Gas Content in Metals. The Bureau is now in the process of producing standards for oxygen content of unalloyed titanium metal, a titanium alloy containing 8 percent manganese, and an alloy of titanium containing 6 percent aluminum and 4 percent vanadium. Work is also under way on gas standards for an ingot iron, a stainless steel (type 431), a vacuum-melted and cast alloy steel, and a valve steel containing high nitrogen.

Such standards are necessary for the calibration of chemical analytical equipment used to measure the gas content of metals. Low gas content is a characteristic of metals with desirable properties, and the acceptable amount of gases present is often stipulated in procurement specifications for metal products.

Corrosion Reactions Observed on Metal Surfaces. A study was undertaken on the influence of light on the film-growth kinetics of copper surfaces immersed in pure water containing oxygen. The results so far indicate that white light speeds up the formation of cupric oxide. Both the rate of oxidation and the type of rate law obeyed are influenced by the light.

Studies of the kinetics of metal oxidation are also being made with an ultra-high-vacuum field emission microscope. In this work, the rates of formation of the initial oxide monolayers are being determined on clean metal single crystals of iron and nickel. Preliminary iron experiments showed that crystal growth could be initiated by heating in an electric field.

Stress Corrosion Cracking. Stress corrosion cracks occurred in type 304 stainless steel specimens exposed at 57 °F to corrodents containing as little as 5 parts per million of chloride ion, provided oxygen was also present. The specimens were subjected to stresses of 20,000 pounds per square inch (psi). In notched specimens of low-carbon steels, cracks occurred in pairs in the regions where shear strains were believed to be highest. Crack propagation most probably results from strain rates of the order of 0.001 to 0.01 per second.

Polarization Measurements Used to Study Corrosion Rates. Polarization techniques used at the Bureau in calculating corrosion rates (based on total weight loss) of low-alloy ferrous metal exposed to aqueous media, and of aluminum and steel underground, were successfully applied

The NBS-developed electronprobe microanalyzer performs a nondestructive quantitative chemical analysis on a preselected, 1-micron diameter spot of a metal specimen. An optical system permits simultaneous visual observation of the spot being irradiated and analyzed. **(See p. 98.)**

to measuring the total corrosion on a series of ferrous alloys containing up to 18 percent of chromium and 3.5 percent of silicon. In this work, the apparent area corroded varied from 85 percent of the exposed surface for unalloyed iron under cathodic control to less than one percent for the 18-Cr iron under anodic control. Thus, since the polarization method seems to be quite flexible, it may be of value in studying the effects of alloying constituents on corrosion behavior, or for the screening of alloys for long-time exposure tests.

Alloying Behavior of Uranium. Studies of metal reactions are dependent upon the results of phase equilibrium studies, which at the Bureau are presently concerned with uranium alloyed with the individual elements of the platinum-metal family. Recently completed binary phase diagrams for the various systems reveal apparent anomalies existing between these diagrams that are as intriguing as are their similarities. For example, the

compound adjacent to the uranium-rich side of the uranium-iridium system is the U_3Ir phase; in the uranium-ruthenium system it is U_2Ru; and in the uranium-platinum system it is UPt. This program, undertaken to provide information on the reactions of the platinide metals with uranium for nuclear reactor applications, was sponsored by the Atomic Energy Commission.

Ni-Cr Alloy Resists Oil-Ash Attack. Recent studies of the reaction of experimental alloys to vanadium-rich salts showed the superiority of chromium-nickel binary alloys and of ternary alloys based on chromium-nickel in resisting the attack of oil ash in oil-fired naval boilers. The resistance properties of these alloys can be further improved by utilizing alloying techniques such as vacuum melting, and by selecting ternary additive elements such as magnesium, titanium, and yttrium. This research was sponsored by the Navy Bureau of Ships.

Nuclear Magnetic Resonance. An improved technique was developed for measuring nuclear resonance frequency shifts that are much smaller than the resonance line width. In this method, resonances are obtained by varying the frequency of the radiofrequency magnetic field of a crossed-coil spectrometer, instead of by the usual method of varying the steady magnetic field. Nuclear magnetic resonance holds this field constant. Voltage pulses from a frequency counter are used to mark frequency pips that are 200 to 300 cycles per second apart on the recorded resonance line, and the value of the frequency corresponding to each pip is simultaneously printed out. Thus, the central frequency of a broad, weak line can be measured to within one percent of the line width. The technique is being applied to the study of lead-indium and other lead alloy systems to obtain information on their electronic structures.

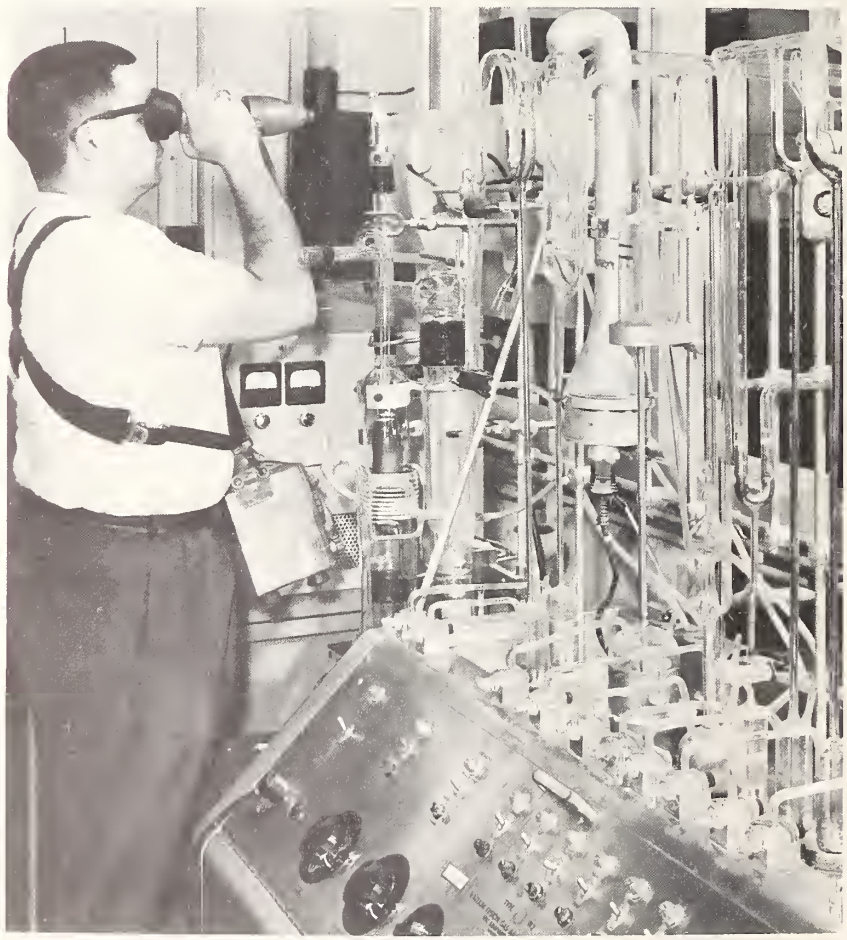
Soft X-Ray Spectroscopy Utilized. Soft X-ray spectroscopy, using a grating spectrometer at grazing incidence, was selected to obtain information on the distribution of electronic states in the valence band of metals and alloys. With this technique, it is possible to develop distribution data throughout the width of the valence band, although other techniques often yield more detailed information about the shape of the Fermi surface. In the present program, studies are planned of the effects of crystal structure transformations, of magnetic transformations, of superconducting transition, of temperature, of intermetallic compound formation, and of solid solution alloying. The results will help in formulating a quantitative theory of metal bonding.

Crystal Diffusion Equations Modified. When diffusion in crystals occurs by means of vacancies, the random-walk diffusion equations must be modified. Theoretical research on these modifications now in progress include studies of (1) vacancy-flow effects with an external driving force and (2) correlations between successive atom jumps in the absence of an external driving force. Equations modified according to (1) and (2) were recently applied to the simultaneous diffusion of two isotopes of an ionic

impurity in an electric field. The results obtained provide additional information on vacancy-jump frequencies.

Metal Crystallization Process Investigated. In Bureau studies of the basic process of metal crystallization, the growth kinetics of potassium whiskers were observed by means of an electron field emission tube, and crystallization rates were measured as a function of time, temperature, and supersaturation. These metal whiskers, grown from the vapor phase, are nearly perfect crystals, extremely small in size. However, the patterns appearing on the fluorescent screen of the tube during crystal growth are greatly magnified so that precise measurements may be made.

Results of the present study indicate that sputtering and photoemission may play important roles in the growth of alkali metal whiskers when an



An optical pyrometer is used to determine the furnace temperature of the vacuum fusion gas analysis apparatus which measures quantitatively the amounts of gases in metals to be issued as NBS standard samples. **(See p. 99.)**

electron field emission technique is employed. The work represents the first known use of an alkali metal as a field emitter.

Physical Behavior of Metals Studied. Single crystals of 99.999 percent copper were deformed from 12 to 20 percent by rolling, and then thinned for examination by transmission electron microscopy. A high concentration of small prismatic dislocation loops was observed, in addition to a cellular distribution of glide dislocations. Quantitative data were obtained on the dislocation loop density and line density as a function of deformation. The experiments revealed the large numbers of point defects generated during plastic deformation, as well as some of the annealing processes that reduce these defects.

Low-Temperature Study of Metals Initiated. A program was recently undertaken to study the thermal properties of metals at low temperatures. Investigations will be made of specific heats of various metals at low temperatures to obtain information on the electronic density of states at the Fermi surface. Also, the nuclear magnetic and electrical quadrupole interactions, and the magnetic and superconducting transitions of the metals will be studied. The resulting data are expected to aid in the understanding of fundamental interactions in metals.

Electrochemical Reactions. A new technique for studying electrochemical reactions was developed. In this technique, a column of liquid is suspended under tension in a glass tube about 1 meter long. Electrodes are inserted into the top of the tube, and the most minute discharge of gas at an electrode causes the column to drop. This "dropping" is used as an indicator for studying the decomposition potentials of liquids, hydrogen and oxygen overvoltage, and rates of electrode reaction, and for determining the concentration of electrolytes in a solution.

Hydrogen Embrittlement Studied. High-strength steel subjected to electrodeposition absorbs a small amount (in parts per million) of hydrogen which apparently causes some loss of ductility in the metal. In a study of this effect, the gas content of embrittled steel was measured. Both hydrogen and deuterium were used as embrittling agents. Data from the experiments showed the concentration of gas in the steel did not vary in a systematic manner with the degree of embrittlement. Thus it appears that the present theory accounting for the phenomenon may have to be revised.

Tungsten Deposition. In investigating some of the variables affecting the deposition of tungsten from the vapor phase, it was found that the rate of deposition was increased by increasing the concentration of tungsten hexafluoride in the vapor phase, even though the concentration was greater than that which corresponded to stoichiometric proportions. However, since tungsten hexafluoride is rather costly, a simple and inexpensive process for its production was developed. In this method, hexafluoride is prepared by passing hydrogen fluoride gas through tungsten hexachloride at about 70 °C. The reaction produces tungsten hexafluoride which, being gaseous, can be led directly into the reaction chamber.

2.2.5. POLYMERS

Research on polymeric materials—rubber, textiles, paper, leather, and plastics—is directed toward (1) development of new and improved measurement techniques for evaluating the physical and chemical properties of these materials: (2) determination of the structure and properties of pure polymers to advance our understanding of the chemical and physical factors involved in their behavior; and (3) utilization of these measurement techniques and fundamental data in standardization programs of scientific and technological organizations. The contribution made by such activities to the Nation's economy is reflected in the continuing expansion of the polymer industries and in the corresponding demand for national standards for polymeric materials.

During the year studies were made of molecular weight distributions in polymers, thicknesses of adsorbed polymer films, methods for measuring hardness of rubber, thermal expansion of microspecimens, air-drag effect on fibers subjected to high-velocity impact, and interlaboratory evaluations of test methods. Among the properties of materials investigated were atomic radiation effects on polymers, thermal decomposition of polystyrene, fluorescence of cellulosic polymers, viscoelastic behavior of rubbers, fracture phenomena, structural relationships in ethylene-propylene copolymers, degradation of polymers, and the wearing quality of U.S. currency. Chemical studies were made of fluoropolymers, nonrubber constituents in natural rubber latex, and free radicals in small molecules. Basic investigations were undertaken of light scattering in solutions, configurational distributions in polymer chains, conformational changes in peptide-containing polymers, kinetics of collagen precipitation, and the constitution of mercury-tin dental alloys.

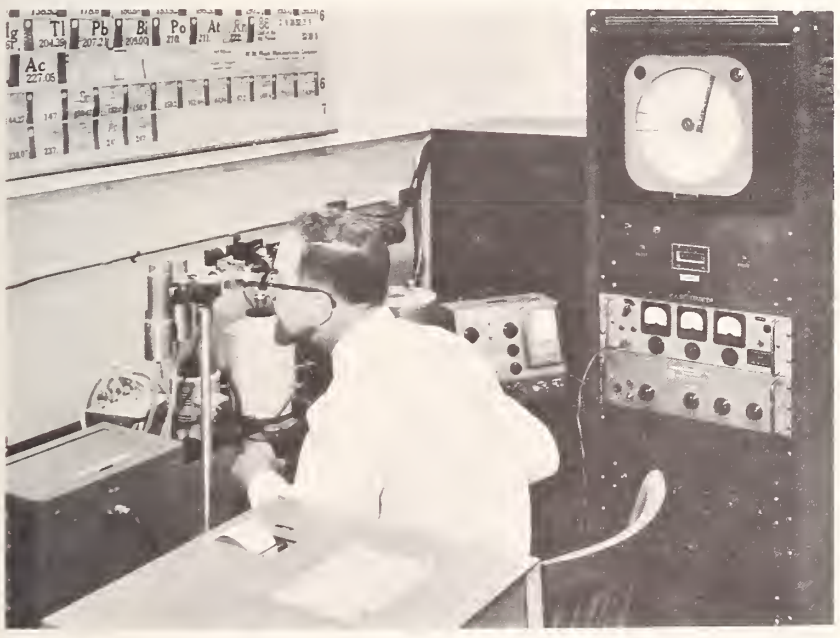
Molecular Weight Distributions of Polymers Studied. All synthetic polymers have a distribution of molecular weights which theoretically can be determined from the moments of this distribution. Evaluation of each successive moment requires a successively higher order derivative of the equilibrium sedimentation curve. However, it is difficult to measure even the first few moments accurately, in particular the third and fourth, both of which are needed to interpret the rheology and polymerization kinetics of polymers.

In a recent study, samples of polystyrene, in which the actual distribution was known from laborious fractionation, were analyzed in three different ultracentrifuges. These centrifuges represent the most advanced type of existing instrumentation. However, even with this advanced equipment it was not possible to determine an accurate third moment of molecular weight. The ratio of the third moment to the second moment differed from the true value by 8 percent in the most favorable determinations and deviated by 15 percent in others. Even greater difficulty was encountered in experiments with different solvents and very high molecular-weight samples. The fourth moment could not be determined with any reliability.

Ellipsometry Used to Measure Polymer Adsorption. When polarized light is reflected from a substrate surface with or without a thin film coating, the differences in the state of polarization that occur can be measured with an ellipsometer. The resulting data can be used to calculate the optical properties of the surface or the thickness and refractive index of the covering film. In investigations sponsored by the Army Research Office and the Bureau of Naval Weapons. this technique was used to determine the thickness of polymer layers adsorbed from solution onto highly polished chrome and optical glass surfaces.

In both polystyrene from cyclohexane and poly (ethylene orthophthalate) from acetone, the adsorbed polymer layers were found to be 100 to 400 Angstroms (A) thick, depending on the concentration, and to contain from 10 to 30 percent polymer, with the remainder being a solvent. When dried, the thicknesses decreased to about 25 A. This investigation is being extended to determine film thicknesses adsorbed from polymer solutions in solvents of various efficiencies.

Rubber Hardness Testers Compared. A comparison of the results obtained with both the standard and microtesters for measuring hardness of rubber indicated that the two instruments are equivalent. The microtester was more responsive to surface conditions, such as surface hardening caused by oxidation, and to nonuniformities in the rubber at or near the surface.



Automatic recording interferometric apparatus for measuring thermal expansion of solid materials. Specimens are in the interferometer in the cylindrical furnace to the right of the observer. Data on length change, temperature and time are collected electronically and automatically recorded on the printer while the specimens are being heated or cooled. **(See p. 106.)**

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This feature makes the instrument useful in research investigations as well as for the measurement of hardness on small rubber parts, but causes a small increase in replication error.

Apparatus Measures Thermal Expansion of Small Specimens. A digital-recording interferometric apparatus was developed for measuring the thermal expansion of small, solid specimens of dental materials, in a study sponsored by the American Dental Association and the Federal dental services. The instrument contains two quartz plates, one placed under and one over the specimens. In the apparatus, interference fringes are produced by the 5461–A green line from a mercury 198 source reflected from the two plates. Expansion or shrinkage of the specimens is indicated by movement of the fringes, with the passage of each fringe representing a change in length of approximately 0.00001 inch. A step, one-eighth wavelength in height on one of the interferometer plates, displaces a portion of each fringe by one-quarter of the fringe-to-fringe distance, and thus provides a means for directional (expansion or contraction) fringe counting by means of photomultiplier tubes. A recorder with a shaft position encoder attachment provides temperature data and automatically controls the rate of heating of the specimen over a wide range of temperatures. Fringe count, temperature, and time are printed automatically on a tape at the passage of each fringe.

Air Drag on Fibers Under Impact. When a textile fiber is subjected to high-speed transverse impact, transverse waves are initiated which travel along the fiber away from the point of impact. Although the fiber between the impact point and front of the transverse wave was expected by theory to be straight, it was found to be curved. This curvature was shown to be due to air drag, and an equation for calculating the amount of curvature was derived. The results will aid in the interpretation of transverse impact measurements on fibers at very high rates of straining.

Interlaboratory Evaluations of Test Methods. A procedure originated at the Bureau for evaluating the reproducibility of test measurements made in various laboratories was applied to analyses of minerals, measurements of physical properties of textiles, rubber, papers, and other materials, and chemical determinations on cellulose, leather, oils, rubber, and blood. Two standardizing groups, the American Society for Testing and Materials (ASTM) and the Technical Association of the Pulp and Paper Industry (TAPPI), adopted "recommended practices" based on this approach.

Several interlaboratory studies of test methods were conducted at the request of technical and industrial groups, including a tongue tear test of textiles for ASTM Committee D–13, a spectrophotometric test for brightness of paper for TAPPI, tensile energy absorption of paper for the Paper Shipping Sack Manufacturers Association, and internal tearing resistance of paper for TAPPI. The last investigation showed that a reference material for calibration of the measurement process would reduce the coefficient of variability to less than one-half of the value found. Accordingly, NBS Standard Sample No. 704, Reference Paper for Tearing Test, was developed and issued with a certified average value for internal tear strength.

Atomic Radiation Affects Polystyrene and Cellulose. Atomic radiation alters the structure of polymers in many ways, and the chemical and physical mechanisms of the process vary from polymer to polymer. Electron spin resonance studies showed that two or more radicals are produced by irradiating polystyrene, deuterated polystyrenes, and cellulose derivatives. The lifetimes of these radicals were measured in post-irradiation studies and the changing character of the electron spin resonance spectra was observed. The results yield an improved comprehension of the mechanisms involved in atomic radiation processes and of the molecular structure of irradiated materials.

Thermal Decomposition of Polystyrene. Earlier Bureau studies on the thermal decomposition of polystyrene at elevated temperatures in a vacuum showed that the long polymer chains of the material split at random positions along the chain to form smaller molecules with free-radical chain ends. These smaller molecules do not continue to split at random; they decompose by "unzipping" from the free-radical end into very small components, chiefly monomer units. At pyrolysis temperatures near 350 °C the rate of degradation increases to a maximum and then immediately decreases; at lower temperatures, however, the rate remains at the maximum value over an extended range of decomposition.

Recent decomposition studies at the lower temperatures on fractionated polystyrene samples of molecular weights varying from 24,000 to 5,000,000 showed that the rate of decomposition maintains a constant value only when the molecular weight is high. Evidently, under these conditions, a state of equilibrium is established in which the number of polystyrene chain ends disappearing through the unzipping reaction is exactly balanced by the number of chain ends formed through the random scission reaction of the larger chains. This constant rate of decomposition indicates that the overall degradation reaction is of zero order.

Fluorescence of Cellulosic Polymers. Ultraviolet radiation, which causes many polymeric materials to fluoresce, was recently used to identify and analyze cellulose derivatives. Results of the study showed that these polymers consistently fall into three groups: (1) cellulose nitrate, which has a weak fluorescence with a maximum at 3200 A; (2) aliphatic esters and ethers of cellulose, which have fluorescent maxima at 3400 to 3600 A; (3) cellulose derivatives containing either double bonds (e.g., benzyl) or carboxyl groups (e.g., cellophane) which have maxima at 4400 A. Cellulose itself exhibited strong fluorescence with a maximum at 3650 A.

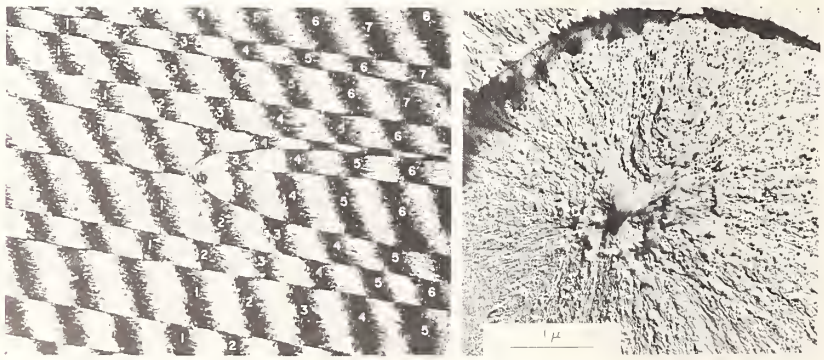
Viscoelastic Behavior of Rubbers Investigated. Measurements of the indentation of a flat rubber surface by a rigid sphere as a function of time and temperature were made over a range of times, beginning at the lowest temperature at which rubberlike deformation becomes perceptible and extending upward to room temperature. The compliance J (limit of the ratio of strain to stress at zero deformation) was computed from each observation. J was multiplied by the absolute temperature T and an empirically-determined number was added to the logarithm of the time at each temperature to make the values of JT agree.

The shift required for a pure-gum vulcanizate of natural rubber from +25 to −40 °C corresponded to a constant "activation energy" of 38 kilocalories per mole (kcal/mole); that required for butyl rubber, 20 kcal/mole; and styrene-butadiene rubber, 22 kcal/mole. The resulting curve of *JT* against log-time had a sigmoid form, with an increase of slope over 2 to 3 decades and a decrease at higher values. An extended region of nearly constant slope, corresponding to the conditions of normal use of rubber products, was usually found. For natural rubber this slope was 1 to 2 percent per decade; for the synthetics it was appreciably higher, reaching a value of 15 percent per decade for nitrile rubber. This behavior differs from the behavior of a classical idealized polymer network, for which the compliance would approach an equilibrium value at long times.

Color Phenomena Observed in Polymer Fracture. A film containing predominantly red and green colors was recently observed on the fractured surface of a poly(methyl methacrylate) specimen after it was broken under static tensile conditions. Specific colors differentiated individual markings in the surface and the colors were reversed in the two matching sides of broken surfaces. Strong colors were also observed in large internal cracks, called "craze" cracks, developed by tension in polystyrene and in copolymers of styrene.

Data obtained from light and electron-optical studies indicate that the colors were due to interference effects in a thin layer of oriented molecules which were sheared by the primary fracture front. Fracture films and craze films were found to vary greatly in their physical properties and in their adherence to the polymer matrix.

Ethylene-Propylene Copolymers Studied. Ethylene-propylene copolymers, currently the subject of intense developmental activity by industry because of the low cost of the raw materials and the wide range of physical properties attainable, were investigated for the Office of Naval Research. Specimens used consisted of industrial pilot-plant copolymers and experimental copolymers varying in propylene content from 10 to 50 mole percent.



Left: Multiple-beam interferogram, and right: electron micrograph of a fracture surface of poly(methyl methacrylate). The numbers identify displaced lengths of the same interference fringes. Study of the failure of materials under stress yields much information on intermolecular forces. **(See p. 108.)**

The degree of unsaturation of the specimens was, in general, about 0.15 percent, and one pilot-plant sample had 0.90 percent unsaturation, comparable to that of butyl rubber. Observations of specimen compliance and creep at temperatures from −50 to +25 °C indicated that a copolymer containing 50 mole percent propylene, compounded with carbon black and cured according to an American Society for Testing and Materials formula, behaves similarly to commercial styrene-butadiene rubber, type 1500.

Polymer Degradation. To provide data needed for the utilization of polymers in outer space environments, studies are being made of polymer degradation by thermal, radiative, and chemical processes. The work is sponsored by the National Aeronautics and Space Administration.

Recent studies of thermal decomposition during and after irradiation showed that the kinetics of the degradation process differ for polyolefins and polytrifluoroethylene. An increase in the amount of irradiation prior to heating promotes a more rapid thermal decomposition in both polymers. Alkali-treated halopolymers, particularly polytrifluoroethylene, decompose more slowly and leave an increasingly greater amount of a thermally stable residue as the alkali treatment is increased.

These results indicate possible new approaches to the production of materials of improved heat resistance.

Wearing Quality of U.S. Currency Determined. A comparison of the wearing properties of two types of one-dollar notes, one printed by a wet intaglio process and one by a dry intaglio process, was made in an investigation sponsored by the Bureau of Engraving and Printing. Data on the type, fitness, and age were obtained for 30,000 notes representing several samplings of dollar notes in circulation in the Washington, D.C., area.

Statistical survival curves were drawn for each of the two types, relating the percentage of remaining "fit" notes to the time of their circulation. According to U.S. Treasury Department standards for the evaluation of fitness, the median life of the notes printed by the dry intaglio process was found to be approximately 30 percent longer than was that of the notes printed by the wet method.

Fluoropolymers Synthesized. The fundamental chemistry of aromatic fluorocarbon compounds is being investigated for the Bureau of Naval Weapons to provide basic data needed for the development of heat-resistant materials, especially elastomers. In one part of the research, the nucleophilic reactions of hexafluorobenzene were found to be convenient for replacement of a fluorine atom by a hydroxyl, amino, alkoxy, alkene, or aryl group. Condensation polymerization of the resulting pentafluorophenol, pentafluoroaniline, and pentafluorotoluene into long chain polymers is being studied.

New methods were found for producing polyfluoroaromatic species from presently available aliphatic fluorocarbons. For example, 4-chloroperfluoroheptadiene-1,6 could be "telomerized' to cyclic compounds capable of dehalogenation to polyfluoroaromatics. The heptadiene thus produced polymerized to give a polymer of greater thermal stability than polychlorotrifluoroethylene.

Other new monomers prepared for polymerization studies were trifluorovinylphenyl ether, trifluorovinylpentafluorophenyl ether, octafluorostyrene, and alpha-hydroheptafluorostyrene.

Nonrubber Constitutents of Natural Rubber Identified. An analysis of *Hevea brasiliensis* latex was made to determine the identity of the compounds present other than the natural rubber hydrocarbon, *cis*-1,4-polyisoprene. Paper chromatography showed that the serum of latex had nine amino acids—alanine, aspartic acid, glutamic acid, glycine, lysine, ornithine, serine, threonine, and tyrosine—present in the free state. Glutathionine (glutamyl cystenyl glycine) was also identified in the latex, but cysteine was not found to occur in the free state.

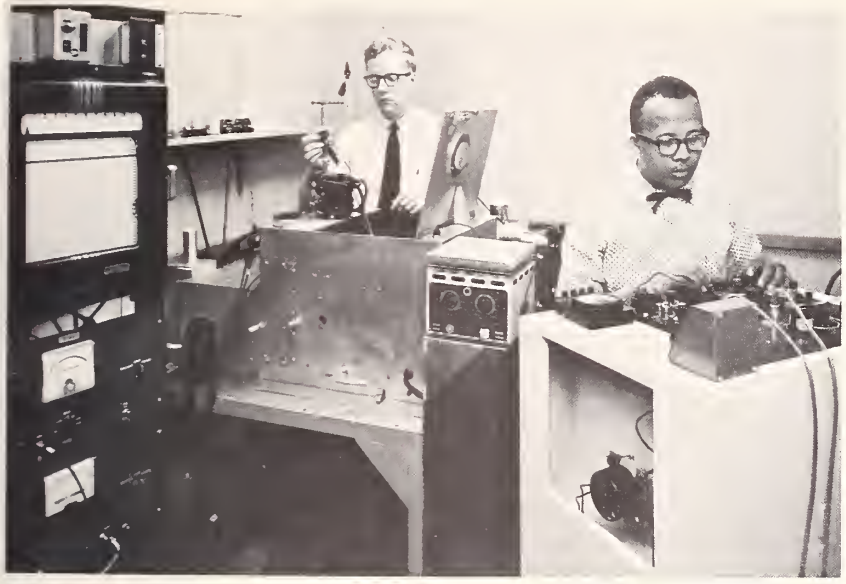
A protein of latex having an isoelectric point of *p*H 9.5 was isolated by paper electrophoresis methods; its *N*-terminal amino acid was identified as phenylalanine, and it also contained aspartic acid, glutamic acid, glycine, serine, tyrosine, and leucine and/or isoleucine. Of the trace metals studied, copper was found associated only with the rubber hydrocarbon; magnesium and zinc were associated with the serum as well as with the polyisoprene. The nucleoprotein of latex was identified as having an isoelectric point of *p*H 4 to 4.5.

Free Radicals in Small Molecules. Free radicals and atoms, elusive and extremely reactive species, are intermediates in numerous chemical reactions and in radiation chemistry. At 4 °K these species can, in many instances, be trapped in solid matrices and observed. A recent study of the kinetics of buildup and disappearance of species such as hydrogen. deuterium, and nitrogen atoms and small radicals such as hydroxyl and methyl demonstrated the complex nature of the formation and decay processes. An autoignition theory may explain the observed behavior. The results obtained will aid in predicting and choosing conditions for observing free radicals in irradiation studies.

Light-Scattering Phenomena Studied in Solutions. Many solutions have a phase transition similar to the transition of a gas to a liquid. At one particular "critical" composition, an initially homogeneous solution becomes increasingly turbid as the temperature is lowered to a "critical" temperature. Below this critical temperature, the homogeneous solution separates as two distinctly different phases of differing composition. An investigation was made of the intense scattering of light which gives rise to the milky appearance of an otherwise clear solution just prior to phase separation. Solutions of polystyrene in cyclohexane were used for the work.

The angular correlations of scattering differed from the earlier theoretical predictions of statistical mechanics. The activity isotherms and phase diagrams obtained may provide a basis for refinement of the theory of phase equilibria and for the determination of molecular weight distributions.

In other work, light scattered from solutions of cyclohexane–aniline was measured to within 0.001 degree of the critical temperature. The correlation of concentration fluctuations was found to be very long-range near this



Data on light scattering in solutions, obtained with this apparatus, can be used to calculate the weight-average molecular weight of polymers, to characterize molecular size, shape, and distribution, and to define interactions between solvent and polymer molecules. **(See p. 110.)**

temperature. However, further work with less intense scattering solutions is necessary before it can be stated definitively that there are clear deviations from the classical theory of light scattering.

Configurational Distributions in Polymer Chains. One feature of linear polymeric systems is the capability of their elements for being ordered in one-dimensional (that is, straight-line) arrays. In certain cases, the position or state of a given element is a random variable influenced only by its predecessor in the array. The process of ordering the elements in such systems, known as a regenerative process, was applied to some problems of configurational distributions in real polymer chains. One of these problems dealt with length-force relationships in an array of mesh points connected by flexible chains. This array simulates in one dimension a real rubber network in which individual chains cannot cut through each other, and thus it preserves the topology of the network under the influence of external forces. Another of these problems dealt with the arrangement of alternating crystalline and amorphous sequences of chain units in a semicrystalline polymer.

Not all problems in polymer configuration may be treated by the method applicable to regenerative processes. For example, polymer configurations with excluded volume affects arising from solvent-polymer interactions are no longer regenerative. The probability that a given element of the polymer can be found in a given location depends on the locations of every other element of the same polymer. The best approach to such problems is a

numerical one. Random-walk polymers subject to given preimposed restrictions on the propagation of their elements can be generated on a high-speed digital computer. The effect of the configuration of the entire polymer chain on the distribution of individual elements can thus be considered. This method was utilized in calculating the mean dimensions of polymers subject to solvent-polymer interactions.

Conformational Changes in Peptide-Containing Polymers. Naturally occurring proteins and synthetic polypeptides contain peptide bonds whose ordering (as in a crystal) and disordering (as in a liquid) allow the remarkable dimensional changes of fibrous proteins (wool, hair) and the conformational changes in solution of soluble proteins (gelatin). In recent research, lithium salts caused dimensional changes in alpha-keratin, beta-keratin, and elastoidin fibers that appeared to follow all of the criteria adduced previously for melting in synthetic polymers. The transformation of alpha-keratin to beta-keratin that occurred was reversible and thus was considered to be a crystal-liquid transformation.

Ribonuclease in solution underwent a change of optical rotation in lithium bromide solutions analogous to transitions of length or volume in a melting process. Poly-L-proline also showed the same type of optical rotation change when the solvent composition was changed from pure acetic acid to almost pure-*n*-propanol. The environmental effects on bulk protein systems like the keratins or on solutions like those of ribonuclease therefore appear to be related.

Observations of the effect of anhydrous lithium perchlorate on *N*-methyl propionamide indicated that the carbonyl bond of this low molecular weight amide interacts with the lithium ion and disrupts the hydrogen bonding in the liquid amide system. These same effects may account for the conformational changes in the synthetic and natural polypeptide systems.

Kinetics of Collagen Precipitation. It is well known that degraded collagen in the form of gelatin solutions forms aggregates on cooling and redisperses on warming. Only recently, however, was it established that native undegraded collagen in solutions of proper concentration, *p*H, and ionic strength forms a rigid opaque gel as the temperature is raised to 37 °C. This change occurs without alteration of the unique helical structure of the collagen monomer units.

The kinetics of this change were analyzed over a wide range of temperature, concentration, *p*H, and salt content of the medium. The rate of gelation was found to be markedly sensitive to temperature, decreasing a thousandfold over a 10-degree temperature drop. This reaction is consistent with a system possessing a negative temperature coefficient of solubility. The analysis substantiated the concept that a phase transition was involved.

Mercury-Tin System Investigated. The mercury-tin binary system was investigated because of its importance in the setting reactions of mercury-silver-tin dental amalgams. Thermal analysis, diffusion-chemical analysis, metallographic microhardness, and X-ray diffraction data showed that the system is more complicated than previously reported. The beta phase

indicated by Pytherch was confirmed by determining the separate peritectic temperatures of the beta and gamma phases. The limits of the gamma phase were shifted, Gayler's delta phase was confirmed, and a new epsilon phase was discovered. On the basis of these results, a revised tin-mercury diagram was proposed. This study was sponsored by the American Dental Association and the Federal dental services.

2.3. SPECIAL TECHNICAL SERVICE PROGRAMS

2.3.1. APPLIED MATHEMATICS

The Bureau's applied mathematics facility performs basic and applied research and renders advisory services in various mathematical fields. These services are available to other government agencies as well as to the Bureau's staff. Modern computing equipment is used by the facility in support of its program.

During the past year the Bureau continued to give special attention to the mathematical fields fundamental to its mission, such as statistical and numerical analysis, mathematical physics, and operations research. Extensive assistance was rendered in these areas and in digital computation. Emphasis was placed on problem formulation and analysis in order to select and develop numerical methods for the solution of problems in engineering and the physical sciences. Automatic high-speed computing machines were utilized when appropriate. An appreciable share of the mathematical program was devoted to government problems of business management and operation, sometimes called data processing problems. Significant progress was achieved in exploring the use of modern digital computers in the mechanical translation of scientific publications, for which there is an urgent need.

As in previous years, the Bureau's applied mathematics program was strenthened by the active interest and support of other government agencies. The Office of Naval Research, the USAF Office of Scientific Research, the Atomic Energy Commission, and the National Aeronautics and Space Administration supported basic and applied research in numerical analysis and mathematical physics. The National Science Foundation continued to support the compilation of a handbook of mathematical functions. The study of mechanical translation of scientific publications was jointly supported by the U.S. Army Signal Corps and the U.S. Army Research Office.

Asymptotic Expansions. Frequently, in calculating a function $f(x)$ for large values of the argument x, mathematicians must use what is known as an asymptotic series. These series are divergent, but they have the property that their early terms steadily decrease in size, and at first the nth partial sum s_n appears to be settling down as n increases. After n passes a certain value, however, the terms begin to increase and the series assumes its true divergent character. If an asymptotic series is truncated at (or near) its smallest term, the resulting partial sum is often a good approximation to the

wanted function $f(x)$, particularly for large values of x. Because of this property these series are frequently used in computations, even though they are really divergent. Only a few scattered special results are known concerning the precise magnitude of the error committed by approximating a given function by a partial sum of its asymptotic series.

Current research is directed toward filling this gap. Considerable success has already been achieved with certain types of asymptotic series originating from second-order ordinary differential equations; some general theorems have been established giving precise, and realistic, errors bounds which are easily evaluated. The theorems also show, for example, why these series provide inaccurate results near the boundaries of their regions of validity in the complex x-plane.

Applications of the theorems have been made to determine error bounds for asymptotic expansions of Bessel functions, parabolic cylinder functions, and Hermite polynomials. Another application has been to determine error bounds for the so-called WKB approximation frequently used by mathematical physicists, particularly in diffraction problems.

Matrix and Determinant Theory. A significant breakthrough was achieved in the study of a function of fundamental importance, the "permanent-function." A long-standing conjecture concerning the nature of this function was proved to be true for the positive semidefinite case. The permanent was characterized as an inner product in a suitable unitary space, and application of the well-known Schwarz inequality yielded a large number of significant facts about this function.

Numerical Experimentation. There are areas of numerical analysis in which either no theory exists or existing theory is merely suggestive of possible approaches to problem solution. In these areas, numerical experimentation may provide insight into a method of problem solution. The Bureau has undertaken a series of numerical experiments to investigate one such area of great importance in engineering and physics, the evaluation of highly multiple integrals, such as those of fundamental importance in statistical mechanics.

Machine Translation. Further progress was made on the mechanical Russian language translation scheme being developed by the Bureau. Special attention has been given to one of the significant innovations by the Bureau in this field, called "profiling," by which clause and phrase boundaries are recognized mechanically and which effects a substantial speed of translation. Computer programs for a rather large portion of the Bureau's translation method have been prepared and successfully tested on selected sentences of considerable grammatical complexity.

Mathematical Tables. Ten volumes of the Bureau's applied mathematics series of publications, eight of which were mathematical tables, were reissued in response to demand. Completion of a *Handbook of Mathematical Functions* is near. Still to be accomplished are only the updating of bibliographical material, preparation of indexes, and checking of galley and page proofs.

Digital Computation. The Bureau strengthened its computational facility by replacing the IBM 704 with an IBM 7090–1401 computing system. Extensive application of digital computers continued in both the scientific and data processing fields. In addition to performing computations on its own equipment, the Bureau assisted other government agencies in setting up problems for other computing machines. The experience gained in the performance of service computations stimulated significant research in programing and computational methods.

About half the computing services tasks performed during the year originated in the Bureau. The remainder were performed as services to such agencies as the National Institutes of Health, Diamond Ordnance Fuze Laboratory, National Aeronautics and Space Administration, Bureau of Public Roads, Weather Bureau, Treasury Department, Veterans Administration, and Federal Communications Commission. Significant computations were performed on problems in the thermal dissociation of diatomic molecules, diffusion and reactions in gases, trajectory computations, multilayer adsorption studies, thermal boundary-layer studies, paramagnetic relaxation investigations, and contour plotting of magnetic fields. Important data processing problems handled were mortgage loan surveys, tax depreciation revisions, availability of television service by ultrahigh frequency TV stations, analysis of interhospital differences of effective treatment of patients, and a fallout shelter survey. Services were provided on a continuing basis throughout the year on domestic airline traffic surveys, electrocardiographic analysis, highway planning and traffic studies, and monetary research reports.

The fallout shelter survey deserves special mention. This task was performed at the request of the Department of Defense, Office of Civil Defense. The technical data needed were furnished by the NBS radiation physics laboratory; the field data were collected under the direction of the Army Corps of Engineers and the Navy Bureau of Yards and Docks, and were prepared by the Bureau of the Census for transmittal to NBS for processing. In performing this task, the Bureau received the whole-hearted and effective collaboration of the other agencies involved. The Bureau itself made a significant contribution by decreasing the time and cost required—the latter decrease being one of millions of dollars—through modification of computational techniques made possible by analysis of the mathematical model.

Extensive research was continued in the fields of automatic programing and artificial, programer-oriented computer languages. A monitoring system which utilizes the 1401 computer as a secretary for the 7090 computer was installed. This system accepts programs in the Fortran language, translates these into machine code, supplies useful subroutines, and assists in code checking. The Bureau cooperated in efforts to maintain and improve the Algol 60 programer-oriented language. Studies were conducted on artificial mechanical languages as participation in the work of the Business

Equipment Manufacturers Association subcommittee on standard computer languages.

Statistical Engineering. The principal function of the Bureau's statistical engineering program is to advise the Bureau's scientific and technical personnel on the application of modern probability and statistical methods to physical science and engineering experimentation. The aim of this service is to help the Bureau's scientists and technicians conduct their research, development, and testing programs so as to reach conclusions of desired scope and reliability at the lowest possible cost. This goal must be achieved under existing limitations of funds, equipment, materials, and personnel, through effective use of modern probability and statistical methods. Extensive services were rendered, ranging from short informal conferences to active collaboration with project leaders for periods of several months.

Probability and Mathematical Statistics. Basic research in probability theory and mathematical statistics was conducted to maintain and increase the effectiveness of the statistical engineering program. This research, geared to fit the particular needs of the Bureau's laboratories, was concerned with (a) the shortcomings of confidence limits derived from a small number of measurements, as part of a program related to the evaluation of the precision and accuracy of measurement processes; (b) methods for making confidence interval estimates of the variances of two measurement processes in a situation where simultaneous measurements of a series of objects are obtained by two instruments, but repeated measurements of the same object are unobtainable; and (c) studies of nonparametric statistical techniques, i.e., techniques that do not depend upon assumptions regarding the underlying distribution.

Research was also continued on applications of probability theory and mathematical statistics to problems and measurement of the reliability of complex systems. New methods were developed for the derivation of approximate nonparametric confidence limits for the reliability of multicomponent systems, using data obtained from component tests. These methods can be applied when the probability distributions of component characteristics are unknown, and can be adapted to many forms of functional relationship between system performance and component characteristics.

Experiment Design and Consultation. Major cooperative activities were carried out in connection with the Bureau's calibration programs. Methods for representing the precision and accuracy of measurement processes, and statistical designs for eliminating the effect of environmental factors were the subjects of most of the consulting activities.

One especially noteworthy achievement in statistical engineering was the development of statistical tests for use in the interpretation of experiments involving the measurement of a number of objects by different methods, operators, laboratories, or other such categories. The interpretation of such tests is almost always complicated by the presence of one or two categories having results which are fairly consistently divergent from the consensus of

the remaining values. A test was developed based on the ranking of the results for use in detecting those categories having systematic differences with respect to the others. The mathematical properties of the test, such as its asymptotic properties and its power under different conditions, were investigated.

This test is simple to compute in that it involves only sums of small whole numbers, is easily understood and interpreted, and has all the mathematical advantages associated with tests that do not require that the measurements follow a specified distribution such as the normal (i.e., Gaussian) in order that the interpretation of the results be correct in the probability sense.

This new test is of great value in the interpretation of interlaboratory test programs as it calls attention to nonconforming laboratories by a simple, easy-to-understand method based on a minimum of mathematical assumptions.

Mathematical Physics. In its research in mathematical physics, the Bureau continued to emphasize the formulation of mathematical theories basic to the development of theoretical physics and engineering science. Investigations included research in the dynamics of plasmas, the determination of bounds on the solutions of various types of problems in linear elasticity—for example, the solution of the first boundary-value problem of plate theory—a combined theoretical and experimental study of nonlinear viscoelasticity, and the behavior of the trajectories in the phase plane of a nonlinear differential equation which arises in acoustical problems and vibration theory.

Plasma Research. Increased knowledge of the physics of ionized gases is essential for the Bureau's performance of its mission and is extremely important to the National Aeronautics and Space Administration. This fact has been demonstrated by studies of the propagation of electromagnetic waves through the ionosphere, and by phenomena occurring in devices proposed for plasma propulsion. During the past year, the mathematical research in the field was pursued from three different but fundamental viewpoints: kinetic, magnetohydrodynamic, and stochastic. Results obtained were applied to find the mathematical structure of electric shielding and plasma oscillations, and as an application of the magnetohydrodynamic approach, turbulence in plasma was studied. A weekly seminar discussing fundamental advances in plasma dynamics was instituted for the purpose of stimulating and coordinating research in this important field.

Theory of Satellite Orbits. Investigations concerning satellite orbits were continued. Emphasis was placed on the development of the theory of perturbations produced in the intermediate orbit of a satellite of an oblate planet in the case where the orbit has been calculated by theory developed by the Bureau. Such an orbit is associated with an assumed gravitational potential which is closer to the empirically accepted value for the earth than those which have been proposed earlier. Work was begun and substantial progress was made on improving the accuracy of the calculated orbit by taking into account deviations from the model used, such as equatorial asymmetry.

Operations Research. General areas of investigation during the year included game theory, graph theory, weapon simulation, Boolean functions, and mathematical models of distribution networks.

Significant progress was made in devising a procedure for finding maximum matchings (isolated sets of edges) in linear graphs. Algorithms were developed generalizing the Hungarian method from bipartite graphs to more general ones. Investigations continued on the embeddings of graphs in surfaces.

In connection with a study of optimal radar site distribution, systematic computer experiments were carried out to compare several methods for maximization of analytically intractable functions. Work continued on a long-range study of mathematical models of distribution networks, with a view to optimizing the location of sorting centers and the degree of system centralization. Other major activities included continuation of the analysis and computer simplification of Boolean functions (important in network and circuit theory) and the analysis and simulation of missile system operation.

The Bureau's endeavors in operations research have been geared to a two-fold objective—the determination of appropriate approaches to problems encompassing several professional fields, and the achievement of the interdisciplinary collaboration for necessary successful handling of such problems. Significant accomplishment was made in this direction during the past year. In addition, there was increasing demand for consulting and advisory services in operations research.

2.3.2. DATA PROCESSING SYSTEMS

As one of the special mission laboratories of the Bureau, the data processing systems division continued to provide information-processing services to the Bureau's own research laboratories and to other agencies of the Government. A primary function is to devise, test, and demonstrate theoretical and operational approaches to both systems design and the appropriate equipment for the handling, processing, and presentation of information necessary for the varied activities of the Government. In meeting its central responsibility to provide such services, the division engaged in a program of research and development using the techniques of several scientific disciplines. The Bureau maintains a technical facility and staff competence to foster and assist in automation studies within the Government.

Present areas of activity include study of new components for use in computer circuitry; exploratory investigations in artificial intelligence, particularly the syntax of natural and artificial languages, the logic of computing processes, and the theory of automata; design procedures for assembling electronic, magnetic, electromechanical and optical components into prototype equipments; application of computer technology to laboratory data gathering; the solution of data processing problems involving both human performance and equipment operation; and application of related sciences in solving information processing problems arising in government activities.

Research Facilities: SEAC, ANALOG, PILOT. During the design and construction of the new PILOT data processor, the SEAC continued to be utilized as a major research tool, particularly in the fields of linguistic data processing, picture processing, and patent search experiments. The addition of four tape units made possible the preparation of patent data for an exhaustive series of tests of the HAYSTAQ search system. Instruction in using the analog facility for research problems was given to a selected number of the Bureau's scientists. The analog facility was used for the following problem types: multivariable derivatives, temperatures in refractory furnace, squaring and rooting, dynamics of scale-pan balances, mass corrections, ordinate selection for spectrometer flux, optimum postal distribution, membrane transport properties, magnetization reversal, and mechanism of oxidation.

The initial configuration of the PILOT Data Processing research facility was completed and is now available for use on selected information processing tasks. The installation, essentially a network of computers served by a variety of input-output devices, consists of (1) a primary computer with a 256-word, 1-microsecond memory for arithmetic and logical processing operations, (2) a secondary computer having a register-memory for manipulating pieces of data, keeping track of them, and supplying them as needed to the primary computer, (3) a format controller, the third computer, to select and convert data in anticipation of their requirement as input to the primary computer, (4) input-output facilities comprised of a Flexowriter, a magnetic wire unit, a high-speed paper tape punch and reader, and four magnetic tape units. Plans are already being made, on the basis of best technical appraisal of additional requirements for handling government problems in the forseeable future, for the first set of auxiliaries augmenting the present installation, i.e., a large-volume, high-speed magnetic core memory, a large-volume magnetic disk file, several high-speed, high-performance magnetic-tape units, and an off-line, high-speed printer-plotter. An interim computer-assembler was prepared for the programer's uses as well as diagnostic and service routines for the maintenance staff.

Research Information Center. The Research Information Center and Advisory Service on Information Processing, under joint sponsorship of the National Science Foundation and NBS, continued its collection and organization of literature and bibliographic references concerning information storage, selection, and retrieval. The compilation of literature and bibliographic references (now over 10,000 items), information on current and proposed research projects, and the list of research workers continued to grow. The work of abstracting, indexing, and establishing subject control of the pertinent literature received expanded attention. Two state-of-the-art studies, one a revised guide to the literature of automata theory and the other a survey of information selection systems yielding facsimile copies, were completed and two more studies contracted for. The survey of information selection systems was partially supported by the Council on Library Resources, Inc.

Work was initiated on a report reviewing psychological research potentially applicable to the problems involved in improving the utilization of scientific information.

The center continues to give bibliographic and other services to cooperating workers in the field, government agencies, and interested correspondents.

A comprehensive literature search of character recognition efforts, including a survey of existing equipment and developments for printed character recognition, speech recognition, and code recognition, is being made under the sponsorship of U.S. Army Signal Supply Agency. The special problems associated with recognition of Chinese characters and possible approaches to Chinese character recognition are also being studied.

Components and Techniques. New components were evaluated and old ones investigated further for their possible contributions in the development of faster, more complex, and more reliable computers and data processors. A study of the rotational mode of magnetization reversal elucidated the role of the magnetocrystalline anisotropy energy and the demagnetizing energy peculiar to this film geometry. A number of iron films were studied by means of electron diffraction in an attempt to correlate the crystal structure with anisotropy energy. A study of the hysteresis loop tracer indicated its possible usefulness for quantitative anisotropy determinations with some changes in its design. Thus strip chart recorders were added to the vacuum evaporator to obtain a simultaneous recording of pressure, crucible current, and substrate temperature during deposition.

The tunnel-diode large-signal simulation study was continued, using an analytic approximation to the static voltage-current characteristics displayed by the diode in the negative-resistance region. Investigation and measurement of high-speed junction transistor parameters also continued. Charge control techniques for optimum high-speed circuit design were investigated and a 50-megacycle per second (Mc/s) pulse generator and a collector-triggered flip-flop designed. Semiconductors and storage devices are still being studied for use in basic solid-state circuits for memory and logical functions in computing and control devices. A reappraisal of the requirements for signal stability in the general binary-signal computer net led to a mathematical description of the net in terms of the signal-script transfer-functions of the digital repeaters. This description's independence of particular physical realization and logical organization makes it possible to compare computer nets that differ widely in physical and logical aspects. Feasible applications in the design of new high-speed circuits are in the planning stage.

Automatic Data Retrieval. Work continued on the development of automatic programing systems for processing information in collections of documents, under the sponsorship of the Patent Office and the National Science Foundation, using syntactic analysis of natural language text and associated pictorial information.

The machine sentence grammar was enlarged to accommodate more English syntactic structures and research begun on a new type of constituent structure grammar which will allow more than two constituents per construc-

Control module for special multi-purpose data-logging equipment developed to record experimental observations. Pin board (left) is used to program the control sequence. The modular approach makes possible assembly of data-logging systems appropriate to individual experiments. **(See p. 121.)**

tion but disallow discontinuous constituents. Programs for generating sentences from grammars, compiling concordances of elements within grammars, and checking grammars for mistakes and inconsistencies were written, debugged, and run on the 704 computer, in the COMIT language of the 7090, and on the 7090 itself. A recognition routine, also written in the COMIT language, analyzes input strings with respect to the generative grammar.

Research continued on formalizing (in a logical notation) the English sentences produced by a grammar for a fragment of English. The formalization is expressed in an applied first-order functional calculus. The "formalizer," which converts an English sentence and its syntactic analysis into an expression in the functional calculus, is a necessary step in developing a question-answering routine, which has been designed but is not yet programed.

Technical Assistance for Data Processing. Increased assistance in using automatic data processing techniques to laboratories throughout the Bureau, many of which have special data-conversion problems, led to the identification of several more potential areas for automatic data recording and processing. Technical assistance included determining whether analog and/or digital techniques were applicable and demonstrating the feasibility of selected techniques. The program of designing special data-logging equipment for other laboratories was expanded through the development of five wide-utility modules, each including several functional circuit "packages." These modules are capable of flexible interconnection and operation under the control of a supervisory module equipped with an internally stored program similar to that of a digital computer. This modular approach per-

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mits the ready assembly of data-logging systems appropriate to the particular requirements of the individual experiments.

Typical problems on which assistance was provided include photodetachment of negative ions, study of electron scattering in gases, and determination of color of light sources.

Development of Information-Retrieval Systems. Under the sponsorship of the Navy Bureau of Ships, the specifications for a new improved film transport for high-speed coded microfilm search were completed and a contract let for its construction. It will be incorporated in the new information selector system for retrieving information from large files of documents stored on coded microfilm. Other modifications included (1) redesign of the interrogator to set up the search question by use of a punched card, and (2) the preparation of specifications for two types of input cameras, one a flow camera and the other a fixed frame camera to provide a built-in code raster using separate optics to insure precise alinement and permit the use of various reduction ratios. An IBM 026 card punch and printer were modified for preparing the encoding and question cards; a 6-bit, 45-character punch was ordered for encoding alphanumeric symbols.

An automatic message-generating system, developed for the Navy Bureau of Supplies and Accounts for ordering Federal stock items, was completed and its operation analyzed. A systems study of the input and output requirements of the data processing installation, the cataloging procedures, and the data transmission requirements was begun.

Work was started, under the sponsorship of the Naval Intelligence Agency, on the design, development, and updating of an efficient, low-cost, information-retrieval system centered around the Lodestar reader/printer.

Special-Purpose Computer Systems. AMOS IV, a special-purpose digital computer, was developed in a program sponsored by the Weather Bureau as the central element in an automatic weather station to collect and reduce weather data prior to transmission. Five AMOS IV machines were assembled by the Weather Bureau, based upon the design of the prototype unit built by NBS for use at field sites. A training program conducted for the Weather Bureau on the operation and maintenance of the machines included working out a variety of sample programs and concluded with the development of various operational routines.

A high-capacity system capable of multipurpose data conversion and editing is being developed and constructed under the sponsorship of Office of Emergency Planning for damage assessment and resource status information in case of a national emergency. The integrated system design has as major components a central data processor, a FOSDIC scanner and control, a Flexowriter, a communications system, four magnetic tape units and control, and a plotter controlled by the processor. A map scanner with preprocessor and display is an additional component now under development. Approximately 80 percent of the system was designed in detail and about 30 percent constructed and tested.

Pictorial Data Processing. Continuing research in and development of techniques for scanning aerial stereophotographic information and com-

puter programs for translating the scanning information into a form suitable for auomatic production of three-dimensional terrain models was sponsored by the Naval Training Device Center. A high-resolution scanner was developed for use with a digitizer and magnetic tape-recorder to convert pictorial information into a form suitable for computer processing.

Additional research efforts were directed to processing pictorial information from photomicrographs of metallic crystals. A program for determining the perimeter length of a crystal boundary was written and technical assistance was provided to the Metallurgy Division in developing computer methods for quantitative metallography.

Engineering Applications. An evaluation of the automatic data processing requirements at the Goddard Space Flight Center for orbital determinations, telemetered data reduction, and satellite control calculations for nonmilitary satellites was undertaken for the National Aeronautics and Space Administration. Preliminary recommendations, hardware suggestions, and refinements in the specifications for two new automatic data processing systems, were made.

Consultative services were supplied to the Weather Bureau in connection with processing and transmitting photographic and infrared data from the new weather satellites of the NIMBUS series. On the basis of this advice, the Weather Bureau decided to replace the alphanumeric dial indicators in the high-speed photographic-copy camera systems used in the TIROS satellite with the more versatile CRT character generation.

Technical assistance was rendered to the Defense Communications Agency in connection with procurement and use of a simultation program for the defense communications system. The DCA controls a worldwide communication system, a composite of the separate long-line communication systems of the three services, that provides service to defense and related organizations on both regular and emergency bases. The Bureau simulated the operation of this system to determine effects of proposed changes in equipment and operating procedures, without the cost or disruption which would result from trial runs of the fully integrated systems.

Studies of evaluation and test procedures for analog-digital encoders were continued for the Bureau of Naval Weapons. The increased use of digital techniques for test-range instrumentation and for missile control and sensing elements created a need for procedures to determine the performance of interface equipment. The prototype system procured and assembled by NBS demonstrated to the sponsor an approach to testing and evaluating analog-digital encoders. In addition, consultative services were provided for the Bureau of Naval Weapons to a contractor developing a direct digital transducer for measuring pressure from 0 to 15 psi, and specifications were developed to prove the feasibility of a unique and promising technique for high-speed digitizing of analog voltages.

Engineering Application Devices. A combined analog-digital differential analyzer (CADDA) was under development for the Bureau of Naval Weapons to demonstrate the feasibility of representing each variable in a

computing system partly in digital and partly in analog form. Critical areas in two of its major components, integrators and multipliers, were examined, and their appropriate circuitry and logic evaluated and redesigned as necessary. The revised integrator is now nearing completion.

A prototype personnel peer-rating machine, to make rapid measurements of performance and evaluations of leaders for platoons, was designed under the sponsorship of the Department of Army and is nearing completion. The logical design, the electronic and mechanical design, and the procurement of all necessary components were completed. A technical description of the overall operation, including keying of plug-in packages, color-coding for system wiring, and the design of a new type of package used in this device, was written.

Technical assistance was given to the U.S. Air Force in connection with evaluating proposals for a Versatile Automatic Test Equipment (VATE) for Inertial Guidance Packages including the Error Signal Computer. Five proposed systems were studied and evaluated prior to Air Force award of a contract for standardized automatic test equipment capable of insuring the readiness of complex inertial guidance systems now employed in ballistic missiles.

Data Processing Applications. Study of the objectives, functions, and operational units of the Office of Technical Services, Department of Commerce, was continued to determine the feasibility of applying automatic data processing techniques to its operations. This necessitated a survey of the information processing activities of the Armed Services Technical Information Agency, the Atomic Energy Commission, and the National Aeronautics and Space Administration, the principal contributors to the OTS document collection, to determine the feasibility of exchanging data in machineable form. Study objectives were set and a sequence of mechanization was proposed and accepted.

A feasibility study was made of the information-handling procedures of the Bureau of Medicine, the Bureau of Biological and Physical Sciences, and the several District Offices of the Food and Drug Administration, to determine to what extent such procedures could be improved in speed, efficiency, and economy by use of mechanized systems. Attention was centered on the Pesticides Branch of the Food Division of the Bureau of Biological and Physical Sciences, since its problems were typical of those in other parts of FDA and the sets of data were fewer in number. A preliminary report of the NBS findings and recommendations to date was submitted to FDA in February 1962 and a final report in May 1962. In addition, an experimental computer program was written to process findings reported by hospitals on adverse reactions to drugs.

Exploratory investigations were conducted into possible computer applications in some of the Public Health Service's Division of Radiological Health's long-range studies dealing with radionuclide intake distribution, diet selection for minimal radiation hazard, and methods for control radio-

nuclide testing. Two operational programs were started: a linear regression program for the IBM 1620 and a geographically-oriented printout system for processing radiation sample data.

Technical assistance was continued in analyzing the Interstate Commerce Commission's major objectives, functions, and operational units to determine the feasibility of applying automatic data processing techniques to selected activities and operations. Computer programs were written for several of the cost-finding activities and are currently in production-run status. A system analysis of the Inventory of Motor Carrier Authorities was completed, and the design and programing of an experimental retrieval system were undertaken.

New computer programs, needed because of changes in legislation effective January 1, 1962, were written to aid the Public Housing Administration in its review of reports on low-rent housing occupancy. These reports cover reexaminations for continued occupancy and new admissions. The computer program analyzes the reports for errors and inconsistencies, makes corrections where possible, writes letters to the authority submitting the report, and accumulates approximately 30 statistical arrays comprised of about 9,500 tally counts.

Mechanization of Patent Searching. Major emphasis in the cooperative program with the Patent Office for mechanizing composition-of-matter patent search operations was on preparing data for trial runs of the computer search program, HAYSTAQ, and on establishing record-keeping procedures for each stage of the data preparation. A report describing the system's data-checking, data-compiling, and assembly routines was written. Research on methods of file organization continued, the objective being to develop more effective screening techniques to increase the efficiency of mechanized search operations. Preliminary investigation of mathematical models for information retrieval was undertaken to ascertain whether any existing models can be applied to Patent Office operations and requirements. An attempt is being made to model the HAYSTAQ system in such a way that the philosophy of the system will be more generally applicable. A preliminary survey of the attitudes of patent examiners was conducted to assess the opinions of the examining corps toward their profession and the idea of mechanized search. The report submitted recommended a full-scale survey.

Automatic Mail-Sorting Developments. The Bureau continued its assistance to the Post Office Department's Office of Research and Engineering in applying automatic equipment and data-handling techniques to mail-sorting operations. A new computer program developed selects "optimal" paths, for which speed and cost are the criteria, in routing mail; this is a variation of the well-known "shortest route problem." The new program can handle 45 cities and 2,500 scheduled nonstop trips. Adaptations of the Washington, D.C., manual-sorting procedures for use with codesort equipment were designed to take full advantage of its flexibility and to serve both as a model for short-term system planning and as a base for future

research and development. The updated sorting schemes were written and procedures for routine updating of the codesort schemes developed. Liaison with the contractor developing the equipment was maintained to assure compatibility between the sorting schemes and the equipment. NBS personnel also assisted in monitoring a large-scale simulation project and in initiating and coordinating several human factors projects in connection with development contracts of the Post Office Department. The network studies of the overall sorting and transportation problem also were continued.

2.3.3. INSTRUMENTATION

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

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

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

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

Electronic Equipment Fault Location. The goal of the fault location program sponsored by the Navy Bureau of Ships is to develop measuring techniques to replace present manual techniques. Much research is being undertaken today in the area of semiautomatic fault location in electronic equipment. Unfortunately, however, most of the fault location test sets are large, costly, complex, specialized, or require highly trained operators. The NBS fault location program is intended to develop quick and easy measurement devices for such variables in electronic equipment as the following: a-c, d-c, and RF voltages; peak voltages of periodic waveforms; pulse widths; pulse rise time; rate of rise time; amplification; limiting action; frequency response; resistance; inductance; capacitance; a-c impedance; current; and

Cross section photograph of a failed transistor sliced in half shows the perforation (large vertical dark region) which forms a short circuit between the emitter (top) and the collector (bottom). (Small divisions of comparison scale through middle of view are approximately 0.00035 inch.) Recent NBS transistor failure studies have clarified the mechanisms of such breakdowns. **(See p. 127.)**

temperature. All of these measurements are automatically programed in a simple manner and the test information so displayed that no interpretation of the measurements or special training is required of the operator.

Second Breakdown in Transistors. The Bureau undertook a study of the second breakdown of transistors in response to a need expressed by industry. It was believed that a better understanding of the physical processes involved must precede either the elimination of the effect or the development of a basis for rating transistors to permit avoiding the effect.

Second breakdown of transistors is evidenced by an emitter-to-collector short circuit resulting in the catastrophic failure of the device. It occurs under many operating conditions and some internal changes accompanying it are well known. In typical alloy junction transistors which undergo second breakdown, the emitter alloys with the collector through a tunnel crossing the base region. Hypotheses previously advanced to explain second breakdown did not aid in obtaining a practical solution to the problem.

The Bureau study disclosed new characteristics of the second breakdown phenomenon which indicated that it was more fundamentally rooted in the character of the transistor than previously thought. The energy absorbed by the transistor, the ambient temperature, and the duration of the causative conditions were found to control initiation of second breakdown, which was further found to occur in all types of transistors and under all base bias

conditions. A means of rating transistors on the basis of the factors identified was introduced for use, pending further results of this continuing research program.

Semiconductor Contact Studies and Surface Physics. A study of the effects of various electrodes on such semiconductors as silicon and silicon carbide has provided new insights into processes taking place at the electrode and within the semiconductor. Work function considerations controlled conduction of pulses near 100 volts; the effects of surface states were so inconsequential that two-terminal resistivity measurements could be made.

Data obtained with the use of low and intermediate voltages, however, were used to calculate surface barrier height and width. Porous electrodes were used in a variation of the experiment to determine the effects of various gases, such as water vapor and ammonia, in the ambient. Selection of particular ambients transformed the normally ohmic interface into a rectifying one. By applying pulses to such selectively conducting layers in *p*-type silicon, it became possible to measure the charge stored in the surface states. The current conducted was found to be independent of the applied pulse voltage, but controlled by a small bias (such as ± 1 volt at ± 0.1 milliampere) which could change the surface potential.

The use of porous electrodes has opened up a new method of studying semiconductor physics and also has made possible the design of new devices for such applications as pulse shapers, delay lines, and logic circuits.

FOSDIC. A Film Optical Sensing Device for Input to Computers, FOSDIC V, is being developed for the Office of Emergency Planning. The new unit is part of a large data processor being developed by the NBS Data Processing Systems Division for OEP. Features of the FOSDIC V include a scanning unit that is a transistorized version of that of FOSDIC III, electronic programing of all FOSDIC functions, low heat dissipation, and compactness. Electronic programing using the magnetic core and drum memories of the data processor will greatly increase the versatility of the FOSDIC scanner.

As the processing of the 1960 Decennial Census data came to an end at the Bureau of the Census, FOSDIC III was applied to other data-collecting surveys of the Government. The monthly collection of employment and unemployment information of the Census Bureau was converted to FOSDIC III processing in October 1961. The National Fallout Shelter Survey, conducted by the Department of Defense, was carried out by means of a machine system using FOSDIC as the input device. Both the Census Bureau and the National Aeronautics and Space Administration are converting their personnel records to magnetic tape, using FOSDIC as the primary vehicle.

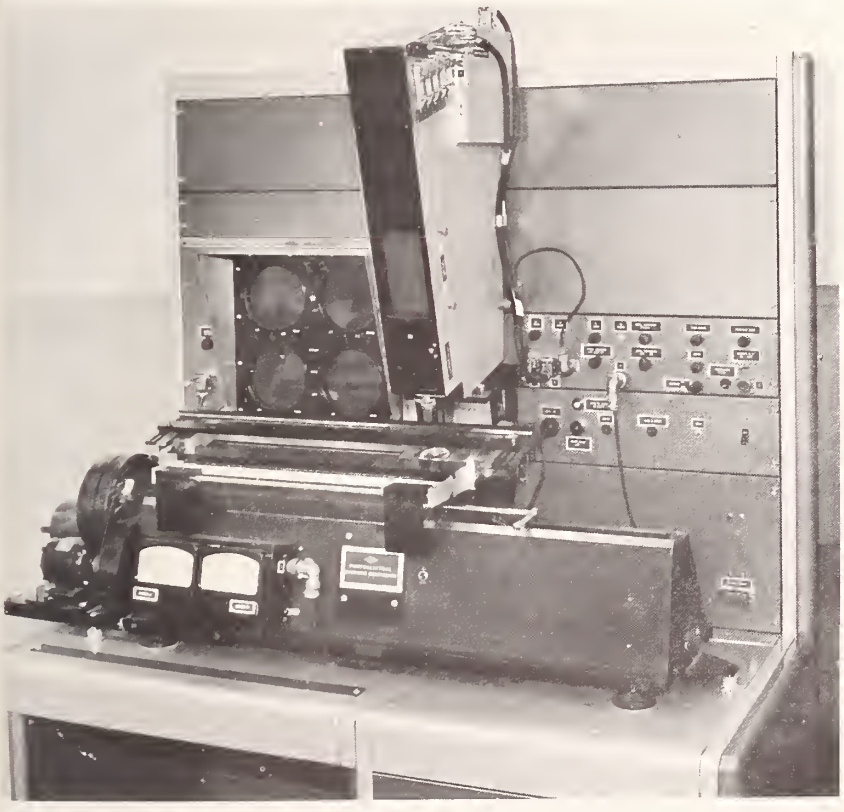
Electronic Scanning Microscope. An improved model of the electromechanical scanning microphotometer was constructed to read data from spectrographic plates more nearly automatically. This device measures the light-transmission density of an incremental area on a previously exposed and processed spectrographic plate as it is slowly moved by mechanical means across the area sensed. The photometer signal and a signal repre-

senting the plate position are converted into a display of wavelength versus density on X-Y coordinates.

In practice the density signals from a pair of microphotometers are scaled by a digital voltmeter and the density and wavelength readings automatically recorded in digital form on punched cards. The densities are obtained as three-digit numbers on a logarithmic scale and the wavelengths as seven-digit numbers by micrometric translation of the spectrograph plate position. Resolution of the plate's position is obtained with a consistency better than 0.001 millimeter.

The X-Y coordinate display provided by the equipment as an oscilloscope presentation is a greatly magnified plot of density versus wavelength for a small portion of the spectrographic plate, obtained by a combination of the mechanical and an electronic scan. It is used in making manual settings on the equipment.

Hygrometry. The development of a secondary humidity standard, arranged in a Wheatstone bridge configuration was begun. A pneumatic bridge hygrometer, containing four critical-flow nozzles, with a pressure gage connected across the bridge, and with a desiccant inserted in one branch, was constructed and tested. The differential pressure across the bridge is



Improved electro-mechanical scanning comparator makes reading data from spectrographic plates more nearly automatic. **(See p. 128.)**

a measure of the moisture content of the test gas flowing through the bridge. The bridge response is essentially linear with vapor pressure over a range of 1 to 22 mm Hg vapor pressure. An effort is being made to improve the design and to determine the accuracy with which this instrument will measure the moisture content of gases.

Telemetering Pickups. The Bureau is conducting a continuing investigation of the characteristics of telemetering transducers, a program sponsored jointly by the Bureau of Naval Weapons, the Army Ordnance Corps (WSMR), and the Air Force Aeronautics Systems Division. During the year the Bureau was concerned principally with the development of test methods and equipment.

Work on a liquid step function pressure calibrator which will produce a monotonic step function of pressure of 500 psi with a 1-millisecond rise time and 1,000 psi with a 2-millisecond rise time is nearing completion. It is anticipated that this equipment will permit the determination of nonlinear creep, commonly associated with hysteresis, in transducer responses of 5-millisecond duration or longer. Selected transducers were tested, calibrated, and evaluated to keep abreast of the state of the art of commercial pickups and to determine the adequacy of test methods and equipment.

2.3.4. RADIO PROPAGATION

The Central Radio Propagation Laboratory, located at Boulder, Colo., has the primary responsibility within the U.S. Government for collecting, analyzing, and disseminating information on the propagation of radio waves at all frequencies along the surface of the earth, through the atmosphere, and in outer space.

Ionosphere Research and Propagation

The Bureau conducts and coordinates research on the propagation of radio waves as affected by the ionosphere and on the special factors (such as solar flares) which can give rise to large departures from the normal behavior. It is also concerned with research on the nature of the media through which these radio waves are transmitted and the interaction of radio waves with the media. One of the important functions of the Bureau is the preparation of predictions of radio wave propagation and warnings of solar and geophysical disturbances.

Second Topside Sounder Rocket Test. The second rocket test of a topside ionospheric sounder, conducted at about midnight on October 13, 1961 from Wallops Island, Va., was characterized by excellent instrumentation performance and provided much useful data on the nature of ionospheric irregularities. In this test the rocket was fired into the ionosphere during known disturbed conditions, bearing a 4.07 megacycles per second (Mc/s) ionosonde to an altitude of about 1,070 kilometers (km) to the east of the launching site. This experiment was performed, like the previous rocket-borne sounding of June 1961, to determine if ionized layers appear the same

when probed from above as when investigated by conventional earth-bound sounders. as well as to observe soundings made during transit through the ionized layer.

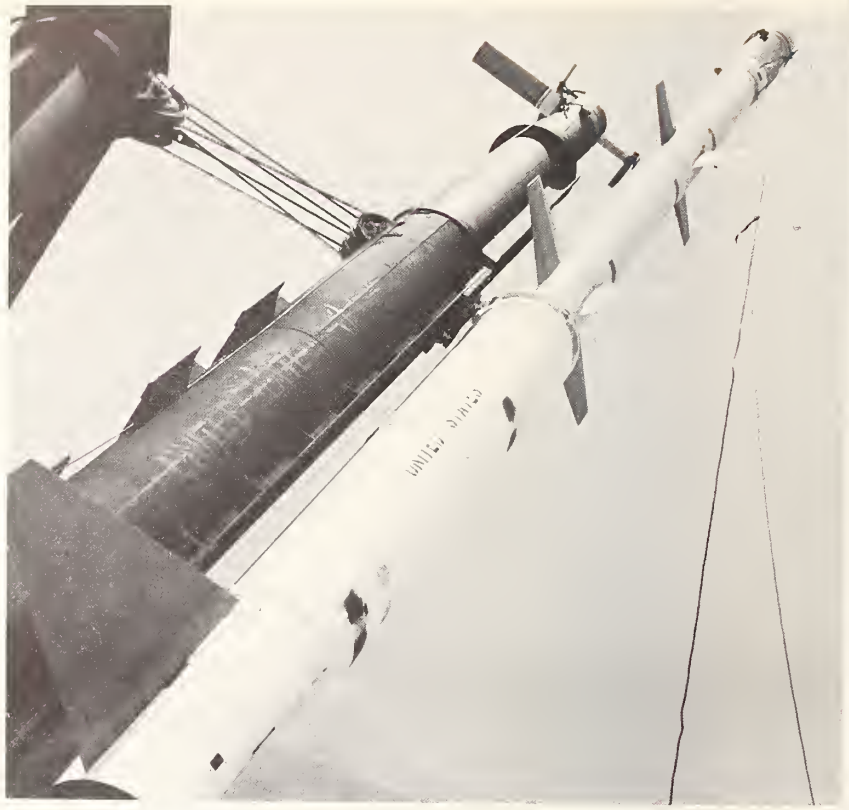
The rocket was intentionally fired while spread-*F* echoes were observed using the bottomside sounder, to determine if similarly disturbed conditions prevailed on the upper side also. Both normal echoes and spread echoes were observed during the first half of the flight. The spread echoes were at a range six to eight percent greater than the normal echoes, suggesting that they were due to longitudinal propagation in ducts caused by ionization alined along the earth's magnetic field.

Analysis of data obtained in this experiment showed that ionization irregularities responsible for spread-*F* conditions noted in bottomside measurements actually extend into the upper ionosphere to an altitude of at least 1,000 km. The local ionization irregularities detected were typically about 2 km in diameter and at an east-west spacing of 1 to 30 km. Analysis of the variation of virtual ionospheric depth with rocket altitude determined the neutral atmosphere scale height to be 53 ± 2 km between the altitudes of 375 and 600 km, equivalent to a temperature of about 850 °K in an atmosphere composed predominantly of atomic oxygen. This can be compared with a scale height of 72 km and temperature of about 1,150 °K obtained in the first rocket test, which took place about sunset in late June 1961.

These results have several important effects on the design of a satellite topside sounder experiment. The receiver characteristics, for example, are being modified to accommodate the strong signals received as the ionosonde passes through a duct. Also, preparations are being made in the satellite sounder data analysis program for handling longitudinally propagated echoes as well as normally propagated returns. This program is a joint effort with the Airborne Instruments Company and is sponsored by the National Aeronautics and Space Administration.

Solar Flares and Their Radio Effects. Recent worldwide cooperation of more than fifty solar observatories achieved an almost continuous solar flare patrol. This is of interest to NBS because the appearance of solar flares is accompanied by marked radio disturbances. Unfortunately, systematic errors in estimates of flare areas and magnitude are inevitably present because of the large number of investigators involved. A machine program to group reports of a single flare and to normalize on a common scale each reported area and importance value was completed. The program was applied to the flares reported in the CRPL *F*-series for the IGY; the resulting grouped and normalized flare list and a description of the methods used were published in the IGY Solar Activity Report Series. No. 17.

The phase of VLF radio waves is proving to be a sensitive indicator of radiation from solar flares. Changes in phase indicates a change in reflection height and is a measure of the ionizing effect in the lowest part of the ionosphere. It is found that the phase excursion can indicate quite different ionizing properties for the flare than would be deduced from optical



Four-stage, solid-propellant rocket which carried the second topside sounder package to a height of 1070 kilometers for soundings of a disturbed ionosphere. Results of the sub-orbital flight suggested modifications to make the proposed satellite package more effective. **(See p. 130.)**

measurement of flare importance, based on the affected area of the sun's physical surface. An example is a flare of optical importance 3+ on March 22, 1962 which produced small ionospheric effects.

The ionospheric effects of solar flares have also been studied by spectral analyses of reflected HF radio signals. A statistical study of transmissions from WWV and Boulder transmitters showed that more flare events can be detected by this technique than by those which depend on increased ionization produced in the *D*-region. In this technique excursions of received frequency, from a few tenths of a cycle to the order of ten cycles, identify the presence of ionization produced between the *E* and *F* layers, in addition to that in the *D*-region. The frequency variations observed bear a direct relationship to the time variation in the flux of solar ionizing radiation.

A study of certain solar flares indicates that large solar flares followed by cosmic ray increases at sea level often produce a short increase in *F*-region ionization.

Theory of the Formation of the Ionosphere. Recently H. E. Hinteregger of the Air Force Cambridge Research Laboratories made accurate

rocket observations of the solar extreme ultraviolet flux for various heights. The rates of photoionization of the atmospheric gases can be computed from these fluxes. With known rates of photoionization and a reasonable scheme of recombination reactions it is now possible to achieve a fit between the theoretical and observed ionospheres by adjusting the rate coefficients of the different reactions. For this it was necessary to assume that (a) the rate of the ion-atom exchange reaction, $N^+_2+O \rightarrow NO+N$, is greater than the dissociative recombination of N^+_2; (b) the rate coefficients for dissociative recombination of O_2^+ and NO^+ are of the order of 10^{-7} cm^3/sec (consistent with laboratory measurements but ten times larger than most previous ionospheric determinations); and (c) that these rate coefficients are proportional to T^{-n} where n lies between $\frac{1}{2}$ and 1.

Further study of these processes should lead to more precise values of the rate coefficients, to an evaluation of other reactions, and to a more detailed understanding of the neutral atmosphere.

Low-Latitude Propagation Effects. Low-latitude radio propagation experiments were performed in Africa, sponsored jointly by the United States Information Agency and the Bureau. Time-delay and fading measurements over a six-week period in September and October 1961 were made of high-frequency transmissions over the 3,300-km path from Tripoli, Libya, to Accra, Ghana. The most interesting phenomenon discovered was the appearance of highly spread echoes on the records just after sunset, at maximum frequencies exceeding 50 Mc/s. The time-delay varied from one ionogram to the next, suggesting that the reflections resulted from scattering by rapidly moving clouds of electrons.

A similar conclusion was obtained from spectral analyses of fading signals. It was deduced that during the evening signals are reflected from electron clouds elongated along the earth's magnetic field and moving from west to east with velocities on the order of 100 meters per second.

Operations Research. The previously used methods of predicting the monthly median value of the critical frequency were analyzed statistically, with the assistance of the mathematical statistics consultant, in a study of the ionospheric prediction services. A new method of predicting the critical frequency developed is based solely on past data, but produces prediction accuracies comparable to those using present counts of sunspot numbers. This study is being continued.

Tropospheric Propagation and Radio Noise

Most efficient use of the radiofrequency spectrum is the aim of the Bureau's program in tropospheric propagation and radio noise. Attaining this objective requires a basic understanding of radio-wave propagation, noise, and interference. To this end theoretical and semi-empirical prediction methods are developed and compared with statistical samples of data on radio-wave propagation and radio noise. During the past year, a major part of the effort was devoted to work in support of the activities of the Consultative

Array of 25 antennas used to study the effects of ionospheric irregularities on radio signals propagated over long distances. **(See p. 144.)**

Committee on International Radio. This change of emphasis was made in anticipation of the Xth Plenary Assembly of the C.C.I.R. to be held in New Delhi, India, in January and February of 1963 and the International Telecommunications Union Extraordinary Administrative Radio Conference on Space Radiocommunication, including Radio Astronomy, to be held in Geneva, Switzerland, in September 1963.

Reports to the C.C.I.R. The advent of space radio communication focused attention on the need for more precise methods for predicting the characteristics of radio signals after propagation through the troposphere. It is now generally recognized that the large portions of the radio spectrum needed for long-range space satellite communications systems can be obtained only by developing cooperative use techniques for the portions of the spectrum (between 1 and 10 gigacycles per second (Gc/s)) now extensively used for line-of-sight radio relays. Such sharing appears feasible and it only remains to develop (1) methods for assigning the locations of the earth space service stations for negligible mutual interference between the space and terrestrial radio relay services and (2) methods for maintaining a proper balance between the radio power radiated by the two systems.

In support of the C.C.I.R. program the Bureau prepared 16 reports for several C.C.I.R. study groups. Reports were made to the receiver study group on figures of merit for radio receiving systems in the presence of noise, system sensitivity, receiver and operating noise factors, and operating noise temperature. The three reports to the study group on space systems dealt with spectrum sharing by earth and space telecommunication links, tropospheric factors affecting this sharing, and the feasibility of radioastronomical

observations in bands used by terrestrial communications systems. The reports to the propagation study group covered the topics of transmission loss prediction, climatological data, radio-meteorological parameters, the radio refractive index of air, and tropospheric factors affecting sharing of space and terrestrial communications systems. The reports submitted to the ionospheric propagation study group discussed the measurement of atmospheric and manmade radio noise. The C.C.I.R. study group on standard frequencies and time signals was given a report on a cause of reduced stability and accuracy of received time- and frequency-standard signals.

Electromagnetic Theory. A number of seemingly unrelated topics, loosely classified under electromagnetic theory, were considered by methods having much in common.

Reflection Coefficients. Previously developed theory for propagation between a spherical earth and a concentric ionosphere was advanced by employing an idea of Brekhovskikh to derive an expression for the reflection coefficient of a continuously stratified ionized medium. The result is in the form of a series whose first term is a Fresnel-type coefficient and succeeding terms account for the finite thickness of the transition layer.

Propagation in Irregular Layers. Understanding propagation in irregular layers was aided by an approximate treatment of modes in a waveguide of variable width. It was assumed that the boundaries satisfy impedance-type boundary conditions. The model used consists of two parallel-plate waveguide regions connected by a linearly tapered section. The results have application to the theory of VLF radio-wave propagation when the ionospheric heights are not constant along the path.

Field Intensity in Waveguide. A simplified treatment of propagation in the earth-ionosphere waveguide was carried out to describe some of the broad features of VLF propagation in a relatively concise fashion. It was shown that if the square of field amplitude is averaged over the width of the waveguide a very simple formula for the averaged intensity is obtained.

Reflection From Changing Strata. The oblique reflection of plane electromagnetic waves from a continuously stratified medium was considered by means of various approximations. The WKB (Wentcel-Kramers-Brillouin) method and its extension are most suitable for slowly varying profiles, but certain modifications must be made when the ray has a turning point. It was shown that under this situation the phase integral method is applicable and that when the medium is rapidly varying the adoption of an alternative approach is particularly suitable at low frequencies.

Field at Localized Obstruction. The field of an electric dipole at a smooth spherical or cylindrical surface containing a localized obstruction was studied for application to ground wave propagation. An approximate solution was obtained by combining the rigorous theory of diffraction by a sphere and the approximate Kirchoff diffraction theory for black screens.

Reflection From a Grid Ground Plane. The reflection of electromagnetic waves from a parallel wire grid near the interface plane of two media was applied in the design of radial wire ground systems for vertical

monopole systems. It was found that when the incident wave is polarized with the magnetic vector perpendicular to the grid wires the grid can be represented by a pure shunt element in the equivalent transmission line circuit.

Reflections at Stratified Plasma. Boundary value problems involving plasma media in certain two-dimensional configurations were analyzed for exact solutions. Explicit results were obtained for the reflection coefficients of stratified plasma in planar and cylindrical geometry.

Path Impedance Formulas. Mutual impedance formulas were developed for two- and three-section paths between two vertical electric dipoles on the surface of an inhomogeneous spherical earth in a form suitable for computation. The path parts between the dipole antennas were homogeneous and surface impedances were constant. Specific numerical results were presented for combinations of frequencies from 20 to 1000 kc/s and conductivities from 10 millimhos/meter to 4 mhos/meter.

Point-Point Moon Communication. Manned flights to the moon were anticipated in a program sponsored by the Jet Propulsion Laboratory to establish guides for planning communications between exploring parties and base installations on the surface of the moon. The transmitter power needed to obtain a desired receiver signal-to-noise ratio at specified distances was predicted. Plots of lunar ground-wave attenuation were derived in this project and ground-proximity losses for the antennas suggested and the expected noise sources discussed in the report on this work.

VLF Microwave Models. A multimode waveguide is being constructed for simulating low-frequency propagation between the earth and ionosphere with frequency scaled upward to the microwave region. This waveguide, now nearing completion, is approximately 8 free-space wavelengths in height and 250 wavelengths long. In this double-height waveguide, the field in the lower half of the guide corresponds to the field in the earth-ionosphere "waveguide." It was constructed in such a manner that perturbations in the ionosphere can be simulated in it. During construction of the waveguide, experimental and theoretical studies were conducted on launching the desired modes in the waveguide and on methods of measuring the field in the guide to determine the effect of perturbations in the walls.

Analog Correlation Computer. An analog system for computing the statistical correlation coefficients for radio propagation and associated data was developed. Signals to be analyzed are derived from data recorded on magnetic tape. The analysis can be performed in either real time or speeded up in playback time by factors as high as 100, referenced to recorded time. The system was designed to provide two basic types of correlation analysis, using both standard and modified analog computing techniques. Auto- or cross-correlation parameters can be computed for discrete values of time delay (τ) for a wide range of sample lengths or averaging time, chosen for a sample length or, with a series of averaging periods, a time-history of the parameter.

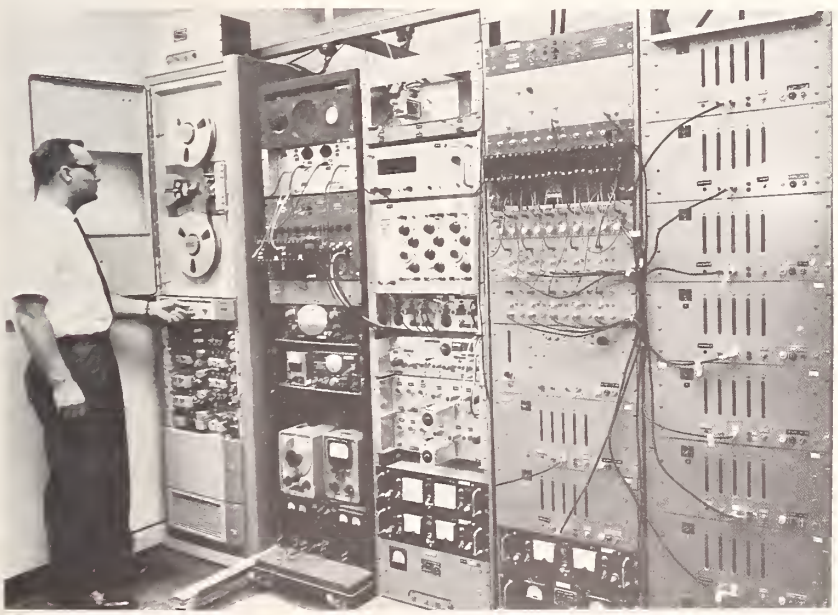
A complete correlogram can be derived and plotted automatically as a continuous function in (τ), in place of the conventional point plot of the

function for discrete values of (τ). This type of analysis is performed on finite data samples, using a dynamic time delay translated to the computer from a special-purpose tape transport as a linear function in time. The computer contains an automatic self-normalizing system for computing the correlation coefficient and accepts input data in the -100 to $+100$-volt range over a bandwidth of 0 to 10 kc/s.

Statistical Studies. Data on distribution functions of vector time series were studied, with the assistance of the mathematical statistics consultant, to obtain more reliable estimates of distribution, density, and other functions of transmission.

Samples of Atmospheric Radio Noise. A magnetic-tape system for recording atmospheric radio noise was developed and put into operation. The various statistical analyses performed on the recorded sample of the noise envelope are extremely useful in determinating the correlation between various parameters of the noise and error-rate measurements.

The tape system consists of a seven-track tape recorder and auxiliary equipment using the noise to frequency-modulate the recorded signal. The auxiliary equipment breaks up the IF signal received from the ARN–2 Radio Noise Recorder into five detected noise envelopes of specific bandwidths and amplitudes for the tape recorder. The radio noise in the 20-c/s (approximate) bandwidth is recorded on one track and the low-probability, high-amplitude, and the overlapping low-amplitude noise in the 200-c/s and 2000-c/s (approximate) bandwidths are recorded on individual channels of the tape.



Tape recordings of VHF signals scattered from the ionosphere are analyzed to determine the characteristics of this type of propagation. **(See p. 144.)**

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The recorded noise information is reduced to the following statistical functions by equipment previously developed at NBS: The amplitude-probability distribution function, the amplitude-probability density function, the envelope crossing rate distribution for varous levels, and the pulse-spacing duration distribution function for various levels. The autocorrelation function is also to be investigated. Parameters derived from these functions are compared with error rate measurements by an electronic computer to predict the performance of a given communication system in the presence of atmospheric noise.

Efficient Television Assignment. The growth in the number of television channel assignments makes it advisable before making future assignments to determine the geographical separation of VHF television stations required for interference-free reception. Meeting the demands for assignments now anticipated will require that this portion of the spectrum be used as efficiently as possible, which implies that station separation be reduced until service is limited by interference, rather than by natural noise.

Methods of making television channel assignments are now being studied by the Bureau, making use of alternating polarization, precise offset carriers, and antenna directivity, to discriminate between the wanted and unwanted signals.

The study indicates that present minimum co-channel spacings could be halved with only a minor reduction in the areas served by individual stations. Assignments from the 12 VHF channels could be made to twice as many markets as at present, with the possibility of six outlets for 102 markets and four or more for 167 markets, instead of for only 17 markets, as at present.

Over-Water Transmission Loss Measurements. Transmission loss measurements are being made over a 300-km path across a portion of the Gulf of Mexico, in cooperation with the U.S. Air Force, to improve propagation prediction methods. Simultaneous radio and meteorological measurements will be made for a period of one year. The data obtained will help to improve prediction methods for over-water scatter paths, for which data at this latitude are very limited.

Bandwidth of Tropospheric Scatter Systems. Tests have been made which will lead to improved prediction of the bandwidth capabilities of long-distance tropospheric-scatter radio paths. Tests in a continuing series of experiments indicate that the commonly used distance dependence may not adequately describe the variations actually encountered on paths of different lengths. The present experiments are investigating the correlation of bandwidth to the performance of specific systems.

Surface-Satellite Communication-Interference. Artificial earth satellites have opened up new horizons in long-distance communication possibilities. Optimum frequencies for satellite communication purposes lie generally in the 1 to 10-Gc/s portion of the radiofrequency spectrum. This portion of the spectrum is now used by many communication services, with which satellite communication systems using these frequencies would be expected to share the use.

The conditions under which these frequencies can be shared by conventional point-to-point microwave relays and satellite systems were predicted. Studies indicate that frequency assignments can be shared with adequate geographical separation of terminals and proper consideration to antenna directivity. Theoretical studies and an experimental program using 60-foot parabolic antennas were conducted to determine the minimum separation distance and antenna elevation angles for the space communication system, to keep the unwanted signals at the receiver input terminals below the interfering level. The effects of scattering from aircraft were reported. Measurements of the cumulative distributions of the directive gain of a 60-foot diameter parabolic antenna provide the basis for a tentative description of antenna patterns for predicting possible interference. These measurements will be conducted over an extended period in order to make reliable estimates of interfering conditions.

Air-Ground UHF-TV Measurements. Data on air-to-ground transmission are now being collected to predict coverage attainable for airborne broadcasts. The study of signal variability is of primary importance in determining the reliability of service fields and the potental interference to other services for air-ground communication systems. Only relatively low terminals (with a mountain top simulating the aircraft in flight) were used in previous systematic data recording plans, and the applicability of such data to aircraft flying at great heights was not known. Signal variations depend on the terminal height as well as on the steepness with which radio waves traverse atmospheric irregularities, such as layers.

The complex antenna system of the U.S.N.S. *Eltanin* was evaluated using a 60:1 scale model ship and the NBS antenna test range. The *Eltanin* is a National Science Foundation ship designed for geophysical research in the Antarctic. **(See p. 145.)**

A unique opportunity for the systematic collection of data on transmission was presented by the television transmissions from an aircraft flying at 23,000 feet elevation, undertaken in connection with the Midwest Program on Airborne Television Instruction. Signals in the 800 to 850 Mc/s range received over several different paths from within to slightly beyond the radio horizon are being recorded. Analysis methods now being developed will permit separation of the flight pattern of the aircraft as a component in the observed signal variations recognizable from the variability introduced by the atmosphere. Ultimate results of this study may permit performance prediction of air-ground communication systems in the UHF range for given system parameters and for a given flight pattern of the airborne terminal.

Special Refraction Effects. A system of equations has been derived for determining range errors as a function of refractive index characteristics (primarily the surface value, N_s). The system forms a general method for correcting baseline type tracking systems at any arbitrary location, and allows between 97 percent and 98.5 percent of the systematic error due to tropospheric refraction to be removed. This method was checked against hypothetical cases for targets located in observed two-dimensional N-profiles.

Refraction Effects in Microwave Tracking Systems. Modern precision missile radio guidance systems using microwaves are limited in ultimate accuracy by refractive index irregularities in the troposphere. An improvement in accuracy is being sought by conducting a program to measure the effects of atmospheric inhomogeneities and turbulence on such systems. An experimental tracking system was constructed on the unique terrain of the Boulder area, using specially developed techniques, to simulate the basic functions of the Mistram system being built for the Air Force. This system is being used to record variations in apparent positions resulting from atmospheric variations. Simultaneous recordings are made of atmospheric variations and refractive index at each of the antennas in the system and at various levels on a tower near the system terminals. Microwave refractometer measurements are made, in addition, by aircraft flying approximately along the propagation paths. These data are being examined for correlation with the apparent position variations of a fixed target simulating a missile to investigate the feasibility of using such data for correcting the radio system data. Preliminary work showed that some of the long-term (several hours and more) errors can be reduced significantly by proper atmospheric measurements. However, no methods have been found as yet to make significant or reliable correction for the short-term (hourly or less) effects.

Sky Temperature Theory. A computer program was developed to calculate the thermal noise temperatures to be expected in the troposphere. Preliminary calculations, made using older estimates of water vapor and oxygen molecules, are now being revised in accordance with the present estimates of water molecule parameters. Further modification may be necessary when more exact parameters for the oxygen molecule are known.

The program includes rain absorption parameters. Sufficient information for other gaseous and nongaseous components is not available for inclusion in the present calculations.

The NBS Jicamarca Radio Observatory located near Lima, Peru. This facility provides a powerful and very sensitive research tool for ground-based observations of the ionosphere, exosphere, interplanetary medium, and the sun. **(See p. 147.)**

Radio Systems

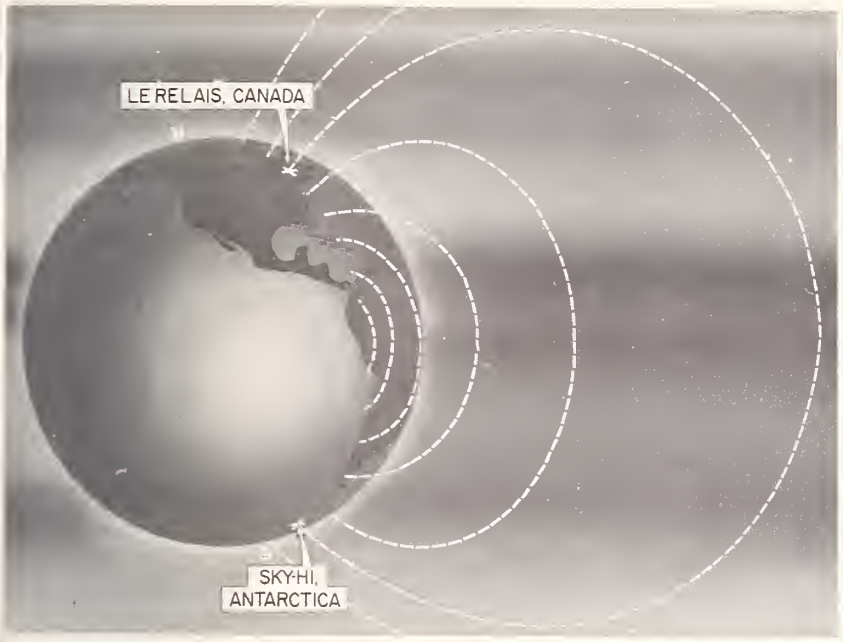
The aim of the Bureau's program in radio systems is to provide technical information to Government and industry on radio propagation factors affecting design and use of radio systems. The emphasis of this work is on long-range radio transmission problems and methods of measurement for radio communication, navigation, timing, detection, and positioning systems. Radio wave propagation studies are carried out for ionospheric, ground-wave, and line-of-sight paths to define the limitations, disturbances, and capacity of the transmission medium as a channel. The information obtained is directed toward guidance of engineering practices, allocation and use of radio frequencies, and evaluation of system capabilities and limitations. Standards and methods of measurement are developed for radio systems to fulfill the needs of federal agencies and industry involved in radio telecommunication operation and regulation. Studies of information theory and coding, modulation, and antenna design are directed toward improvement of the reliability of systems and to the efficient utilization of the radio frequency spectrum. Consulting and advisory work is done in accordance with the needs of other government, commercial, and scientific agencies.

Frequency Utilization. New services were established for computation of HF radiopath performance and optimum frequencies. Comprehensive computer programs were completed for obtaining maximum usable frequency,

frequency of optimum transmission, lowest usable frequency, field strength, signal-to-noise ratio, and circuit reliability. A fee schedule was proposed for services such as making these computations for government and commercial agencies.

Applied Electromagnetic Theory. The nature of low-frequency radio wave propagation around the earth is, in large measure, determined by the shape of the lower ionosphere electron-ion density transition region. A computational technique which has been developed utilizes a flexible theoretical plasma model which can fit most measured electron-ion altitude profiles. The reflections and transmissions in the ionosphere can be determined with the aid of this model, together with available geophysical data on the ionosphere and with the aid of classical magneto-ionic theory for quiescent and disturbed propagation conditions. The complex indices of refraction of the medium were deduced and a coupling in the plasma between ordinary and extraordinary, upgoing and downgoing modes of propagation investigated. The corresponding reflection and transmission coefficients were then calculated and certain phenomena predicted as the expected results of a solar disturbance on the reflection process. The average electron-ion collision frequencies of the classical magneto-ionic theory were modified to introduce electron collisions with a linear Maxwellian energy distribution dependence. Although some interesting changes of detail in the reflection coefficients were obtained, in general the application of the continuously stratified layer concept to models of the ionosphere having such electron collisions does not drastically change the coefficients.

The rigorous mathematical treatment for the propagation of a radio wave from a Hertz dipole source current moment around a finitely conducting spherical earth surrounded by a concentric electron-ion plasma can be expressed as a series of zonal harmonics. Such a solution to the problem was previously obtained for the terrestrial sphere without a concentric plasma, but the summation of the series was then considered to be impractical and the Watson transformation was introduced. A new numerical technique was developed at the Bureau whereby the field of the propagated radio wave less than 50 kc/s can be evaluated by a summation of a series of zonal harmonics. The speed with which the terms can be summed on an electronic computer makes it feasible to use the summation technique, despite the large number of terms, instead of the Watson transformation. The structure of the field in the absence of a concentric plasma is characterized by the quite regular behavior of the ground wave as a function of distance. The steady decrement of the ground wave field is modified only near the antipode, at which a standing wave pattern which is a function of distance is created where waves circling the sphere in different directions meet. The concentric electron-ion plasma shell traps the waves heading out into space and reflection from the plasma augments traveling waves at increased distances from the transmitter. Thus, the series of zonal harmonics is comprised of individual waves traveling in the radial direction



Receiving stations at opposite ends of a magnetic line of force can often observe the same geophysical event simultaneously. Many such events were recorded at the conjugate stations of Le Relais, Canada, and Eights (Sky-Hi), Antarctica. The information contributed to a better understanding of the behavior of energetic particles and their effect on the earth's ionosphere, and the mechanisms of the production and propagation of VLF emissions. **(See p. 148.)**

with respect to the center of the sphere and standing in the direction of increased angular distance around the sphere, building up in the direction of increased angular distance. Under special circumstances, standing waves can be noted, especially near the antipode of the transmitter.

Experimental Ionospheric Propagation. The continuing program using the Loran-C navigation system (100 kc/s) in propagation studies has revealed that some solar flares produce a phase advance in the first-hop sky wave, corresponding to a lowering of the *D*-region, while other flares produce a phase retardation, and still other flares cause little if any change. Usually an increase in signal amplitude accompanies the phase advances, while either an increase or a decrease in amplitude may be associated with the retardations. A sparsely ionized begion below the *D*-layer could contribute significant attenuation with virtually no influence on the phase, while somewhat greater ionization would affect the phase. The measurements tend to confirm that such a sparsely ionized region below the *D*-layer does exist, and that some sort of particle bombardment is responsible for the ionization in this region. since amplitudes have been related to magnetic latitude.

High-frequency propagation studies have been carried on in behalf of the Department of Defense Advanced Research Projects Agency. Measure-

ment of wave-phase-path changes, wave-group path time delays, and relative absorption of continuous wave (cw) signals reflected from the ionosphere at near vertical incidence have been made to determine the short-term behavior of the natural ionosphere in relation to limitations in detection of nuclear explosions at long ranges. Both short- and long-term variations are being measured in an effort to determine sporadic and cyclic effects. Observations of solar flare events indicate that phase path change is much greater at 4 Mc/s than at 2 Mc/s, abnormal rates of phase change occur from a fraction of a minute to several minutes after time of visual observation, and the magnitude of phase change has not shown a relation to the visual importance of the flare. This program is being expanded to study short-term phase changes occurring on HF oblique paths.

A study is being conducted for the U.S. Navy Bureau of Ships to obtain information on sun-earth relationships and ionospheric variations to improve predictions of HF circuit performance. Special problems studied were the inclusion of the sporadic-*E* mode in prediction computation, worldwide patterns of f_0F_2 variation and repeatability, and backscatter techniques for monitoring ionospheric conditions.

A comprehensive HF propagation study was undertaken for the Rome Air Development Center to obtain information on ionospheric irregularities and their effect upon signals propagated over long distances. Observations of the time variation in phase, range, and angle of arrival are being made on both backscattered and forward propagated signals. A direction-finding array of 25 log periodic antennas covering the range of 12 to 25 Mc/s was recently put into operation, using a beam-scanning rate of 500 per second to observe azimuthal variations of signal arrival. Another scanning array is under construction to provide data on the variation in vertical angle of arrival.

The study of VHF signals scattered from the *D*-region was continued. Analyses of fade duration at different thresholds of scattering loss at five frequencies gave characteristic wave length dependencies of speed and duration of fading. Little difference was found in diurnal curves of signal intensity obtained in 1958 and in 1961. This is another confirmation that sunspots have negligible control of scatter signals. Observation of the azimuthal variation of angle of arrival of the scatter signal began, utilizing a VHF scanning array. Cumulative distributions of the signals received at various angles of arrival differ greatly from a Rayleigh distribution, however, and indicate that the system noise level is so great that the data obtained so far are due principally to reflections from bursts.

A program for investigating the characteristics of HF signals propagated through the exosphere along the earth's magnetic field lines was continued. Around-the-world echoes were observed on numerous occasions. Signals which could be ducted exospheric echoes, or other than around-the-world echoes were small in number and very low in amplitude when observed.

Surplus radar equipment from the Ballistic Missile Early Warning System was obtained to serve as a nucleus of a 5-megawatt transmitter to be built

as a basic ionospheric and propagation research tool. One possible future application is for solar radar research. Further planning for construction of the transmitter is underway.

Installation of equipment to make infrasonic observations at Boulder was begun. Observation of the low frequency atmospheric pressure variations, made in conjunction with a similar station operated in the Washington, D.C., laboratories, will be correlated with other investigations of ionospheric characteristics.

Antenna Research. The principles of electronic scanning previously developed were adapted for long range ionospheric radar study to an array of 25 planar type log-periodic dipole antennas. The broadside array is operable over a frequency range of 12 to 25 Mc/s; its beamwidths vary from 3° at 12 Mc/s to 1½° at 25 Mc/s, and its azimuthal scan sectors vary from 90° at 12 Mc/s to 40° at 25 Mc/s. A method of vertical scanning to determine the elevation angle of arriving signals is in process of development. The vertical scanning system will use 10 planar log-periodic dipole antennas mounted 16 meters apart on a 500-foot supporting tower. The vertical scan will extend from 0 to 51° at an operating frequency of 12 Mc/s and from 0 to 22° at 25 Mc/s.

Studies are being conducted to provide an antenna with a relatively narrow beam which can be steered through 360° in azimuth. A receiving array of this type, made up of concentric circles of elements with close spacing between elements, was developed under Air Force sponsorship for air/ground communication applications. The load on amplifiers resulting from varying mutual impedances between closed-spaced elements of the array would cause problems during steering in a transmitting array. Large element spacings in a lattice array, with phasings departing from "co-phasal" just enough to suppress the secondary lobes, are being considered to overcome the variations in load. Separate RF power amplifiers driven by a central driver stage could be used at each element of the array to minimize the problems inherent with high voltage and high power transmitters.

Gain contours for rhombic antennas can be plotted directly by use of programs written for the electronic computer. Contours of constant gain for elevation and azimuthal angles and elevation angle as a function of frequency can be obtained directly from the computer printer. Programs are also available for plotting the radiation patterns in any plane.

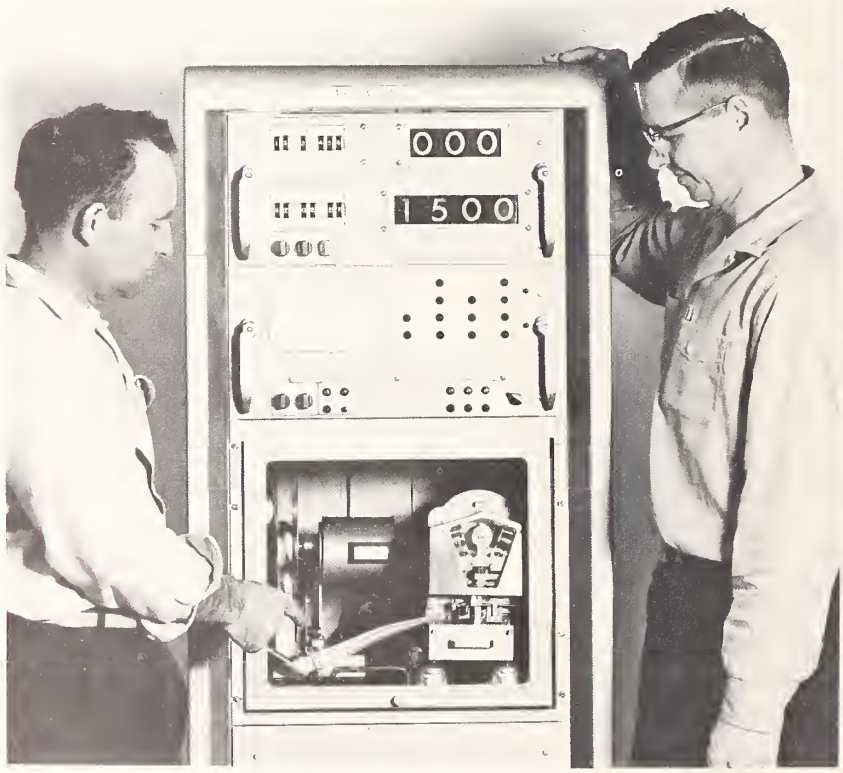
A study is being conducted on techniques and methods of measuring radio-frequency fields under practical conditions. An aperture-synthesis method developed for measuring amplitude, direction of arrival, polarization, and relative phase of multipath components of a complex field is now being tested. Field strength meters are being examined to determine their adequacy for both cw and pulse measurements.

Modulation Research. Theoretical element error rates in multiple-frequency-shift keying systems were calculated. Symbol error rate in frequency-shift keying systems and the signal-to-noise figures of frequency modulation and pulse code modulation frequency shift systems were studied

for wide ranges of system parameters. A continuing analysis is being made of the advantages and capabilities of error-detecting and error-correcting digital codes when used in radio links that are subject to signal fading and interference. It was found that for certain shifting of bits within a cyclic code word the linear encoding matrix is invariant and that certain error-correcting patterns are more effective than others. Calculations were made which show the effectiveness of a number of Bose-Chaudhuri-Hocquenghen codes for realistic conditions of atmospheric noise interference and Rayleigh signal fading. Instrumentation was partially completed on a large, flexible, digital encoding-decoding system for studying error rates and distributions and their relationship to noise and fading of digital HF signals.

A program was initiated to determine experimentally the optimum parameters of a LF digital communication circuit which will provide extremely reliable, low-error-rate long-distance communication under all ionospheric conditions. Investigations of effective methods of reducing the interference of atmospheric noise in VLF communication systems were continued.

An investigation is now in progress to determine the maximum information rate at 10 Gc/s of signals between a space vehicle and the earth at low elevation angles. The maximum information or bandwidth will be determined



A digital recorder of the data output from night airglow photometers has reduced the time necessary for processing of the data through the high-speed computer. **(See p. 150.)**

by multipath propagation effects of the atmosphere, since the ionosphere has negligible effect on propagation at this frequency. Propagation information applicable to space vehicle-to-earth links will be obtained by operation of an experimental system now nearing completion. It consists of equipment to transmit nanosecond pulses from a mountaintop to lower receiving sites, at which the arrival times of the short pulses will differ for different transmission paths.

A study of the psychological aspects of visual perception was made in cooperation with the University of Colorado Medical Center to determine how patterns of visual perception can be used in reducing television bandwidth requirements. Tests on the five cognitive styles involved in visual perception studied verified that the styles do not involve value judgments and are not independent of one another. The results of this program can be very significant in evaluating television bandwith reduction tests.

Upper Atmosphere and Space Physics

The research program in upper atmosphere and space physics made notable progress during the past year, using three very different experimental approaches: Ground-based geophysical observations, satellites, and experiments conducted in the laboratory. All three approaches are valuable and necessary in the continuing search for new knowledge and understanding of the physical properties of and processes in the media surrounding the earth and in interplanetary space. Such knowledge and understanding are essential to the expanding application of radio communications in the space age and to inform man of his environment in space.

Jicamarca Radio Observatory. The Jicamarca Radio Observatory, located close to the magnetic equator near Lima, Peru, was completed after a major construction effort over the past two years. The transmitter was successfully tested for reliability; results from the antenna tests exceeded expectations for gain and sidelobe configuration. Measurements of the intensity of the incoherent scatter are in excellent agreement with predictions based on the theory of incoherent scatter of radio waves from free electrons. This achievement marks one of the first known times when precise findings from a plasma experiment agree with theory, thus providing a firmer basis for continuing experiments.

This powerful and sensitive research facility achieved some notable new observations during the past year. Measurements of electron density were made to a height of 7000 kilometers and prospects are favorable for extending measurements to greater heights. Also of significance is the fact that direct measurements were made of diffraction due to spread-*F* irregularities in the *F*-region. Radio star signals observed were spread over a 5° to 10° beam width, providing a definite explanation for radio star and satellite signal fadeout in the equatorial regions.

Cylindrical Shock Waves from Exploding Wires. A series of experiments in plasma physics is being performed in an attempt to duplicate in

the laboratory the phenomena occurring when bursts of plasma enter and perturb the media surrounding the earth. The radio properties of similar perturbations can be studied in detail in the laboratory by controlled and reproducible experiments using diagnostic techniques.

Shock waves from exploding wires are used to produce a dense, highly ionized plasma in a current series of experiments. The velocity of the ionization front is measured by a microwave Doppler technique at pressures ranging down to 1/100 atmosphere. The energy in the shock wave, determined from the velocity measurements, can consist under optimum conditions of nearly half of the energy available from the capacitor bank. Unexpected ionization far in advance of the shock front has been detected and studied. Hydromagnetic interactions have been observed between the expanding shock front and a strong magnetic field parallel to the wire axis.

Study on Radiation Hazard in Space Completed. An understanding of the variation with time of the energy spectrum of solar cosmic rays near the earth is essential for estimating radiation hazards in nearby space. A study based on the results of continuous radio observations of the effect of solar cosmic radiation on the very low ionosphere at high latitudes was completed and published. These observations were combined with the direct determinations of the solar cosmic-ray fluxes and energy spectra made with balloons, rockets, and satellites during the past three years. This investigation indicates that solar cosmic radiation near the earth is not the severe hazard predicted by earlier estimates. Such studies have a significant impact on the design of the radiation shielding used in spacecraft.

Studies Conducted on Gaseous Electronic Processes. During the past year the ability to calculate electron energy distribution functions in air in the presence of electric and magnetic fields was steadily improved to permit application under wider ranges of experimental conditions. As a result a number of researches were undertaken which would not otherwise have been possible. The conditions controlling stimulation of optical emissions from the atmosphere in the presence of high-power-density radar beams were calculated for a number of wave lengths. Recent studies also considered the point at which atmospheric breakdown can occur.

The theoretical studies of the behavior of the atmosphere in a high-density radio field was the basis for two investigations of d-c electric fields in the atmosphere, being carried out in collaboration with scientists from other laboratories. In addition this work was part of the motivation for starting a gaseous electronics laboratory, the experimental data from which will be interpreted with the aid of the theory which has been developed here.

Geophysical Studies Conducted at Conjugate Points. It is well known that auroral disturbances occur at high latitudes in both hemispheres, but detailed, quantitative information on the degree of correlation between events occurring simultaneously in the two hemispheres is almost completely lacking. This information would be of considerable importance in auroral theory, particularly when referred to events occurring at opposite ends of

a magnetic field line. For this reason a pilot study was set up during the 1961–62 Antarctic summer.

A temporary station was established in a previously unvisited region of Antarctica and three similar stations, one at the conjugate point and the other two 80 km north and south of it, were set up near Quebec, Canada. Magnetometers, ionosondes, riometers, and VLF-receiving equipment were used at the Antarctic and the central Quebec stations; riometers and magnetometers were used at the two outlying Quebec stations.

Although analysis of the data obtained in the eight weeks of simultaneous measurements in the two hemispheres is taking place at present, it is possible to make some clear statements now about the correlation observed between geophysical phenomena occurring simultaneously at both ends of the 60 degree geomagnetic field line (L value=4.0). Excellent and detailed correlation was observed on many occasions between riometer and magnetometer data obtained at the points in the two hemispheres, separated by 14,000 km along the earth's surface and 55,000 km along the field line. At times the

Balloon-borne spectrometer used to measure the composition of the atmosphere by means of its infrared absorption spectrum. The sun serves as the infrared source.

correlation between the data at the conjugate stations was better than between the two outlying Quebec stations, separated by the 160 km.

One unexpected result was that the riometer absorption at the northern end is typically twice as great as at the Antarctic station, despite the fact that both the mirror height for energetic particles and the solar zenith angle are lower for the Antarctic station. Information obtained on the size and shape of the conjugate areas suggests that the northern one is not fixed, but tends to move toward the equator as the magnetic activity increases. In addition, the observation of many VLF events at both conjugate points contributed to an improved understanding of VLF emissions, the mechanisms of their production and propagation, and their relationship with subsequent absorption events. The initial results of the short-term experiment, analysis of which is still proceeding, are sufficiently exciting to warrant a year-round study at conjugate locations during 1963 and 1964. This work was in large part supported by the National Science Foundation.

High-Speed Camera Developed for Plasma Physics Research. A high-speed framing-type camera was perfected for use in conjunction with experiments in laboratory plasma physics. The original design of a camera developed at the Aberdeen Proving Grounds was modified and improved to enable the camera to be used for streak photographs, stroboscopic effect photographs, and single-exposure photographs. The precision and flexibility of this laboratory instrument permit diagnostic analysis of the behavior and characteristics of the luminosity front in a strong shock wave. These studies are basic to understanding of shock wave effects in a hot plasma and the mechanisms leading to the generation of radiofrequency radiation by a plasma.

Satellite Radio Signals Used to Study Structure of Ionosphere. Radio waves received at the earth from a vehicle in space are frequently perturbed by irregularities in the electron density of the ionosphere. Observation of variations in the polarization of the radio wave provide a particularly sensitive measurement of large-scale irregularities which have dimensions of 50 to 300 km. Recordings were obtained of satellite radio signals received simultaneously at three separate field sites, selected at spacings of 30 to 100 km and in both triangular and straight-line configurations. Information concerning magnetic alinement, height, location, and shape of the large scale ionospheric irregularities is expected to result from these records.

The spaced-station technique permits the observation of ionosphere structure irregularities in electron density along the track of a satellite. The three-dimensional structure of these irregularities is not revealed by conventional techniques of resolution of radio signals from either above or below the ionosphere. The "strip photographs" obtained should show, when compared and analyzed, the large-scale internal irregularities within the ionospheric layers. This work is supported by the National Aeronautics and Space Administration.

New Digital Recorder Speeds Analysis of Airglow Observations. During the past year the flow of new airglow observation data increased sub-

stantially, largely as a result of the successful operation of the observatory on Mount Haleakala, Maui, Hawaii in collaboration with the University of Hawaii. Particular interest in the red line (6300 A) airglow intensities encouraged development of an efficient method for observing and recording airglow data automatically. A digital punched-paper-tape recorder was designed, constructed in the instrumentation laboratory, and placed in service at the Fritz Peak Observatory near Boulder to record the data output from airglow photometers. Its use substantially reduced the time required to process the raw data through a high-speed computer to prepare it for analysis.

The finished recorder can record and visually indicate the intensity of the airglow, the orientation of the photometer, and the time of the observations. Such auxiliary data as the observing station designation, filter color, photometer sensitivity, and date are also recorded. Measurements of airglow intensity can be made at rates up to 17 per second and are recorded at an accuracy of one percent. In normal operation a survey of the whole sky, consisting of 2160 measurements of intensity, is made each five minutes.

Atmospheric Spectroscopy. The constituents of the atmosphere are being determined in a continuing study, using the services of the Consultant in Physics of the Atmosphere, of radiation transfer, transmission, and spectroscopic measurements of atmospheric absorption and emission. A promising technique uses a balloon-borne, far-infrared spectrometer kept constantly aimed at the sun, used as light source, by a "sun-seeker." It is hoped that this technique will produce concentration measurements of carbon dioxide, ozone, methane, heavy water, and other constituents of the troposphere and lower stratosphere.

Spectrometer measurements of the OH emission of the night sky have also been made with a specially designed Ebert instrument, permitting extremely fine spectral resolution.

Cosmic Noise Study Completed at USSR Mirnyy Base, Antarctica. A cosmic noise absorption experiment conducted by an American scientist attached to the USSR Antarctic Base, Mirnyy as part of the cultural exchange program has been completed. This work provided the first systematic data on anomalous ionospheric absorption recorded within the southern auroral zone. The data were compared with similar data obtained from Spitsbergen which is near the magnetic conjugate to Mirnyy. Since there is a wide variation in the solar zenith angle difference between the two stations in the course of a year, it has been possible to make quantitative measurements of the strong solar zenith-angle control of the ionospheric absorption during polar cap events. Funds for the conduct of this program were supplied by the National Science Foundation.

2.3.5. CRYOGENIC ENGINEERING

The Bureau's activities in cryogenic engineering, a rapidly growing specialized field, center at the Boulder Laboratories. The Bureau provides information needed for practical applications of materials, systems, and

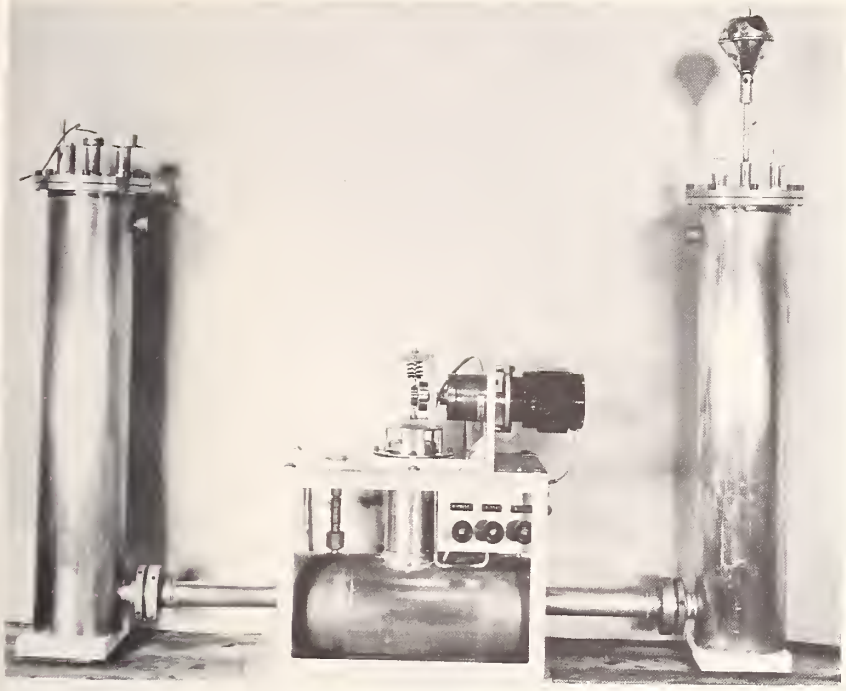
techniques at very low temperatures, and assists Government and industry with problems arising in this field.

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

Properties of Parahydrogen. The most advanced chemical and nuclear rockets utilize hydrogen as a fuel and as a propellant fluid, respectively. Data on the thermodynamic and transport properties of hydrogen now need to be known with higher accuracy and over wider ranges of temperature and pressure than have been necessary before. With the support of the National Aeronautics and Space Administration and the Air Research & Development Command, the Bureau has been engaged in an extensive program to determine these properties. In the past year, in response to urgent demands, provisional tables and charts of the thermodynamic functions of parahydrogen were prepared and published. These were based on pressure-volume-temperature measurements recently made by the Bureau. Measurements of the specific heat were completed while refinement of the calculations of thermodynamic functions and experimental measurements of viscosity, thermal conductivity, sonic velocity, and dielectric constant remain to be completed.

Phase Transformations in Steels. Austenitic stainless steels are widely used in cryogenic equipment because of their toughness at low temperatures. Certain of these steels transform partially to martensite on cooling or during plastic deformation. This has been a cause for concern, as the martensite phase is brittle. However, extensive experimentation, carried out under sponsorship of the Advanced Research Projects Agency, has shown that the austenite-martensite matrix produced on cooling the alloys in question is generally well-behaved as a structural material, although minor anomalies, found at temperatures below 100 °K, are attributable to the transformation. A recently discovered new phase having hexagonal crystal structure has been shown by X-ray techniques to be present in surprisingly large proportions (up to 35 percent) at intermediate stages of plastic deformation. Mechanisms were deduced for the austenite-martensite transformation via the hexagonal phase as an intermediate structure.

Physical Equilibria. A major problem in liquefaction and refrigeration processes is to eliminate the collection of frozen impurities in low-temperature heat exchangers through adequate purification. Research in physical equilibria is necessary to establish accurate design criteria for impurity removal. In addition, physical-equilibria research yields information on the



Instrument for measuring densities of flowing cryogenic fluids. The development of new measuring techniques and devices is essential to the rapidly expanding cryogenic field. (See p. 154.)

nature of forces between molecules of different species that is vital to understanding mixtures and solutions. Experimental studies were conducted in the areas of pure component and impurity adsorption. Second virial coefficients for several fluids of cryogenic interest have been calculated. In addition, the vapor pressures of nitrogen, oxygen, hydrogen, methane, and ethylene have been calculated to temperatures well below the normal boiling point.

Cold Neutron Moderator. In certain types of solid-state physics investigations it is desirable to have available an intense beam of low-energy neutrons. This may be accomplished by extracting a neutron beam from a moderator, maintained near 20 °K, located close to a nuclear reactor core. The thermalization of neutrons liberates energy within the moderator that must be removed by a cryogenic refrigeration system. A preliminary study of feasible refrigeration systems was made under the joint sponsorship of the Argonne National Laboratory and the NBS reactor group. Two basic refrigeration processes are considered applicable. The first is a conventional Joule-Thomson hydrogen refrigerator coupled to a cold helium gas loop for in-pile service; the second utilizes an expansion engine in an all-helium-gas refrigerator circuit. A further study was performed relating to the final design, acquisition, assembly, and installation of a refrigerated cold moderator system.

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Magnet Research. Problems associated with the production of high-intensity magnetic fields by means of low-temperature, normally-conducting, solenoids are being investigated. The results of these investigations are expected to be useful for thermonuclear power reactors, particle accelerators, and other applications where large volumes of high-intensity fields are required. A liquid hydrogen cooled, high-purity aluminum-foil magnet has been built and is operational. This magnet, designed to produce a steady-state field of 100,000 gauss in a cylindrical volume 3 inches in diameter by 8 inches long, is being evaluated while it is being used as a research tool, the maximum field depending upon the research needs. To date, the maximum field produced is 70,000 gauss. Measurements of the effects of temperature, strain, purity, and magnetic-field intensity on the electrical resistivity of aluminum are being made. The results are most important to progress in this area, and will permit the optimization of these types of solenoids.

A high-energy power supply (130,000 joules) for pulsed magnets has been designed and built and is being used for research on superconducting materials. It is also to be used in the development of very high field intensity, low-temperature pulsed solenoids with long time constants.

Instrumentation and Cryogenic Equipment. The growing use of cryogenic fluids in general, and liquid hydrogen in particular, necessitates research into measurement problems and into considerations which limit ability to design and predict the behavior of equipment. Investigations concerned with the characteristics of pressure transducers down to 20 °K have been completed. Both theoretical and experimental work on the dynamic characteristics of temperature sensors has been undertaken; one piece of experimental apparatus has been completed and data are being accumulated and analyzed. A cryogenic prototype for measuring the density of flowing cryogenic (and normal-temperature) fluids has been built and evaluated. The tests indicate that the densitometer performs satisfactorily with both single- and two-phase fluids; however, due to the low density of hydrogen, some modifications may be necessary to obtain the desired accuracy with that fluid. An experimental program to determine all of the information necessary for the design of carbon resistance liquid level instrumentation is almost complete. An apparatus for the evaluation of hydrogen liquid level instrumentation has been designed, and is being fabricated.

A program, undertaken with the Air Force, NASA, and the AEC, to develop standardized liquid hydrogen couplings, is in the active testing and evaluation phase. Two units have been designed and built, and are ready to be evaluated in the test apparatus which is now operating. More advanced designs have been completed and will be fabricated in the near future.

Cryopumping. The most promising method for achieving the low pressures found in outer space and for obtaining the pumping speeds required for space simulation is cryopumping, the freezing and adsorption of gases on cold surfaces. Investigations oriented towards the evaluation of cryopumps as vacuum pumps have been pursued. Pumping speeds and capture coefficients of readily definable cryopump configurations have been

measured. The data indicate that pumping speeds greater than theoretical can be achieved. To date, data have been accumulated and analyzed for CO_2 and N_2 on surfaces at 77 °K and 20 °K.

Heat Transfer. As heat transfer must be controlled and/or predicted in most cryogenic systems, there are numerous problems in this area which must be investigated. A current study is concerned with heat transfer between the atmosphere and surfaces at low temperatures (20 to 90 °K). The experimental apparatus for conducting this investigation has been perfected and information is being accumulated and analyzed. The ranges of the atmospheric parameters are: wind velocity, 5 to 60 mph; temperature, 40 to 100 °F; and specific humidity, 17 to 325 grains per pound. Tests with a horizontal cylindrical surface at 77 °K have been completed. Information on heat transfer mechanisms, the mechanism of frost formation, and frost conductivity has been obtained. A most interesting result is that the condensation which takes place in the boundary layer, but which does not contribute to the frost layer on the surface, has an important effect on the heat transfer; it is expected that the theoretical analysis being done on frost formation will quantitatively predict this effect.

Two-Phase Fluid Phenomena and Fluid Flow. Because the fluids in cryogenic systems are usually close to saturation, the simultaneous existence of both liquid and vapor phases together (two-phase fluids) is common. A fundamental understanding of the behavior of these systems therefore requires basic knowledge of two-phase fluid phenomena. To contribute to

Miniature high-speed turbine expander is a vital component in a cryogenic refrigeration system. The turbine rotates at speeds up to 9000 revolutions per second. The shaft is supported by hydrostatic helium gas-lubricated bearings. **(See p. 156.)**

such understanding, choked flows of two-phase fluids are being investigated theoretically and experimentally, basic work concerned with cavitation is being pursued, and an investigation of the behavior of cryogenic systems during cooldown is well under way.

Work on the bulk density of boiling liquid oxygen is essentially completed. This work was stimulated by needs in the rocket propulsion programs—what weight and what volume of propellant are aboard a vehicle at any time during loading? Preliminary computations based upon the theoretical analysis compares favorably with the experimental results. Experimental work will be extended to liquid hydrogen to determine the predictive accuracy of the theory for this fluid.

A project concerned with the cooling of cryogenic liquids by the injection of a noncondensible gas has been completed. The results of this investigation are extremely important to our space effort because gas injection is one of the most effective techniques for achieving the cooling necessary for the reliable starting of large rocket propulsion systems. The experimental results which were obtained with liquid hydrogen, using helium as the injection gas, agree extremely well with the predictions of the theoretical analysis.

Refrigeration Processes. The development of methods for providing refrigeration in the cryogenic temperature range is of considerable importance in present-day military, industrial, and research programs. With the partial support of the Atomic Energy Commission, the Bureau has conducted a theoretical study of feasible cycles adaptable to the temperature region 1.5 to 30 °K and a consideration of components necessary to provide a reliable, maintenance-free refrigeration unit.

A vital component of refrigeration systems is the expansion engine needed to produce the required refrigeration. Considerable progress has been made on the development of a miniature high-speed turbine expander supported by hydrostatic helium gas-lubricated bearings. The turbine is 0.3116 inch in diameter and rotates at speeds up to 9,000 revolutions per second. Successful tests have been performed on a system which provides 200 watts of refrigeration at 21 to 30 °K and 8 watts 4.2 °K.

Computational work, with the aid of a digital computer, is being performed on the analysis of refrigeration systems applicable to a particular task. This work has centered on the compilation, correlation, and tabulation of the properties of helium, hydrogen, nitrogen, and neon gas.

Consultation and Advisory Services. The Bureau is providing consultation and advisory services of a cryogenic engineering nature in several areas. The broad accumulated experience of NBS personnel is being utilized by commercial contractors to government agencies in the design of equipment and in the handling of cryogenic fluids.

Assistance is being given to Projects Centaur, Rover, and NERVA under the sponsorship of the National Aeronautics and Space Administration. The Centaur is the first space vehicle to use liquid hydrogen as a propellant. The nuclear engine development programs, Rover and NERVA, are now using,

and are planning more extensive use of. liquid hydrogen. The physical properties of hydrogen are sufficiently different from other propellants to present many new problems to the industry. Support has been given to the principal contractors on these programs in the areas of ground support equipment, insulation, low-temperature seals, and rolling element bearings. In addition, an investigation was started on solid formation in cryogenic propellants.

Facilities and operating staff were provided to test a zero-gravity centrifugal liquid-vapor separator for a government contractor, Beechcraft Research and Development. The separator, designed by General Dynamics/ Astronautics as part of the Centaur program, was operated at exhaust pressures of 1 to 3 pounds per square inch absolute. NBS has the only known facility which can conveniently pump the turbine exhaust to such a low absolute pressure.

Under the sponsorship of the Bureau of Naval Weapons, assistance was given to establish equipment and techniques for producing, transporting, storing, and handling large quantities of liquid helium. As a consequence, large shipments of helium may be transported, in liquid form, at a greatly reduced freight rate compared to compressed gas transport. Technical guidance was given in the development of a portable helium liquifier with a capacity of 65 liters per hour, an 850-liter liquid-helium transport container, and a 722,000-standard-cubic-foot capacity (7700 gallons) helium transport container.

A study was performed relating to the storage and distribution of liquid nitrogen from different sites of the University of California Lawrence Radiation Laboratory. On the basis of facts accumulated during the engineering evaluation, recommendations were made leading to more efficient use.

The Bureau is providing consultation and advisory services to the Air Force Cambridge Research Laboratory in connection with the cryogenic problems encountered in the development of a cryogenic "whole air" sampler. The sampler, which is carried by rockets into the upper atmosphere, uses liquid hydrogen to condense the sample of atmosphere which is collected, and will provide a means for sampling the atmosphere which promises to be much more effective than equipment currently in use.

Low-Temperature Seals. There are numerous applications in industrial and research activities for seals which must operate successfully at all temperatures from ambient to cryogenic. A study of elastomeric seals for these applications, sponsored by the Aeronautical Systems Division of the U.S. Air Force, has progressed from the initial development and functional testing to a more analytical and fundamental program. Several pertinent physical properties of elastomeric polymers, such as thermal expansion, resilience, and force-temperature relationships, as well as seal performance under standardized conditions, are being measured. These measurements will provide data which will aid in predicting seal effectiveness. The mechanical behavior of plastics and elastomers, which are derived from chain polymers, is in itself a subject of great fundamental interest.

Cryogenic Materials Data Handbook. Under Air Force sponsorship, a handbook consisting of 800 loose-leaf pages in two volumes has been completed. The handbook presents mechanical and physical properties data on about fifty structural materials, mostly alloys but including a few plastics. Some of the data were compiled from the literature, but a large part resulted from new experimental measurements by the Bureau. The original goal was to make possible improved reliability of missile-control components through making available more extensive and accurate design data. However, the handbook should prove to be generally useful in low-temperature technology. The Air Force has arranged to make it available through the Office of Technical Services, U.S. Department of Commerce.

Cryogenic Engineering Literature. The Cryogenic Data Center maintains a centralized activity for the procurement, distribution, storage, and retrieval of world literature of cryogenic interest and the preparation of bibliographies for both the Bureau staff and the cryogenic industry. Nearly 2,000 documents were procured for projects during the last year; over half of these documents were not previously recorded and were therefore added to the bibliography system. More than 1,000 additional citations were also added to the system as a result of systematic searching of current journals and abstract bulletins. This search for citations was restricted to literature concerning "properties of fluids" and "properties of solids" in order to be able to provide a comprehensive coverage of these categories. Over 16,000 items, including reprints, reports, and thermodynamic charts, have been distributed to the cryogenic industry during this past year.

More than 5,000 listings of properties of fluids and solids are now coded on magnetic tape for automated bibliography searching. A computer program using the CDC 1604 digital computer has been developed that will process as many as 99 requests for selected bibliographies in one pass of this search tape. Considerable progress has also been made in converting the bibliography citations to an eight-channel flexowriter tape. These tapes are currently being used for assembly of bibliographies and will later be printed out as a *Catalog of References.* Ultimately they will be transferred to magnetic tape for automatic printing of bibliographies.

Compilation of Thermophysical Property Data. The Cryogenic Data Center has accelerated the collection and evaluation of thermophysical property data from the scientific literature, with the emphasis on the evaluation and the selection of "best values." These data are compiled for a wide range of temperature and pressure in tables and charts of property values in a form convenient to the engineer and scientist engaged in the design of cryogenic systems.

During the year, considerable progress has been made in the compilation and evaluation of the thermodynamic property data for several cryogenic fluids. A compilation of the thermodynamic properties of helium has been published; a compilation of P-V-T values of neon extending the range of values to higher pressures and lower temperatures by the "theory of corresponding states" has been completed for publication; and considerable prog-

Helium transport container with a capacity of 7,700 gallons. With this container, large shipments of helium, in liquid form, are possible at a reduced freight rate compared to compressed gas transport. Development of the container by a private firm was supervised by NBS. **(See p. 157.)**

ress has been made in the evaluation of the data for argon, oxygen, and carbon monoxide. A compilation of the surface tension data for the cryogenic liquids is essentially complete and additional property compilations for cryogenic materials, such as surface tension, dielectric constant, thermal conductivity, viscosity, and Prandtl number, are in progress. A series of graphs of the thermodynamic properties of parahydrogen has been constructed for the new data from the Bureau project on hydrogen properties. Bibliographies of the literature on these subjects have been compiled and copies of the pertinent literaure obtained. A comprehensive bibliography on the properties of oxygen has been published, and bibliographies on the properties of fluorine and on the two-phase properties of the cryogenic fluids have been undertaken.

In all of these studies, use is made of the large digital computer for the many calculations made in the evaluation of data. Considerable effort is also given to theoretical considerations and mathematical analysis techniques. Procedures for producing extensive and comprehensive graphs of properties have also been instituted to assure accurate representation of the data on charts particularly useful in cryogenic systems design.

Liquefaction of Gases. Until liquid helium became commercially available in the spring of 1962, the CEL helium liquefier was operated and over 3500 liters of liquid helium were produced this year for NBS projects and for several research laboratories throughout the country. Liquefied gases purchased for distribution during the year included 52,000 liters of liquid hydrogen, 410,000 liters of liquid nitrogen, and 100 liters of liquid helium. Purified gases handled included 215,000 scf of hydrogen gas recovered from liquid evaporation, 100,000 scf of nitrogen gas produced in CEL facilities, and 180,000 scf of helium gas which was purchased and included 107,000 scf used for liquid helium production. Liquefied and

pure gases were also distributed to 19 laboratories outside of NBS which had no other convenient source of supply; this included the liquid helium and purified hydrogen and nitrogen gas produced in NBS facilities and a small amount of liquid hydrogen, liquid nitrogen, and gaseous helium to a few others in the vicinity of the NBS Boulder Laboratories.

2.3.6. BUILDING RESEARCH

An objective of the building research program is the development of new knowledge through chemistry, physics, and engineering research to solve problems related to building materials, structures, equipment, and facilities. Another objective is the development of measurement and test methods so that such knowledge may be used by the building industry. In one part of the program, assistance is given to other laboratories by devising techniques for accurate measurements, by developing and supplying calibrated laboratory reference standards, and by participating in interlaboratory programs for checking measurement precision. The program also provides for advisory services to government agencies on building problems, and to public and private organizations on the formulation of specifications and national standards affecting the building industry.

During the year, experimental data were obtained for developing and improving building codes, standards for materials, and methods of testing materials and building equipment. Other typical work dealt with the shear strength of concrete beams, and the effect of the properties of the mortar on the strength of masonry walls.

Studies were made of a family-size underground fallout shelter to obtain engineering data on environmental factors that affect shelter habitability. Methods of predicting the performance of building materials when exposed to the weather were continued with emphasis on asphalt roofing materials, plastics, and porcelain enameled steel.

Investigations were continued on methods of retarding and extinguishing fires, ranging from experimental studies of the effects of variations in the composition of gypsum plaster to studies of the possibility that ionic processes are important in fire extinguishment. Progress was made in developing both standard methods for measuring thermal conductivity and the reference materials to be used with these methods.

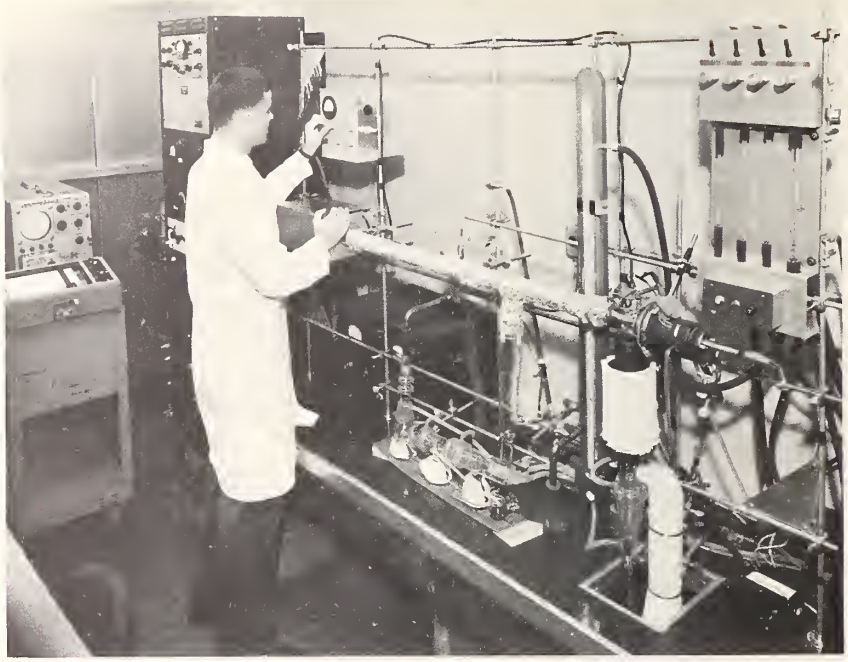
Shear Strength of Concrete Beams Studied. It is known that the resistance to shear of reinforced concrete beams depends to a great extent on the level of stress in the longitudinal reinforcement. In order to formulate satisfactory design criteria for beams in which the stresses in the reinforcement are at various levels, a series of beams made without web reinforcement and designed to fail in shear were tested; both the ratio of shear span to beam depth and the ratio of reinforcement were varied. In beams with the same shear span to depth ratio, the shear stresses at diagonal tension cracking decreased roughly linearly as the stresses in the reinforcement increased. An empirical formula was developed that predicts the shear

strengths of beams with highly stressed reinforcement with greater accuracy than does the formula currently in use.

Effect of Mortar Properties on Strength of Masonry. A comprehensive study of the structural properties of masonry walls constructed with mortars made from different types of cementing materials was sponsored by the National Research Council—National Academy of Sciences. The compressive, flexural, and racking strengths of specimens of full-scale walls were determined for masonry of hollow concrete unit construction, and for masonry of composite construction. The compressive strength of the walls increased, in general, with the compressive strength of the mortar. The racking and flexural strengths of the walls increased with the bond strength, as determined with a test specimen developed to measure the bond between the masonry mortars and masonry units. The data provide information not previously available on the effect of properties of mortars on the structural properties of masonry.

Instrumentation for Fire Extinguishment Studies. A study of about 25 fire-extinguishing agents indicated that a general property of such agents is their tendency for attaching electrons. This observation suggested that an ionic process may be important in the mechanism of extinguishment. Hence, a new type of time-of-flight mass spectrometer was built to study the reactions involved. In this instrument, the ions to be analyzed are sent with equal initial energy through a field-free drift tube. A radio-frequency (RF) voltage is applied at the ends of the drift tube so that the electric field at the entrance is negative to that at the exit. Ions which pass through the drift tube in a whole number of RF cycles, therefore, lose the energy at the exit which they received at the entrance. Ions of different masses which do not traverse the drift tube in a whole number of cycles experience some change in energy. The number of ions with unchanged energy is measured by a technique known as the retarding field method. The new instrument needs no narrow resolving slits as do magnetic mass spectrometers, and, unlike other time-of-flight instruments, it utilizes a continuous nonpulsed stream of ions. The first investigations conducted with the spectrometer involved electron bombardment studies of extinguishing agents without a flame. However, it is expected that this instrument will be useful in experiments using a flame as the ion source.

Fire Studies of Gypsum Plasters. An experimental study intended to furnish information on the effects of "variations of mix" ratio, aggregate, and aging conditions on the fire performance of gypsum plaster was completed. Small specimens tested without either structural load or restraint were exposed to controlled fires similar to the fires large building elements are subjected to in tests by a recognized standard method. Performance of the small specimens was evaluated on a time-to-temperature-rise criterion. It was found that mix ratio and density of lightweight aggregate materials over the ranges normally used, had little, if any, effect on performance. The times-to-temperature rise for such aggregate plasters was essentially equal, but shorter times were observed for sanded gypsum plasters. Dura-



In fundamental research to clarify the mechanism by which chemical combustion inhibitors work, a new type of mass spectrometer is used to study electron capture behavior of inhibiting agents. **(See p. 161.)**

tion of aging periods and relative humidity of the ambient had significant effects only for short aging periods and very high relative humidity conditions.

Electric Energy Usage in Houses Equipped with Heat Pumps. An analysis was made of metered electrical energy usage and power demand for all purposes in 16 sample houses out of a total of 1,535 houses constructed at Little Rock (Ark.) Air Force Base. The monthly and annual energy uses by the air-to-air heat pumps, the electric water heater, the electric range, and the miscellaneous electric devices were determined, and the effect of the electric energy used by appliances other than the heat pump on the heating and cooling loads was evaluated. Energy usage factors relating the amount of energy used, the severity of the weather, and the size of the house were computed for winter and summer conditions. The daily pattern of power demand, the coincidence of component and total power demands, and the frequency of recurrence of high power demands were studied. Program devices were suggested for limiting the maximum demand in the entire housing area. These and other facts regarding the use of energy in all-electric houses were published in NBS Monograph 51. The analysis was made in a study sponsored by the Army, Navy, and Air Force.

Environmental Factors in an Underground Fallout Shelter. Classical mathematics and digital computer methods were used to predict the temperature and humidity conditions in an underground shelter in terms of

the variables of shelter construction, climate, earth characteristics, ventilation rate, and internal heat release. Predicted values of temperature agreed well with the values observed in the family-size shelter installed at the Bureau. The digital computer technique is more versatile and requires less information about the test conditions than do classical methods. Shelter humidity, condensation in the shelter, interior surface temperature, heat flow rate into the walls, heat removed by the ventilating air, and the temperatures in the earth surrounding the shelter were also determined by computer techniques. The study was sponsored by the Office of Civil Defense. Further work is under way to simplify and shorten the computation time and to compare predicted and observed results in other shelters.

New Method for Predicting Roofing Asphalt Durability. A fast, dependable method has long been sought for measuring the degradation of roofing asphalt from weather exposure. Based on experiments with eight roofing asphalts procured from four different sources, California, southeastern United States, central United States, and Venezuela, a rapid, reproducible method for predicting resistance of roofing asphalts to weathering was developed. Thin films (25 ± 2 microns) of the samples are made by pressing vacuum-dried pellets (4 millimeters in diameter) between sheets of unlacquered cellophane in a hydraulic press heated to 250 °F. The thin films are separated from the cellophane, mounted in holders, and scanned in an infrared spectrophotometer. The specimens, at a temperature of 120 °F and a relative humidity of 40 percent, are then exposed to the radiation from a carbon arc for selected periods. The increased absorbance at the 5.88-micron wavelength is used to determine the oxidation rates of the specimens. Results obtained with this method showed oxidation rates and time to film failure of the asphalts to be in the same order with respect to resistance to weathering as were results obtained with other techniques and from actual outdoor exposure tests.

Weathering Resistance of Plastics Determined. The increasing use of plastics as building materials has focused attention on their weathering properties. In a program to develop rapid methods for comparing the weathering resistance of plastics, it was found that weathered specimens develop a pronounced color when treated with a diamine, one of the most effective being *N*,*N*-dimethyl-*p*-penylenediamine. Two methods of measurement may be used, either independently or together, to evaluate the extent of degradation. One method is based on the treatment of the specimen with a known amount of the diamine in a benzene-methanol solution. The extent of coloration is determined by reflectance measurements, with a differential colorimeter, of treated weathered and unweathered specimens. The other method depends upon the quantitative determination of the amount of diamine that has reacted with the surface of the weathered specimen. The two methods yield results with samples exposed to either natural or accelerated weathering conditions that agree within the limitations imposed by the nature of the material.

Performance of Roofings. The construction agencies of the Defense Department have long recognized that roofing failures account for a large portion of building problems both in new construction and in the maintenance of existing structures. The elimination of these problems in the design and construction stages of a project would result in substantial savings. Hence, the Directorate of Civil Engineering, U.S. Air Force; the Office of the Chief of Engineers, U.S. Army; and the Bureau of Yards and Docks, U.S. Navy, are sponsoring a program to investigate the performance of roofing materials and roof systems for both flat and steep roofs. The program includes investigations of the chemical and physical properties of organic roofing materials and of the durability and performance of a roof system when exposed to various climatic conditions. The study will be accomplished in three phases: Laboratory experiments to determine composition and chemical and physical properties; simulated service tests; and field surveys to observe actual performance. Information thus obtained is to be incorporated into material, design, and construction specifications of the Defense Department.

Safety Codes Revised. The Bureau participated in a revision of Part 2 of the National Electrical Safety Code, and the results of this work were published as NBS Handbook 81. Through membership on committees, assistance was given in developing or revising other codes under the procedures of the American Standards Association. They include the National Electrical Code, sponsored by the National Fire Protection Association (NFPA); the Code for Protection Against Lightning, sponsored by NFPA, the American Institute of Electrical Engineers, and the Bureau; the National Plumbing Code, sponsored by the American Public Health Association, the National Association of Plumbing Contractors, and the Building Officials Conference of America; Dimensional Standardization of Plumbing Equipment, sponsored by the American Society of Mechanical Engineers and the American Society of Sanitary Engineering; and Standards for Mobile Homes and Travel Trailers, sponsored by the Mobile Homes Manufacturers Association and the Trailer Coach Association.

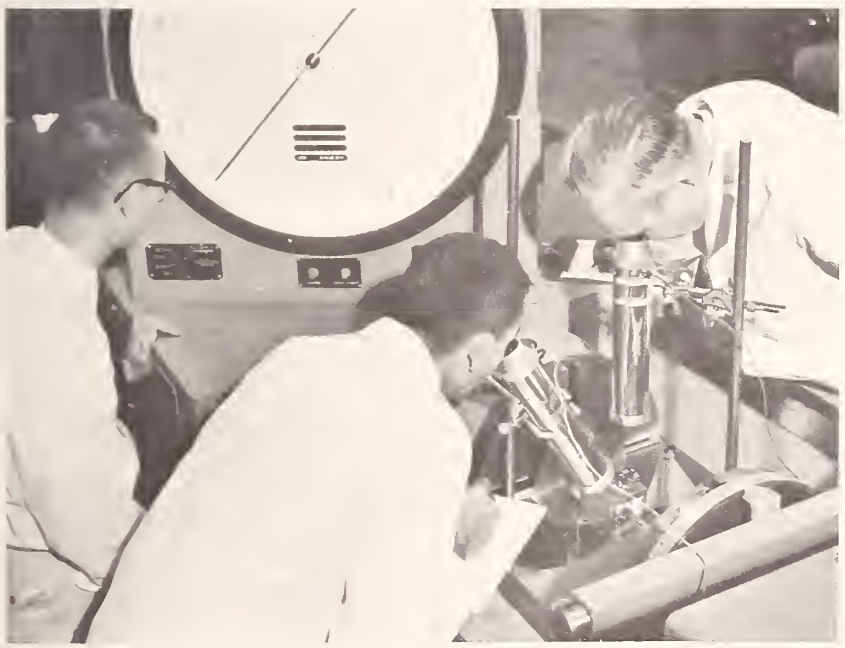
Fluid Dynamics of Plumbing Systems Reviewed. Rational economic design of plumbing systems depends on adequate knowledge of hydraulic and pneumatic capacities, and of probable peak demands by plumbing fixtures. Traditionally, Bureau publications on the fluid dynamics of plumbing have provided the basis for pipe sizing criteria utilized by plumbing codes.

In this area, publications are now in preparation which outline (1) the application of experimental results to the computation of hydraulic loads on horizontal drain systems, and (2) methods for estimating loads on plumbing systems in terms of actual plumbing fixtures. Another publication (NBS Monograph 31) was recently issued on the criteria for sizing main vertical drains and vents.

Preliminary findings in a laboratory study of the fundamental mechanisms of venting indicate that certain significant factors may not be satisfactorily accounted for in current methods for sizing vent pipes.

Thermal Conductivity Measurements and Reference Samples. Industry, defense agencies, and research laboratories have pressing needs for thermal conductivity reference materials, which will enable them to check their own measurements, or to use simplified comparative methods for determining thermal conductivity. In efforts to satisfy these needs, conductivity measurements were made by two or more independent absolute methods on two materials which appear promising for reference use: a chromium-nickel alloy and a microcrystalline glass. Results obtained in the alloy measurements by three methods, covering the temperature range −150 to 1200 °C, agree within a few percent where the temperature ranges overlap. Samples of the alloy were furnished as informal references to seven laboratories in this country, and they were also sent to another laboratory in this country and to three national laboratories in other countries for cooperative independent measurements. The measurements on microcrystalline glass are not complete, but they indicate good stability of conductivity up to 1,000 °C.

Samples of low and moderate thermal conductivities for use as references in checking or calibrating apparatus for determining the conductivity of insulating materials are now made routinely available on a fee basis. Developments of apparatus and methods are in progress so that reference samples for use at temperatures up to and over 500 °C may also be made available.



Measuring the bond between concrete aggregate (quartz, granite, etc.) and portland cement paste in pure shear (torsion). The study is aimed at finding how the mineral nature of the aggregate affects the bond strength. **(See p. 166.)**

Proceedings of Cement Symposium Published. The *Proceedings of the Fourth International Symposium on the Chemistry of Cement,* held at the Bureau, are now available as a Bureau publication, NBS Monograph 43, in a set of two volumes. The work provides a comprehensive review of all aspects of cement chemistry, and also includes 67 research papers on special topics in this field. In collaboration with the Portland Cement Association, the Bureau undertook the editing, proofreading, and indexing of the material presented during the symposium. It is expected that the *Proceedings* will become a major reference work in cement chemistry.

Standard Samples Now Available for Portland Cement Analysis. In the chemical analysis of portland cement and related materials, new techniques are frequently replacing traditional methods of gravimetric chemical analysis. Two examples are the use of a flame photometer to measure the alkali constituents in portland cement and the use of a quantitative X-ray fluorescence spectrometer to measure its other constituents. In some cases the apparatus employing these new techniques must be calibrated by the use of samples of known composition, and in others the use of such samples is required in the evaluation of the performance of the instruments. In addition, the availability of accurately analyzed samples may be useful in the older methods of analysis. During the past year the Bureau made available for sale five such standard samples whose composition covers the range generally encountered in commercial cements.

Cement-Aggregate Bond in Concrete Studied. It has long been recognized that the particle shape and texture of concrete aggregates affect the bond strength between the aggregate and cement matrix in portland cement concrete. The nature of the mineral is also thought to influence the bond strength, and experiments to find if such a relationship exists are under way. A bond test was developed in which polished cylindrical pieces of aggregate with one end embedded in cement mortar are subjected to torsion, and the shear strength at the mortar-aggregate surface is measured. Concurrent experiments are being made in which the surface charges on the aggregate materials are measured by electrophoretic techniques. It is anticipated that a relationship between the two properties will be found.

Resistance of Exterior-Finish Porcelain Enamels to Weathering. The use of porcelain enamel on steel and aluminum as an exterior finish for various building structures has been expanding rapidly during the past decade. The factors responsible for this increase are the trend in the building industry towards curtain wall construction, the emphasis on color in modern architecture, the ease with which most porcelain enamel finishes can be cleaned, and the good stability of most porcelain enamel finishes.

An earlier Bureau investigation resulted in the development of tests that would eliminate the use of porcelain enamels having poor durability. Four geographical sites were used in making the survey, all in the eastern part of the United States.

Recently a new investigation was started in order to compare older enamel types with those introduced since World War II, and also to obtain addi-

An image-glossmeter was developed to measure the image-forming properties of a surface. Image-gloss is an important attribute of some types of building exteriors. **(See p. 167.)**

tional information on the effect of geographical location on the rate of weathering. An examination of specimens exposed for three years in the southwestern and western parts of the country showed that exposure conditions are less severe than they are in the east. Air pollution by acid gases was found in the present study to be an important factor in determining the rate of attack. The investigation resulted in the development of an improved laboratory test that provides increased reliability for the selection of the most durable enamel types.

New Image-Gloss Test Method Developed. Exterior walls of buildings with smooth finishes often reflect distorted images of adjacent objects and structures, as a result of small deviations from flatness and from minor misalinements in panel mountings. Because this condition detracts from appearance, many architects and owners in their specifications now stipulate finishes that do not form images.

A portable image glossmeter for measuring this property of a surface was developed during the year. In this apparatus, the image gloss of a specimen is determined by observing the reflected images of a series of randomly oriented characters (Landolt *C*'s) through a suitable optical system. The

observer starts with a pattern containing characters that are too small to be discernible, and views successively larger ones until he sees an image distinctly enough so that he can report its orientation correctly. The image-gloss rating is the number assigned to the smallest pattern that the observer can identify correctly.

The equipment and test method were adopted as a tentative standard of the Porcelain Enamel Institute in 1962. Although the test was designed for porcelain enameled metal, it is also applicable to any material that may form images by surface reflection.

Standardization of Thermal Emittance Measurements. Thermal radiation properties of materials have always been important in the design of buildings and structures, but with the advent of the space age, the demand for these data has greatly increased. Dozens of new laboratories established to perform the required measurements were necessarily manned largely by personnel with scant background in the field. Hence, widely divergent values were reported by different laboratories on supposedly identical materials.

To help correct this condition, the Air Force requested the Bureau to establish standard equipment and procedures for measuring normal spectral emittance, to prepare and calibrate working standards of normal spectral emittance for use in verifying equipment and procedures used by Air Force contractors, and to conduct an educational program for interested laboratories.

A report was issued shortly after the project was undertaken. briefly reviewing the basic principles of radiant heat transfer, and making general recommendations with regard to instrumentation and procedures for measuring thermal emittance. The educational program resulted in over 200 consultations.

The equipment developed at the Bureau for direct measurement of normal spectral emittance makes use of a double-beam ratio-recording infrared spectrometer. The hot specimen serves as the source for one beam of the spectrometer, and a laboratory blackbody furnace for the other. Extensive tests indicate that the precision of measurement on platinum specimens, expressed as the standard deviation of repeated measurements on the same specimen, is within ± 0.005 in emittance, and that the measurement bias is less than 0.01.

Working standards of platinum, oxidized Kanthal, and oxidized Inconel, representing low, intermediate, and high emittance, respectively, were prepared and calibrated for use by other laboratories at temperatures of 800. 1100, and 1300 °K (1400 °K for platinum) over the wavelength range from 1 to 15 microns.

2.3.7. WEIGHTS AND MEASURES

In the United States, the actual control over weighing and measuring in the buying and selling of goods and services is largely within the respon-

sibility of the country's political subdivisions, that is, the States, the counties, and the municipal governments. To preclude the possibility of many different weights and measures systems, the U.S. Department of Commerce—and through it, the National Bureau of Standards—has been charged by the Congress with the custody, maintenance, and development of the national standards of measurement, and with the provision of means and methods for making measurements consistent with those standards. Particularly with relation to the State weights and measures programs, the Bureau performs the testing, calibration, and certification of standards and standard measuring apparatus, provides technical advisory service, and extends general cooperation in securing uniformity in weights and measures laws and in methods of inspection.

To implement this cooperation, the Bureau maintains an Office of Weights and Measures which is responsible for (1) technical services to the States and to business and industry in the area of measurement; (2) the design, construction, and use of weights and measures standards and of instruments associated with such standards; (3) the training of weights and measures officials in the technical aspects of their programs; and (4) the collection, arrangement, and dissemination of technical data on measurement units and systems.

Technical Services Provided. Among the technical services provided to industry during the year was the establishment of methods for determining the exact quantity in packages of caulking compound and in aerosol

Checking the fifth wheel distance-measuring device used to obtain information regarding the accuracy of vehicle odometers. The investigation is designed to provide car-rental agencies with accuracy requirements, and to provide weights and measures officials with a performance code, testing equipment design, and test methods. (See p. 170.)

containers. A study, including a test series, was made of a positive-displacement meter designed to measure the flow of fresh, raw milk.

An extensive investigation of the performance of odometers on automobiles rented by the mile was undertaken. This will ultimately provide rental car agencies with accuracy requirements, and will provide weights and measures officials with a performance code, testing equipment design, and test methods.

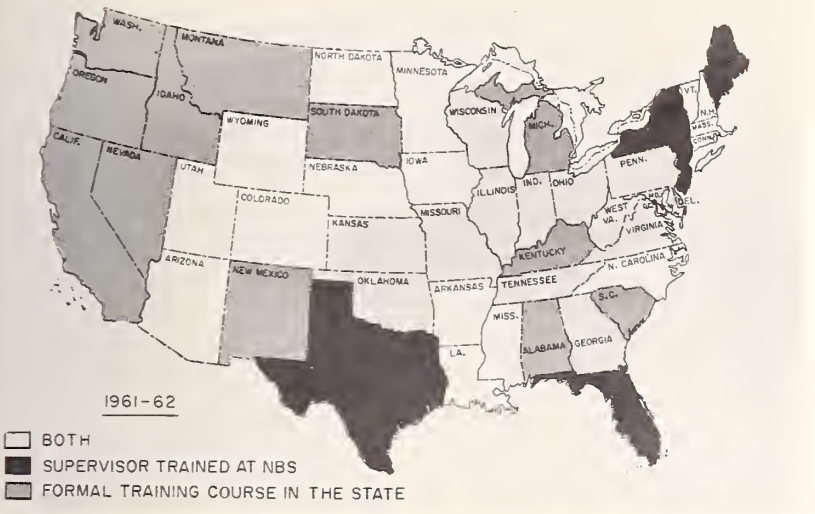
In other studies, testing equipment was designed for large-capacity scales and vehicle-tank meters, special glass flasks were developed for the control of packaged commodities sold by liquid measure, and, cooperatively with industry, refinements were brought about in the weighing instruments used by weights and measures officials in their general package-control programs.

Mass Standards Material Developed. Recent metallurgical developments led to a stainless steel of unusual composition for mass standards. Special melting techniques were used in which a consumable electrode under vacuum insures low gas and nonmetallic inclusion content and provides uniformity in structure and analysis. The resulting austenitic alloy, extremely stable and having a density of 8.0 $\pm$0.1 grams per milliliter at 25 °C, seems ideally suited for State reference standards.

The Technical Training Program. Technical training of State and local weights and measures officials falls into three categories: Formal courses of one-week duration offered to small classes of supervisory personnel in a training laboratory at the National Bureau of Standards; two, three, or four-day formal courses conducted in the various States for all State and local officials; informal training at NBS and in the field to cover laboratory procedures and the use of special testing equipment. Such technical training undoubtedly is a factor in the rapidly developing uniformity and effectiveness of weights and measures regulatory services in the United States.

Technical Information Provided. A basic responsibility is the dissemination of accurate information on units, systems, and equivalents of weights and measures. Tables of interrelation in forms that facilitate ready reference are published, and a large volume of inquiries is handled every year. Two indexed collections of books—an archival collection and a reference collection—and other documents comprise a weights and measures library. This library affords the staff and outside researchers and students complete references on the history and present status of weights and measures.

National Conference on Weights and Measures. The Bureau sponsors an annual National Conference on Weights and Measures, a relatively informal meeting of weights and measures officials, representatives of various agencies of the Federal Government and of equipment manufacturers and users, and others interested in orderly and effective weights and measures control. The Conference sessions develop technical and general recommendations for weights and measures administration, contribute to interstate coordination of weights and measures activity, and explore the entire



Map shows technical training classes for weights and measures officials, conducted by NBS. The classes are a major factor in maintaining uniform and effective weights and measures administration within the United States. **(See p. 170.)**

area of this economically important segment of governmental regulatory service. Among Conference accomplishments are a Model State Law on Weights and Measures, and model regulations covering devices and packages. The Model Law is included among recommended legislative efforts of the Council of State Governments.

The 47th National Conference was held during the year. Thirty-eight States, the District of Columbia, Puerto Rico, Canada, Japan, and Scotland were officially represented among a registered attendance of 420. The principal topic discussed was package labeling and quantity control. The technical papers presented dealt with subjects such as odometers on rental cars, mechanical measurement of milk, and the weights and measures programs in Japan and in Scotland.

3. APPENDIXES

3.1. ORGANIZATION OF THE NATIONAL BUREAU OF STANDARDS*

The Bureau is headed by a Director who is appointed by the President with Senate confirmation. The Director is assisted by a Deputy Director, who is responsible for internal operations. Several Associate Directors participate in the leadership function, coordinating related technical work across division lines, heading important policy committees, and handling special assignments in a staff capacity. One of the Associate Directors, in addition to being responsible for administration and support activities of a continuing nature, is in charge of an extensive special project—planning for the Bureau's new laboratories which are being constructed at Gaithersburg, Maryland. In charge of the Boulder Laboratories is a Director who also has the status of Associate Director of the Bureau. Program activities are conducted in 25 scientific divisions. Most divisions correspond roughly to a major field of physical science or engineering, and are divided into sections responsible for technical areas within each field. Sixteen of the divisions are located in Washington and nine in Boulder. Below the section level, the staff is organized into project groups which may be easily regrouped.

DIRECTOR

Allen V. Astin

DEPUTY DIRECTOR

Robert D. Huntoon

Associate Directors

I. C. Schoonover
R. S. Walleigh
W. A. Wildhack

F. W. Brown, Director, Boulder Laboratories

Assistants to the Director

G. E. Auman
W. S. Bussey

Special Research Group

H. P. Broida
U. Fano

Staff Advisers

NBS Reactor Program	C. O. Mueehlhause
Patent Adviser	D. Robbins
Program Adviser	C. N. Coates

Director Emeritus

Lyman J. Briggs

* As of September 1, 1962.

SCIENTIFIC DIVISIONS AND SECTIONS

(In numerical order)

ELECTRICITY

Chief	C. H. Page
Resistance and Reactance	J. L. Thomas
Electrochemistry	W. J. Hamer
Electrical Instruments	F. M. Defandorf
Magnetic Measurements	I. L. Cooter
Dielectrics	J. D. Hoffman
High Voltage	F. R. Kotter

METROLOGY

Chief	A. G. McNish
Assistant Chief	D. B. Judd
Photometry and Colorimetry	L. E. Barbrow
Refractometry	F. E. Washer
Photographic Research	C. S. McCamy
Length	T. R. Young
Engineering Metrology	I. H. Fullmer
Mass and Scale	P. E. Pontius
Volumetry and Densimetry	J. C. Hughes, *Acting*

HEAT

Chief	R. P. Hudson
Assistant Chief for Thermodynamics	C. W. Beckett
Temperature Physics	J. F. Swindells
Heat Measurements	D. C. Ginnings
Cryogenic Physics	E. Ambler
Equation of State	J. Hilsenrath
Statistical Physics	M. S. Green

RADIATION PHYSICS

Chief	L. S. Taylor
X-ray	H. O. Wyckoff
Radioactivity	W. B. Mann
Radiation Theory	M. Berger, *Acting*
High Energy Radiation	H. W. Koch
Radiological Equipment	S. W. Smith
Nucleonic Instrumentation	L. Costrell
Neutron Physics	R. S. Caswell

ANALYTICAL AND INORGANIC CHEMISTRY

Chief	H. C. Allen, Jr.
Assistant Chief	R. G. Bates
Consultants	R. Gilchrist
	C. P. Saylor
Pure Substances	F. L. Howard
Spectrochemistry	B. F. Scribner
Solution Chemistry	R. G. Bates
Standard Reference Materials	J. L. Hague
Applied Analytical Research	J. K. Taylor
Crystal Chemistry	H. S. Peiser

MECHANICS

Chief	B. L. Wilson
Consultants	J. M. Frankland
	E. C. Lloyd
Sound	R. K. Cook
Pressure and Vacuum	D. P. Johnson
Fluid Mechanics	G. B. Schubauer
Engineering Mechanics	L. K. Irwin
Rheology	R. S. Marvin
Combustion Controls	F. R. Caldwell

POLYMERS

Chief	G. M. Kline
Macromolecules: Synthesis and Structure	D. McIntyre
Polymer Chemistry	L. A. Wall
Polymer Physics	E. Passaglia
Polymer Characterization	N. P. Bekkedahl
Polymer Evaluation and Testing	R. D. Stiehler
Applied Polymer Standards and Research	R. B. Hobbs
Dental Research	W. T. Sweeney

METALLURGY

Chief	L. M. Kushner
Assistant Chief	G. A. Ellinger
Consultant	L. L. Wyman
Engineering Metallurgy	S. J. Rosenberg
Microscopy and Diffraction	H. C. Vacher
Metal Reactions	G. A. Ellinger
Metal Physics	L. M. Kushner
Electrolysis and Metal Deposition	A. Brenner

INORGANIC SOLIDS

Chief	A. D. Franklin
Assistant Chief	C. H. Hahner
Consultant	R. E. Lippincott
Engineering Ceramics	M. D. Burdick
Glass	C. H. Hahner
Solid State Chemistry	Vacant
Crystal Growth	F. Ordway
Physical Properties	J. B. Wachtman, Jr.
Crystallography	H. F. McMurdie

BUILDING RESEARCH

Chief	D. E. Parsons
Consultant	W. F. Roeser
Structural Engineering	D. Watstein
Fire Research	A. F. Robertson
Mechanical Systems	P. R. Achenbach
Organic Building Materials	W. W. Walton
Codes and Safety Standards	Vacant
Heat Transfer	H. E. Robinson
Inorganic Building Materials	B. E. Foster
Metallic Building Materials	W. N. Harrison

APPLIED MATHEMATICS

Chief	E. W. Cannon
Assistant Chief	F. L. Alt
Consultant	W. J. Youden
Numerical Analysis	P. Davis
Computation	D. I. Mittleman
Statistical Engineering	C. Eisenhart
Mathematical Physics	W. H. Pell
Operations Research	A. J. Goldman

DATA PROCESSING SYSTEMS

Chief	S. N. Alexander
SEAC	J. F. Rafferty
PILOT	P. D. Schupe
Research Information Center and Advisory Service on Information Processing	Miss M. E. Stevens
Components and Techniques	R. D. Elbourn
Computer Technology	J. A. Cunningham
Measurements Automation	R. T. Moore, *Acting*
Engineering Applications	S. N. Alexander, *Acting*
Systems Analysis	S. N. Alexander, *Acting*

ATOMIC PHYSICS

Chief	K. G. Kessler
Spectroscopy	W. C. Martin, Jr.
Infrared Spectroscopy	E. K. Plyler
Far Ultraviolet Physics	R. P. Madden
Solid State Physics	H. P. R. Frederikse
Electron Physics	J. A. Simpson
Atomic Physics	H. Boyne
Plasma Spectroscopy	W. L. Wiese

INSTRUMENTATION

Chief	G. F. Montgomery
Engineering Electronics	G. Shapiro
Electron Devices	C. P. Marsden
Electronic Instrumentation	G. F. Montgomery, *Acting*
Mechanical Instruments	A. Wexler
Basic Instrumentation	J. Stern

PHYSICAL CHEMISTRY

Chief	M. B. Wallenstein
Assistant Chief	F. Buckley
Thermochemistry	E. J. Prosen
Surface Chemistry	R. Klein
Organic Chemistry	H. S. Isbell
Molecular Spectroscopy	D. E. Mann
Elementary Processes	R. E. Ferguson
Mass Spectrometry	H. Rosenstock
Photochemistry and Radiation Chemistry	J. R. McNesby

OFFICE OF WEIGHTS AND MEASURES

Chief	M. W. Jensen

ADMINISTRATIVE AND SERVICE DIVISIONS

Office of Technical Information	W. R. Tilley
Accounting	J. P. Menzer
Personnel	G. R. Porter
Administrative Services	H. P. Dalzell
Shops	F. P. Brown
Supply	G. B. Kefover
Management Planning	A. J. Muller
Budget	J. E. Skillington
Internal Audit	J. Seidenberg
Plant	F. P. Brown, *Acting*
NBS Library	Miss S. Jones

BOULDER DIVISIONS

Director, Boulder Laboratories	F. W. Brown

Consultants

Mathematics Group and Computation Facility	J. J. Sopka
Mathematical Physics and Educational Director	E. H. Brown
Statistics	E. L. Crow
Radio Wave Propagation	J. R. Wait
Physics of the Atmosphere	D. M. Gates
Communications Liaison Officer	Allen Barnabei
CRPL Liaison and Program Development	A. H. Shapley
Executive Officer and Chief of Administrative Division	S. W. J. Welch
Technical Information Officer	J. R. Craddock

CRYOGENIC ENGINEERING

Chief	R. B. Scott
Assistant Chief	B. W. Birmingham
Cryogenic Equipment	R. B. Jacobs
Cryogenic Processes	B. W. Birmingham
Properties of Materials	R. J. Corruccini
Cryogenic Technical Services	V. J. Johnson

*IONOSPHERE RESEARCH AND PROPAGATION

Chief	E. K. Smith, Jr.
Assistant Chief	T. N. Gautier
Assistant Chief	R. W. Knecht
Assistant to Chief for Technical Planning & Coordination	J. A. Kemper
Consultants	D. K. Bailey
	H. H. Howe
Low Frequency and Very Low Frequency Research	A. G. Jean
Ionosphere Research	K. Davies
Prediction Services	Miss J. V. Lincoln
Sun-Earth Relationships	R. W. Knecht
Field Engineering	H. G. Sellery
Radio Warning Services	Miss J. V. Lincoln
Vertical Soundings Research	J. W. Wright

*RADIO PROPAGATION ENGINEERING

Chief	K. A. Norton
Assistant Chief for Research and Development	J. W. Herbstreit
Consultant—Terminal Equipment	E. F. Florman
Data Reduction Instrumentation	W. E. Johnson
Radio Noise	W. Q. Crichlow
Tropospheric Measurements	M. T. Decker
Tropospheric Analysis	P. L. Rice
Propagation-Terrain Effects	R. S. Kirby
Radio Meteorology	B. R. Bean
Lower Atmosphere Physics	M. C. Thompson, Jr.

*RADIO SYSTEMS

Chief	R. C. Kirby
Assistant Chief	D. W. Patterson
Assistant Chief	W. F. Utlaut
Consultant	G. W. Haydon
Applied Electromagnetic Theory	J. R. Johler
High Frequency and Very High Frequency Research	W. F. Utlaut
Frequency Utilization	G. W. Haydon
Modulation Research	C. C. Watterson, *Acting*
Antenna Research	H. V. Cottony
Radiodetermination	G. Hefley

*UPPER ATMOSPHERE AND SPACE PHYSICS

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

RADIO STANDARDS LABORATORY

Chief	J. M. Richardson
Assistant Chief for Planning and Coordination	E. C. Wolzien
Consultant	D. M. Kerns

*These divisions comprise the Central Radio Propagation Laboratories.

RADIO PHYSICS DIVISION

Chief	Yardley Beers
Consultants	W. D. George
	P. F. Wacker
Assistant Chief for Technical Planning and Coordination	W. D. Goring
Radio Broadcast Service	A. H. Morgan
Radio and Microwave Materials	J. L. Dalke
Atomic Frequency and Time Interval Standards	R. C. Mockler
Radio Plasma	B. Wieder, *Acting*
Millimeter-Wave Research	R. W. Zimmerer, *Acting*

CIRCUIT STANDARDS DIVISION

Chief	G. E. Schafer
Assistant Chief	H. W. Lance
Assistant to the Chief for Technical Planning and Coordination	W. J. Anson
Consultants	R. W. Beatty
	M. C. Selby
Coordinator Calibration Service	W. F. Snyder
High Frequency Electrical Standards	C. M. Allred
High Frequency Calibration Services	R. C. Powell, *Acting*
High Frequency Impedance Standards	R. C. Powell
Microwave Calibration Services	R. E. Larson
Microwave Circuit Standards	R. W. Beatty
Low Frequency Calibration Services	F. D. Weaver, *Acting*

JOINT INSTITUTE FOR LABORATORY ASTROPHYSICS

NBS GROUP

Chairman	L. M. Branscomb

FIELD ESTABLISHMENTS

Visual Landing Aids Field Laboratory	Arcata, Calif.
Master Railway Track Scale Depot	Clearing, Ill.
Materials Testing Laboratories:	Allentown, Pa.
	Denver, Colo.
	San Francisco, Calif.
	Seattle, Wash.
Radio Transmitting Station WWV	Greenbelt, Md.
Radio Transmitting Station WWVL	Sunset, Colo.

Central Radio Propagation Laboratory Field Stations:

ALASKA
Anchorage
Barrow

ANTARCTICA
Eights Station**

ELTANIN**
(Floating Research Vessel)
Marie Byrd Station**
Pole Station**

AUSTRALIA
Cook**

BOLIVIA
La Paz**

BRAZIL, S.A.
Sao Jose dos Campos**

CANADA
Cape Jones**
Great Whale River**
Manitoba**

CHILE
Concepcion**

COLORADO
Beulah
Brighton
Chalk Cliff Site
Cheyenne Mountain
Erie
Fritz Peak
Gunbarrel Hill
Haswell
Hygiene
Karval
Kendrick
Kolb
Lafayette
Table Mesa
Sunset

**Contract or Mutual Cooperation.

Central Radio Propagation Laboratory Field Stations—*Continued*

COLOMBIA
Bogota**

GREENLAND
Thule**
Goodhavn**
Narsarssuak**

HAWAII
Maui (WWVH)
Kekaha
Mt. Haleakala

ICELAND
Keflavik**
Reykjavik**

ILLINOIS
Long Branch

INDIA
New Delhi**

ISRAEL
Haifa**

JAPAN
Ohira**

KANSAS
Garden City

MALAYA
Singapore**

MISSOURI
Warrensberg

MOROCCO
Rabat**

NEBRASKA
Shickley

NIGERIA
Ibadan**

NORWAY
Andenes**

OKINAWA
Onna**
Okuma**

OKLAHOMA
Altus

PANAMA CANAL ZONE
Balboa**

PERU
Lima**
Jicamarca Radio Observatory

PHILIPPINE ISLANDS
Poro Point**
Baguio

PUERTO RICO
San Juan

SOUTH AFRICA
Pretoria**

SWEDEN
Enkoping**

UTAH
Salt Lake City**

VIRGINIA
Fort Belvoir
Front Royal

WYOMING
Bill

3.2. SUMMARY OF NBS STAFF*

	Washington	Boulder	Total
Total permanent staff	2,351	1,126	3,477
Other staff**	342	197	539
Total on rolls	2,693	1,323	4,016
Research associates & guest workers	149	20	169
Total on rolls at NBS	2,842	1,343	4,185
Professional staff***			
Physicists	439	222	661
Chemists	276	8	284
Engineers	172	165	337
Mathematicians	57	62	119
Other	65	20	85
Total professional staff	1,009	477	1,486

*As of June 30, 1962.
**WAE, consultants, students, teachers, postdoctoral fellows, and temporary-limited employees.
***Full-time permanent (excludes any under **).

3. 3. FINANCIAL DATA ON NBS PROGRAM

The activities of the National Bureau of Standards are financed from three sources: from appropriations provided by the Congress; from payments by other agencies for specific research and development tasks; and from payments by industrial concerns, universities, research institutions, and government agencies for specific calibration or testing services. The following tabulation is a summary of the financial aspects of the Bureau programs for 1962:

Program and source of financing	Obligations incurred (rounded)		
Supported by NBS appropriations:			
Operating programs:			
Research and technical services	$23,359,000		
Special foreign currency program	400,000		
Subtotal		$23,759,000	
Construction and facilities program:			
Plant and facilities	1,628,000		
Construction of facilities	27,454,000		
Subtotal		29,082,000	
Total NBS appropriation			$52,841,000
Supported by other funds:			
Research and development programs:			
Other Federal agencies	14,674,000		
Nongovernmental sources	331,000		
		15,005,000	
Calibrations, testing, standard samples, and other technical services		5,282,000	
Reimbursable administrative services		1,110,000	
Total supported by other funds			21,397,000
Total program			74,238,000

3.4. ADVISORY COMMITTEES

STATUTORY VISITING COMMITTEE

(Reports annually to Secretary of Commerce on NBS activities (Dates indicate expiration of appointment))

DR. M. J. KELLY, Former President and Chairman of the Board, Bell Telephone Laboratories, Inc. (1962), Chairman
PROFESSOR FREDERICK SEITZ, University of Illinois (1966)
DR. LLOYD V. BERKNER, President, Graduate Research Center, Inc. (1963)
MR. CRAWFORD H. GREENEWALT, President, E. I. du Pont de Nemours & Co. (1964)
PROFESSOR CHARLES H. TOWNES, Provost, Massachusetts Institute of Technology (1965)

TECHNICAL ADVISORY PANELS

(Appointed by the National Academy of Sciences-National Research Council in cooperation with the leading scientific and technical societies to advise NBS Director in specific technical areas. Cooperating societies are: American Ceramic Society (ACerS); American Chemical Society (ACS); American Institute of Chemical Engineers (AIChE); American Institute of Electrical Engineers (AIEE); American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME); American Institute of Physics (AIP); American Society of Civil Engineers (ASCE); American Society of Mechanical Engineers (ASME); Conference Board of the Mathematical Sciences (CBMS); and Institute of Radio Engineers (IRE). Appointments at large (AL). Members listed served during fiscal year 1962.)

DR. PAUL D. FOOTE, National Research Council, Executive Secretary

Advisory Panel to Electricity Division

PROF. W. A. LEWIS, Illinois Institute of Technology, Chairman (AIEE)
PROF. NORMAN I. ADAMS, Jr., Yale University (AIP)
DR. WILLIAM G. AMEY, Leeds & Northrup (AIEE)
DR. RICHARD M. BOZORTH, Bell Telephone Laboratories (AIP)
DR. JOHN BRAINERD, University of Pennsylvania (IRE)
PROF. HENRY B. LINFORD, Columbia University (ACS)
MR. J. T. LUSIGNAN, The Ohio Brass Company (AIEE)
DR. ERNEST WEBER, Polytechnic Institute of Brooklyn (AIEE)

Advisory Panel to Metrology Division

DR. BRIAN O'BRIEN, Pomfret, Conn., Chairman (AIP)
PROF. ISAY A. BALINKIN, University of Cincinnati (ACerS)
PROF. CLARENCE E. BENNETT, University of Maine (AIP)
DR. ALSOPH H. CORWIN, The Johns Hopkins University (ACS)
MR. C. L. CROUCH, Illuminating Engineering Society (AL)
MR. A. M. DEXTER, Pratt and Whitney Company, Inc. (AL)
DR. ROBERT E. HOPKINS, Tropel, Inc. (AL)
MR. FLOYD W. HOUGH, Arlington, Virginia (ASCE)
MR. J. J. MORAN, Kimble Glass Company (ACerS)
MR. LOUIS POLK, The Sheffield Corporation (ASME)
PROF. JOHN STRONG, The Johns Hopkins University (AIP)
DR. J. H. WEBB, Eastman Kodak Company (AIP)

Advisory Panel to Heat Division

PROF. JOSEPH E. MAYER, University of California, Chairman (ACS)
PROF. JAMES A. BEATTIE, Massachusetts Institute of Technology (AIP)
PROF. HENRY A. FAIRBANK, Yale University (AIP)
PROF. JOSEPH KESTIN, Brown University (ASME)
DEAN R. B. LINDSAY, Brown University (AIP)
DR. CHARLES SQUIRE, United Aircraft Corporation (AIP)
PROF. GLENN C. WILLIAMS, Massachusetts Institute of Technology (AICE)

Advisory Panel to Radiation Physics Division

DR. H. M. PARKER, General Electric Company, Chairman (AIP)
MR. EVERITT P. BLIZARD, Oak Ridge National Laboratory (AIP)
DR. MARTIN DEUTSCH, Massachusetts Institute of Technology (AIP)
DR. A. O. HANSON, University of Illinois (AIP)
DR. WILLIAM A. HIGINBOTHAM, Brookhaven National Laboratory (IRE)
PROF. HAROLD A. LAMONDS, North Carolina State College (AIEE)
PROF. GEORGE T. REYNOLDS, Palmer Physical Laboratory (AIP)
DR. LEONARD SCHIFF, Stanford University (AIP)

Advisory Panel to Analytical and Inorganic Chemistry Division

DR. T. IVAN TAYLOR, Columbia University, Chairman (ACS)
DR. CLARK E. BRICKER, Princeton University (ACS)

Dr. Norman D. Coggeshall, Gulf Research and Development Company (AIP)
Dr. W. D. Cooke, Cornell University (ACS)
Dr. Herbert A. Laitinen, University of Illinois (ACS)
Dr. W. Wayne Meinke, University of Michigan (ACS)
Dr. J. R. Ruhoff, Malinckrodt Chemical Company (ACS)
Dr. Charles E. White, University of Maryland (ACS)

Advisory Panel to Mechanics Division

Prof. S. R. Beitler, Ohio State University, Chairman (ASME)
Prof. Lynn S. Beedle, Lehigh University (ASCE)
Prof. Arthur T. Ippen, Massachusctts Institute of Technology (ASCE)
Dr. Harry F. Olson, Radio Corporation of America (AIP)
Prof. Jesse Ormondroyd, University of Michigan (ASME)
Dr. Milton Plesset, California Institute of Technology (AIP)

Advisory Panel to Polymers Division

Dr. C. G. Overberger, Polytechnic Institute of Brooklyn, Chairman (ACS)
Dr. Raymond F. Boyer, Dow Chemical Company (ACS)
Dr. J. H. Dillon, Texile Research Institute (AIP)
Dr. Milton Harris, Harris Research Laboratories, Inc. (ACS)
Dr. Frank C. McGrew, E. I. du Pont de Nemours & Co. (ACS)
Dr. Norman A. Shepard, Stamford, Connecticut (ACS)
Dr. J. F. Downie Smith, Carrier Research and Development Company (ASME)
Dr. Charles Scott Venable, Wallingford, Pa (ACS)

Advisory Panel to Metallurgy Division

Mr. Francis L. Laque, International Nickel Company, Chairman (ACS)
Dr. D. J. Dienes, Brookhaven National Laboratory (AIP)
Dr. Morris Eugene Fine, Northwestern University (AIME)
Mr. A. R. Lytle, Linde Company (AIME)
Dr. Oscar Marzke, United States Steel Corporation (AIME)
Prof. E. F. Osborn, Pennsylvania State University (ACerS)
Dr. Joseph A. Pask, University of California (ACerS)
Dr. Albert J. Phillips, American Smelting and Refining Company (AIME)
Mr. D. B. Rossheim, M. W. Kellogg Corporation (ASME)
Mr. J. H. Scaff, Bell Telephone Laboratories (AIME)

Advisory Panel to Inorganic Solids Division

Prof. Pierce Selwood, Northwestern University, Chairman (ACS)
Dr. Orson L. Anderson, Summit, New Jersey (ACerS)
Prof. C. Ernest Birchenall, University of Delaware (AL)
Dr. Joseph E. Burke, General Electric Research Laboratory (ACerS)
Dr. James R. Johnson, Minnesota Mining and Manufacturing Company (ACerS)
Dr. Norbert J. Kreidl, Bausch and Lomb Optical Company (ACerS)
Prof. J. W. Mitchell, University of Virginia (AL)
Dr. E. F. Osborn, Pennsylvania State University (ACerS)
Mr. Karl Schwartzwalder, General Motors Corporation (ACerS)
Dr. Robert B. Sosman, Rutgers, The State University (ACerS)

Advisory Panel to Building Research Division

Dr. W. C. Hansen, Valparaiso, Indiana, Chairman (ACS)
Prof. Jesse H. Day, Ohio University (ACS)
Dr. Albert G. H. Deitz, Massachusetts Institute of Techonology (ASCE)
Prof. Robert A. Hechtman, The George Washington University (ASCE)
Mr. Paul V. Johnson, Structural Clay Products Research Foundation (ACerS)
Prof. James T. Lendrum, University of Florida (AIA)
Dean Warren L. McCabe, Polytechnic Institute of Brooklyn (AICE)
Dr. John S. Parkinson, Johns-Manville Products Corporation (AIP)
Prof E. R. Queer, The Pennsylvania State University (AL)
Mr. Raymond C. Reese, Toledo, Ohio (ASCE)

Advisory Panel to Applied Mathematics Division

Prof. A. H. Bowker, Stanford University (AL)
Prof. Jesse Douglas, City College of New York (AL)
Prof. William Feller, Princeton University (CBMS)
Prof. George E. Forsythe, Stanford University (CBMS)
Dr. Alston S. Householder, Oak Ridge National Laboratory (CBMS)
Prof. B. O. Koopman, Columbia University (CBMS)
Dr. Elliott W. Montroll, International Business Machines Corporation (CBMS)
Prof. R. D. Richtmyer, New York University (CBMS)
Dr. J. Barkley Rosser, Cornell University (CBMS)
Prof. M. M. Schiffer, Stanford University (CBMS)

Advisory Panel to Data Processing Systems Division

Dr. Alston S. Householder, Oak Ridge National Laboratory, Chairman (CBMS)
Prof. George E. Forsythe, Stanford University (CBMS)
Mr. John C. McPherson, International Business Machines Corporation (IRE)
Prof. Charles L. Miller, Massachusetts Institute of Technology (ASCE)
Prof. Raymond Pepinsky, Pennsylvania State University (AIP)
Prof. William H. Radford, Massachusetts Institute of Technology (IRE)
Prof. Morris Rubinoff, University of Pennsylvania (AIEE)

Advisory Panel to Atomic Physics Division

Prof. R. H. Dicke, Princeton University, Chairman (AIP)
Prof. Benjamin Bederson, New York University (AIP)
Prof. Peter Franken, University of Michigan (AIP)
Prof. Jesse L. Greenstein, California Institute of Technology (AL)
Prof. Vernon W. Hughes, Sloane Laboratory (AIP)
Prof. Mark G. Ingham, University of Chicago (AIP)
Dr. Benjamin Lax, Massachusetts Institute of Technology (AIP)
Dr. M. Kent Wilson, Tufts University (ACS)

Advisory Panel to Instrumentation Division

Mr. R. W. Larson, General Electric Research Laboratories, Chairman (AIEE)
Dr. A. O. Beckman, Beckman Instruments, Inc. (AL)
Mr. D. G. Fink, Philco Corporation (IRE)
Dr. R. J. Jeffries, Data-Control Systems, Inc. (AL)
Col. J. Z. Millar, Western Union Telegraph Company (AIEE)
Mr. Leon Podolsky, Sprague Electric Company (IRE)
Mr. Ivan G. Easton, General Radio Company (AIEE)
Mr. William R. Hewlett, Hewlett-Packard Company (AIEE)

Advisory Panel to Physical Chemistry Division

Prof. Henry Eyring, University of Utah, Chairman (ACS)
Dr. A. O. Allen, Brookhaven National Laboratory (ACS)
Dr. Paul Cross, Mellon Institute (ACS)
Prof. Hans H. Jaffe, University of Cincinnati (ACS)
Dr. Daniel R. Stull, The Dow Chemical Company (ACS)

Advisory Panel to Cryogenic Engineering Division

Dr. Clyde McKinley, Air Products Incorporated, Chairman (AICE)
Prof. S. C. Collins, Massachusetts Institute of Technology (ASME)
Dr. Hugh M. Long, Tonawanda, New York (AIP)
Dr. Loyd B. Nesbitt, General Electric Laboratory (AIP)
Dr. David White, Ohio State University (ACS)

Advisory Panel to Central Radio Propagation Laboratory

Prof. Arthur H. Waynick, The Pennsylvania State University, Chairman (IRE)
Mr. Stuart L. Bailey, Washington, D.C. (IRE)
Prof. Henry G. Booker, Cornell University (IRE)

Mr. A. B. Crawford, Bell Telephone Laboratories (AL)
Dr. R. A. Helliwell, Stanford University (IRE)
Dr. S. W. Herwald, Westinghouse Electric Corporation (AIEE)
Dr. John B. Smyth, Smyth Research Associates (AIP)
Dean George Town, Iowa State University (AIEE)
Dr. Albert D. Wheelon, Space Technology Laboratories, Inc. (IRE)

Advisory Panel to Radio Standards Division

Prof. Arthur A. Oliner, Polytechnic Institute of Brooklyn, Chairman (IRE)
Prof. Walter Gordy, Duke University (AIP)
Prof. E. L. Hahn, University of California (AIP)
Dr. E. W. Houghton, Bell Telephone Laboratories (AIEE)
Prof. E. C. Jordan, University of Illinois (IRE)
Dr. R. Kompfner, Bell Telephone Laboratories (IRE)
Prof. W. A. Lewis, Illinois Institute of Technology (AIEE)
Prof. N. F. Ramsey, Harvard University (AIP)
Dr. John C. Simons, National Research Corporation (IRE)

ADIVISORY COMMITTEE ON ENGINEERING AND RELATED STANDARDS

(Members are nominated by the American Standards Association (ASA) and the American Society for Testing and Materials (ASTM))

Mr. W. A. Wildhack, National Bureau of Standards, Chairman
Dr. A. A. Bates, New York University (ASTM)
Mr. Roger E. Gay, American Standards Association (ASA)
Mr. F. L. LaQue, The International Nickel Company, Inc. (ASTM)
Mr. John W. McNair, American Standards Association (ASA)
Mr. N. L. Mochel, Westinghouse Electric Corporation (ASTM)
Mr. Frank H. Roby, American Standards Association (ASA)

ADVISORY COMMITTEE ON CALIBRATION AND MEASUREMENT SERVICES

(Members are appointed on the basis of their broad personal knowledge of industrial measurement problems)

Mr. W. A. Wildhack, National Bureau of Standards, Chairman
Dr. William G. Amey, Leeds & Northrup Company
Mr. H. C. Biggs, Sandia Corporation
Mr. E. J. Brazill, The Martin Company
Mr. Ivan G. Easton, General Radio Company
Mr. Bruno Weinschel, Weinschel Engineering
Mr. L. B. Wilson, Sperry Gyroscope Company
Mr. A. J. Woodington, Convair Astronautics

WEIGHTS AND MEASURES ADVISORY COMMITTEE

(Members are nominated by the National Conference on Weights and Measures)

Mr. W. S. Bussey, National Bureau of Standards, Chairman
Miss Genevieve Blatt, Secretary of Internal Affairs, Commonwealth of Pennsylvania
Mr. C. G. Gehringer, Howe-Richardson Corporation
Prof. L. J. Gordon, Weights and Measures Research Center, Denison University
Mr. Rollin E. Meek, State Board of Health, Indiana
Mr. J. E. Moss, American Petroleum Institute
Mr. E. C. Westwood, City Sealer of Weights and Measures, Salt Lake City, Utah

3.5. AWARDS AND HONORS

Recognition of the Bureau's contributions to science and technology often takes the form of awards and honors from government, academic, professional, and industrial groups. The following list reflects such recognition bestowed on Bureau staff members during fiscal year 1962.

RECIPIENT	AWARD
Ambler, Ernest	Fellowship from the John Simon Guggenheim Memorial Foundation
Astin, Allen V.	American Ordnance Association's Scott Gold Medal Award
Branscomb, L. M.	Arthur S. Flemming Award of the Junior Chamber of Commerce, Washington, D.C.
Brenner, Abner	Scientific Achievement Award of American Electroplaters' Society
Harrison, William N.	John Jeppson Award by American Ceramic Society
Hoffman, John D.	Certificate of recognition from the Washington Academy of Sciences
Judd, D. B.	Gold Medal of Illuminating Engineering Society
Kline, G. M.	Elected a Distinguished Member of the Society of Plastics Engineers
Michaelis, Robert E.	Steel Ingot Award of the Ferrous Metals Subcommittee, ASTM Committee E–2 on Emission Spectroscopy
Montgomery, G. F.	Elected Fellow in the Institute of Radio Engineers
Ondik, Helen M.	Hunter College Award for Outstanding Achievement
Plyler, E. K.	Elected Honorary Fellow of Indian Academy of Sciences
Schiefer, Herbert F.	Honorary Doctor of Science Degree from North Carolina State College
Scribner, Bourdon F.	Medal Award in Spectroscopy of the Society for Applied Spectroscopy, New York Section
Sitterly, C. M.	Honorary Doctor of Science Degree from Swarthmore College
Smith, J. C.	Elected a Fellow of the British Textile Institute
Joint Award: Lawrence, Robert S. Little, C. Gordon	RESA Boulder Scientist Award

DEPARTMENT OF COMMERCE MERITORIOUS SERVICE AWARDS

RECIPIENT	TECHNICAL AREA
Ackerman, Rolland F.	Calibration of "long distance" tapes
Bay, Zoltan L.	Determinations of average energy required to produce an ion pair in gases
Brown, William W.	Long-wave standard frequency broadcast stations
Ehrlich, Margarete	Photographic emulsions for measurement of radiation
Goodwin, Robert D.	Low-temperature physics
Haven, Clyde E.	Dimensional metrology and standardization
Hefley, Gifford	"Loran-C Clock" development
Kruger, Jerome	Surface metallurgy
Lance, Harvey W.	Electronic standards, measurements, and calibrations
Meyerson, Melvin R.	Physical metallurgy
Mijares, Anilo	Instrument craftsmanship
O'Brien, Augusta H.	Administrative competence
Richmond, Martha S.	Analytical chemistry of uranium
Roth, Robert S.	Non-metallic mineral products
Schilling, Reinhold F. P.	Instrument craftsman
Schlarman, Wilfred L.	Instrument craftsman
Scott, Arnold H.	Precision measurements of the dielectric properties of matter
Sera, Frederick	Technical radio services from station WWV
Swan, Reta K.	Administrative competence
Thompson, Moody C., Jr.	Troposphere physics
Wiese, Wolfgang L.	Plasma physics
Joint Award: Spencer, Lewis V. Eisenhauer, Charles M.	Radiation shielding engineering

DEPARTMENT OF COMMERCE EXCEPTIONAL SERVICE AWARDS

RECIPIENT	TECHNICAL AREA
Cannon, Edward W.	Electronic digital computers
Kessler, Karl G.	Atomic physics
Koch, H. William	Radiation physics
Norton, Kenneth A.	Radio propagation research
Plyler, Earle K.	Infrared radiation physics
Wall, Leo A.	Fluorocarbon compounds for preparation of organic polymers
Youden, William J.	Mathematical statistics

3.6. EDUCATION AND TRAINING PROGRAM

The Bureau sponsors a broad employee development program oriented to the education and training needs of all staff members. Primary program objectives are the increase of efficiency in the conduct of official assigned duties and systematic preparation for increased responsibilities. The program is implemented primarily through the NBS Graduate School and training through nongovernment facilities. It covers educational levels up through postdoctoral research and includes general staff development courses. Comparable programs are available in both the Washington and Boulder Laboratories.

The curriculum of the Graduate School includes graduate and undergraduate courses in the physical sciences, mathematics, and certain branches of engineering: and a series of scientific colloquia and seminars led by research leaders from the Bureau staff and from other research centers. A series of general staff development courses is also offered through the Graduate School. Typical examples in this category are scientific German, practical metallurgy, and mathematical symbolism and terminology. Educational counseling and a program of thesis accreditation are also provided.

Course offerings are determined by the NBS Educational Committee through periodic need surveys. The curriculum is divided into NBS in-hours and NBS–university-sponsored out-of-hours courses and is flexible to meet the varied and changing needs of the staff. The Technician Career Program, for example, was established in 1960. Through a series of in-hours courses in the fundamentals of science and mathematics, the Program helps to increase job efficiency and offers educational opportunities for subprofessional laboratory personnel. The Clerical Training Center, initiated in 1961, makes it possible to fill clerical vacancies with fully-oriented employees who can become productive in their permanent assignments in the shortest length of time.

Since the establishment of the Washington educational program in 1908, 282 graduate degrees have been awarded by 45 different universities partly on the basis of credits obtained or thesis work carried on under the Bureau Graduate School program.

During the year the Graduate Program at Boulder has been strengthened by the initiation of a Joint-Course program and an Adjoint Professor plan with the University of Colorado. Under the Joint-Course program, courses are offered simultaneously by the appropriate graduate departments of the

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University and by the NBS Graduate School with mutual benefit to both the Government and the University. Bureau staff members who teach the courses have the title of Adjoint Professor at the University. Another cooperative program with the University of Colorado was the three-week Radio Propogation Course offered during the summer of 1962. Thirty Boulder scientists and seven noted authorities from outside the Bureau prepared the lectures for this highly successful program. In addition to NBS staff members, approximately 200 students from other government agencies, industry, universities, and foreign research laboratories participated in the course.

In another phase of the Bureau employee development program, NBS sponsored three major training programs through nongovernment facilities under authority of the Government Employees Training Act of 1958. These are:

1. Full-time (3 to 12 months) postdoctoral study and research assignments at universities and research centers, both in this country and abroad.

2. Full-time (less than 3 months) attendance at institutes, seminars, short concentrated courses, workshops, etc. Generally, these are offered through the educational facilities of major universities and industrial laboratories throughout the country.

3. Part-time job-related academic courses at local educational institutions, generally in early evening classes.

Three hundred and eighty-nine staff members at Washington and Boulder were trained through nongovernment facilities in 1962. Fourteen selected career scientists were selected for full-time research assignments at universities and research centers. Seventy-four staff members, primarily scientists and subprofessional laboratory personnel, attended short concentrated courses and training programs at universities and in industry. Three hundred and one employees, mostly from technical divisions, attended job-related courses at local educational facilities. The Bureau paid full salaries and expenses for participants in approved full-time nongovernment training programs. These included tuition, related fees, travel and per diem, as well as transportation of family and household effects for long-term training.

Each summer the Bureau sponsors a student trainee program open to college students majoring in the physical sciences, mathematics, and certain branches of engineering. An integrated work-study program, this activity includes lectures, tours, demonstrations, supervised laboratory assignments, and professional counseling. The purpose of the program is to acquaint young people with career opportunities in scientific research at the NBS Laboratories and to prepare select students for such careers. The 1962 student program had a total enrollment of 212 students which included 120 returnees from previous summers. The new group included 10 high school students who had obtained recognition through the Westinghouse Science Talent Search or other national science competition. Approximately 40 percent of the 1962 group were at the graduate level. Students from 65 colleges participated in the 1962 program.

In collaboration with the National Research Council, the Graduate School offers postdoctoral resident research associateships to young scientific investigators of unusual ability and promise of becoming creative leaders in basic research in the various branches of the physical and mathematical sciences. While acquiring basic knowledge, they have opportunities for developing new scientific approaches and laboratory skills, thus advancing scientific knowledge. Twenty new Research Associateships are open each year and are tenable at both the Washington and Boulder Laboratories. During 1962, the following young men were selected and served: Robert A Beaudet, Merritt M. Birky, Gerald T. Cargo, George E. Chamberlain, Sam R. Coriell, Richard D. Doepker, Gordon H. Dunn. John A. Eddy. John L. Hall, Sigurd Y. Larsen, William S. Layne, Melvin Linzer, John T. MacQueen, Billy W. Mangum. Terence L. Porter, Joseph Powers, Terry E. Sharp, William A. Thompson, Jr., and Edward S. J. Tomezsko.

Scientific staff meetings, held weekly from September through May, are also included in the Bureau's educational program. The staff meetings are of a less specialized nature than colloquia and seminars offered in the Graduate School program. They are open to all professional staff members of the Bureau and to scientific personnel from neighboring laboratories.

3.7. PUBLICATIONS AND PATENTS

Publications in the Bureau's Series*

Journal of Research. Contains full research papers, including laboratory data, experimental procedures, and theoretical and mathematical analyses. Advances in measurement standards and techniques . . . physical constants . . . properties of materials . . . instrumentation . . . radio propagation.

The Journal is published in four separate sections . . .

A. Physics and Chemistry—issued six times a year.

B. Mathematics and Mathematical Physics—issued quarterly.

C. Engineering and Instrumentation—issued quarterly.

D. Radio Propagation—issued six times a year.

The papers listed below have appeared in the four-section Journal since July 1961.

Volume 65A (Phys. and Chem.), No. 4 (July–Aug. 1961)

Electrical properties and kinetics of electrode reactions. R. J. Brodd.

Effect of hydrostatic pressure upon the relaxation of birefrigence in amorphous solids. R. M. Waxler and L. H. Adams.

Vapor pressures of platinum, iridium, and rhodium. R. F. Hampson, Jr., and R. F. Walker.

Crystallization of bulk polymers with chain folding: theory of growth of lamellar spherulites. J. D. Hoffman and J. I. Lauitzen, Jr.

Phase equilibrium relations in the binary system barium oxide-niobium pentoxide. R. S. Roth and J. L. Waring.

Solid state reactions involving oxides of trivalent cations. S. J. Schneider, R. S. Roth, and J. L. Waring.

Gamma irradiation of fluorocarbon polymers. R. E. Florin and L. A. Wall.

Inhibition of diffusion flames of methyl bromide and trifluoromethyl bromide applied to the fuel and oxygen sides of the reaction zone. E. C. Creitz.

*Publications in these series are available, unless otherwise indicated, from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. For a discussion of the publications program, see p. 21.

Volume 66A (Phys. and Chem.), No. 3 (May–June 1962)

Glass filters for checking performance of spectrophotometer-integrator systems of color measurement. H. J. Keegan, J. C. Schleter, and D. B. Judd.
Calibration of small grating spectrometers from 166 to 600 cm^{-1}. L. R. Blaine, E. K. Plyler, and W. S. Benedict.
Franck-Condon factors to high vibrational quantum numbers II: SiO, MgO, SrO, AlO, VO, NO. R. W. Nicholls.
Oxidation of aldoses with bromine H. S. Isbell.
An analysis of the solid phase behavior of the normal paraffins. M. G. Broadhurst.
Methylene groups in determination of disulfide and methylene sulfide crosslinks in polycaprolactam fibers. S. D. Bruck.
Purification by automatic gas chromatography. M. Tenenbaum and F. L. Howard.
High resolution investigation of some infrared bands of carbon disulfide. D. Agar, E. K. Plyler, and E. D. Tidwell.

Volume 65B (Math. and Math. Phys.), No. 3 (July–Sept. 1961)

Theory of an accurate intermediary orbit for satellite astronomy. J. P. Vinti.
Note on the "baffled piston" problem. F. Oberhettinger.
Some results on non-negative matrices. M. Marcus, H. Minc, and B. N. Moyls.
Probability inequalities of the Tchebycheff type. I. R. Savage.

Volume 65B (Math. and Math. Phys.), No. 4 (Oct.–Dec. 1961)

Physical entities and mathematical representation. C. H. Page.
On the range of a fleet of aircraft. A. J. Goldman.
Measurement of wave fronts without a reference standard: Part I. The wave-front-shearing interferometer. J. B. Saunders.
On the evaluation of the function $\Phi(\lambda)=\frac{1}{2\pi i}\int_{\sigma-i\infty}^{\sigma+i\infty} e^{u\ln u+\lambda u}du$ for real values of λ. W. Börsch-Supan.
Analyticity and probability properties of one-dimensional Brownian motion. A. Ghaffari.
Some higher order integral identities with application to bounding techniques. J. H. Bramble and B. E. Hubbard.
A priori bounds in the first boundary value problem in elasticity. J. H. Bramble and L. E. Payne.

Volume 66B (Math. and Math. Phys.), No. 1 (Jan.–Mar. 1962)

Error bounds for eigenvectors of self-adjoint operators. N. W. Bazley and D. W. Fox.
Intermediary equatorial orbits of an artificial satellite, J. P. Vinti.
Selected bibliography of statistical literature 1930 to 1957: V. Frequency functions, moments, and graduation. L. S. Deming.
Measurement of wave fronts without a reference standard: Part 2. The wave-front-reversing interferometer. J. B. Saunders.

Volume 66B (Math. and Math. Phys.), No. 2 (Apr.–June 1962)

Hindsight technique in machine translation of natural languages. I. Rhodes and F. L. Alt.
An extension of Jensen's theorem for the derivative of a polynomial and for infrapolynominals. O. Shisha.
Two matrix eigenvalue inequalities. S. Haber.
Graphs for determining the power of Student's *t*-test. M. C. Croarkin.

Volume 65C (Eng. and Instr.), No. 3 (July–Sept. 1961)

Prediction of symptoms of cavitation. R. B. Jacobs.
Heating and cooling of air flowing through an underground tunnel. B. A. Peavy.
Stress-corrosion cracking of the AZ31B magnesium alloy. H. L. Logan.
Coatings formed on steel by cathodic protection and their evaluation by polarization measurements. W. J. Schwerdtfeger and R. J. Manuele.
Calibration of inductance standards in the Maxwell-Wien bridge circuit. T. L. Zapf.
Calibration of loop antennas at VLF. A. G. Jean, H. E. Taggart, and J. R. Wait.
Location of the plane of best average definition with low contrast resolution patterns. F. E. Washer and W. P. Tayman.
Influence of temperature and relative humidity on the photographic response to Co^{60} gamma radiation. M. Ehrlich.

Volume 65C (Eng. and Instr.), No. 4 (Oct.–Dec. 1961)

A new airglow photometer. C. M. Purdy, L. R. Megill, and F. E. Roach.
A guide to the use of the modified reflectometer technique of VSWR measurement. W. J. Anson.

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An X-ray diffractometer cryostat providing temperature control in the range 4 to 300 °K. F. A. Mauer and L. H. Bolz.
Apparatus for determination of pressure-density-temperature relations and specific heats of hydrogen to 350 atmospheres at temperatures above 14 °K. R. D. Goodwin.
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A study by polarization techniques of the corrosion rates of aluminum and steel underground for sixteen months. W. J. Schwerdtfeger.

Volume 66C (Eng. and Instr.), No. 1 (Jan.–Mar. 1962)

Reference tables for 40 percent iridium-60 percent rhodium versus iridium thermocouples. G. F. Blackburn and F. R. Caldwell.
A method for the self-calibration of attenuation-measuring systems. R. L. Peck.
Special shielded resistor for high-voltage d-c measurements. J. H. Parks.
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Creep of cold-drawn nickel, copper, 70 percent nickel-30 percent copper, and 30 percent nickel-70 percent copper alloys. W. D. Jenkins and W. A. Willard.

Volume 66C (Eng. and Instr.), No. 2 (Apr.–June 1962)

Effect of vibration and shock on unsaturated standard cells. R. J. Brodd and W. G. Eicke, Jr.
Experiments on the burning of cross piles of wood. D. Gross.
Transfer of NBS X-ray beam calibrations. J. S. Pruitt, A. Allisy, G. Joyet, W. Pohlit, M. Tubiana, and C. Zupančič.
Identification of metallurgical reactions and their effect on the mechanical properties of 17–7 PH stainless steel. H. C. Burnett, R. H. Duff, and H. C. Vacher.
The ideal Lovibond color system. D. B. Judd, G. J. Chamberlin, and G. W. Haupt.
Systems of electrical units. F. B. Silsbee.

Volume 65D (Radio Prop.), No. 4 (July–Aug. 1961)

Almost fifty years of URSI. J. H. Dellinger.
Power density requirements for airglow excitation by gyrowaves. V. A. Bailey.
On the validity of some approximations to the Appleton-Hartree formula. K. Davies and G. A. M. King.
Amplitude and angular scintillations of the radio source Cygnus-A observed at Boulder, Colorado. R. S. Lawrence, J. L. Jespersen, and R. C. Lamb.
Digital methods for the extraction of phase and amplitude information from a modulated signal. R. S. Lawrence, J. L. Jespersen, and R. C. Lamb.
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Antenna coupling error in direction finders. C. W. Harrison, Jr.
The electrically short antenna as a probe for measuring free electron densities and collision frequencies in an ionized region. R. W. P. King, C. W. Harrison, Jr., and D. H. Denton, Jr.
Effect of multiple atmospheric inversions on tropospheric radio propagation. F. H. Northover.
A few observations of the perturbations in the phase of the low-frequency ground wave. J. M. Ross and J. E. Kirch.
Smooth earth diffraction calculations for horizontal polarization. L. E. Vogler.
On the theory of mixed-path ground-wave propagation on a spherical earth. J. R. Wait.

Volume 65D (Radio Prop.), No. 5 (Sept.–Oct. 1961)

Frequency dependence of *D*-region scattering at VHF, J. C. Blair, R. N. Davis, Jr., and R. C. Kirby.
Theoretical scattering coefficient for near vertical incidence from contour maps, H. S. Hayre and R. K. Moore.
Mutual interference between surface and satellite communication systems, W. J. Hartman and M. T. Decker.
VHF and UHF signal characteristics observed on a long knife-edge diffraction path, A. P. Barsis and R. S. Kirby.

Experimental study of inverted L-, T-, and related transmission-line antennas, S. Prasad and R. W. P. King.
Reflection from a sharply bounded ionosphere for VLF propagation perpendicular to the magnetic meridian, D. D. Crombie.
Resonance of the space between earth and ionosphere, H. Poeverlein.
Observed attenuation rate of ELF (region below 1 kc/s) radio waves, A. G. Jean, A. C. Murphy, J. R. Wait, and D. F. Wasmundt.
A note concerning the excitation of ELF electromagnetic waves, J. R. Wait.
Computation of whistler ray paths, I. Yabroff.
On the analysis of LF ionospheric radio propagation phenomena, J. R. Johler.

Volume 65D (Radio Prop.), No. 6 (Nov.–Dec. 1961)

The solar wind, E. N. Parker.
Attenuation coefficients for propagation at very low frequencies (VLF) during a sudden ionospheric disturbance (SID), E. T. Pierce.
Dipole radiation in a conducting half space, R. K. Moore and W. E. Blair.
Reliability of atmospheric radio noise predictions, J. R. Herman.
Effects of the ionosphere on VLF navigational aids, W. T. Blackband.
On the spectrum of terrestrial radio noise at extremely low frequencies, H. R. Raemer.
The nonsingular embedding of transition processes within a more general framework of coupled variables, J. Heading.
Worldwide VLF standard frequency and time signal broadcasting, A. D. Watt, R. W. Plush, W. W. Brown, and A. H. Morgan.
Design of panoramic ionospheric resources, L. H. Heisler and L. D. Wilson.
A quick method for estimating the stage of the sunspot cycle, W. B. Chadwick.
Measurements of low-angle radiation from a monopole, A. C. Wilson.

Volume 66D (Radio Prop.), No. 1 (Jan.–Feb. 1962)

A survey of the very wide band and frequency independent antennas—1945 to the present. J. D. Dyson.
Numerical investigation of the equivalent impedance of a wire grid parallel to the interface between two media. T. Larsen.
Current on and input impedance of a cylindrical antenna. Y. M. Chen and J. B. Keller.
Radar corner reflectors for linear or circular polarization. G. Latmiral and A. Sposito.
On the theory of wave propagation through a concentrically stratified troposphere with a smooth profile. H. Bremmer.
On the propagation of VLF and ELF radio waves when the ionosphere is not sharply bounded. J. R. Wait.
Fields of electric dipoles in sea water—the earth-atmosphere-ionosphere problem. W. L. Anderson.
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An approximate full wave solution for low frequency electromagnetic waves in an unbounded magneto-ionic medium. W. C. Hoffman.
VHF radio propagation data for the Cedar Rapids-Sterling, Anchorage-Barrow, and Fargo-Churchill test paths, April 1951 through June 1958. G. R. Sugar and K. W. Sullivan.

Volume 66D (Radio Prop.), No. 2 (Mar.–Apr. 1962)

Atmospheric phenomena, energetic electrons, and the geomagnetic field. J. R. Winckler.
The summer intensity variations of [OI] 6300 A in the tropics. D. Barbier, F. E. Roach, and W. R. Steiger.
Generation of radio noise in the vicinity of the earth. P. A. Sturrock.
Fading characteristics observed on a high-frequency auroral radio path. J. W. Koch and H. E. Petrie.
Some problems connected with Rayleigh distributions. M. M. Siddiqui.
Impedance of a monopole antenna with a radial-wire ground system on an imperfectly conducting half space, part I. S. W. Maley and R. J. King.
Theory of the infinite cylindrical antenna including the feed-point singularity in antenna current. R. H. Duncan.
The *E*-field and *H*-field losses around antennas with a radial ground wire system. T. Larsen.
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Schumann resonances of the earth-ionosphere cavity—extremely low frequency reception at Kingston, R. I. C. Polk and F. Fitchen.
Propagation of plane electromagnetic waves past a shoreline. J. Bazer and S. N. Karp.
Currents induced on the surface of a conducting circular cylinder by a slot. G. Hasserjian and A. Ishimaru.

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32. Tables of spectral-line intensities, Pt. I, Arranged by elements, and Pt. II, Arranged by wavelengths, W. F. Meggers, C. H. Corliss and B. F. Scribner. Pt. I, December 29, 1961, $4.00; Pt. II, October 2, 1961, $3.00.
33. An experimental study of phase variations in line-of-sight microwave transmissions, K. A. Norton, J. W. Herbstreit, H. B. Janes, K. O. Hornberg, C. F. Peterson, A. F. Barghausen, W. E. Johnson, P. I. Wells, M. C. Thompson, Jr., M. J. Vetter, and A .W. Kirkpatrick. Novemher 1, 1961. 55 cents.
34. Tables of chemical kinetics. Homogeneous reactions. (Supplementary Tables). Septemher 15, 1961. $2.75.
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488. An ultraviolet multiplet table, C. E. Moore. Sections 3, 4, and 5 (April 6, 1962). Section 3, 60 cents; Section 4, 45 cents; Section 5, 30 cents.

Miscellaneous Publications. As the name implies, this series includes material, which, because of its character or because of its size, does not fit into any of the other regular publication series. Some of these are charts, administrative pamphlets, Annual Reports, Weights and Measures Conference Reports, and other subjects appropriate to the Miscellaneous series.

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239. Report of the 46th National Conference on Weights and Measures, 1961. January 18, 1962. 65 cents.
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Handbooks. These are recommended codes of engineering and industrial practices, including safety codes, developed in cooperation with the national organizations and others concerned. In many cases the recommended requirements are given official status through their incorporation in local ordinances by State and municipal regulatory bodies.

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81. Safety rules for the installation and maintenance of electric supply and communication lines. Comprising Part 2, the definitions, and the grounding rules of the sixth edition of the National Electrical Safety Code. November 1, 1961 (Supersedes H32 and amends in part, Pt. 2, Definitions and the Grounding Rules of H30 and H43). $1.75.
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PATENTS

The following U.S. patents have been granted to NBS inventors; assigned (or licensed as indicated) to the United States of America, as represented by the Secretary of the department noted in parentheses:

Allred, Charles M., and Hudson, Paul A., No. 2,991,430, July 4, 1961. Automatic R–F level control. (Commerce.)

Barbrow, Louis E., and Wyly, Robert S., No. 3,009,751, November 21, 1961. Externally illuminated exit indicator for an enclosure. (Commerce.)

Brenner, Abner, and Sherfey, Joseph M., No. 3,019,174, January 30, 1962. Process for electrowinning titanium from lower valent titanium alkali chlorides. (Army.)

Carter, Thomas J., No. 3,028,755, April 10, 1962. Apparatus for water penetration testing of sole leather. (Commerce.)

Chelton, Dudley B., No. 3,034,319, May 15, 1962. High-efficiency fluid transfer line coupling. (Commerce.)

Cleek, Given W., and Hamilton, Edgar H., No. 3,022,182, February 20, 1962. Infrared transmitting glasses. (Navy.)

Davis, Benjamin L., and Nyberg, Wilbur C., No. 3,019,150, January 30, 1962. Tape capacitor. (Navy.)

Davis, Merlin, No. 3,030,806, April 24, 1962. Seebeck-Peltier flowmeter. (Commerce.)

Duncan, Richard L., Miller, David J., Caldwell, Frank R., Ruegg, Fillmer W. and Fiock, Ernest F., No. 3,016,704, January 16, 1962. Apparatus for introducing a reactive chemical into the pilot zone of a combustion chamber. (Navy.)

Engen, Glenn F., No. 2,997,652, August 22, 1961. Self-balancing D.C. bolometer bridge. (Commerce.)

Hakkarinen, William, No. 3,020,963, February 13, 1962. Cup anemometer. (Navy.)

Hudson, Paul A., and Allred, Charles M., No. 2,995,708, August 8, 1961. Dry static calorimeter for RF power measurement. (Commerce.)

Lederer, Paul S., No. 3,034,332, May 15, 1962. Step function pressure calibrator. (Navy.)

Loebenstein, William V., No. 3,009,121, November 14, 1961. Adjustable frequency rejection filter. (License.)

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Montgomery, George Franklin, No. 2,995,712, August 8, 1961. High-input-impedance transistor amplifier. (Commerce.)

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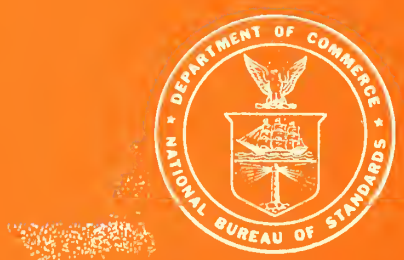

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