
NRL Report 3700
ANNUAL TECHNICAL REPORT
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FISCAL YEAR 1950
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Naval Research Laboratory
Washington, D.C.

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Annual Technical Report

Fiscal Year 1950

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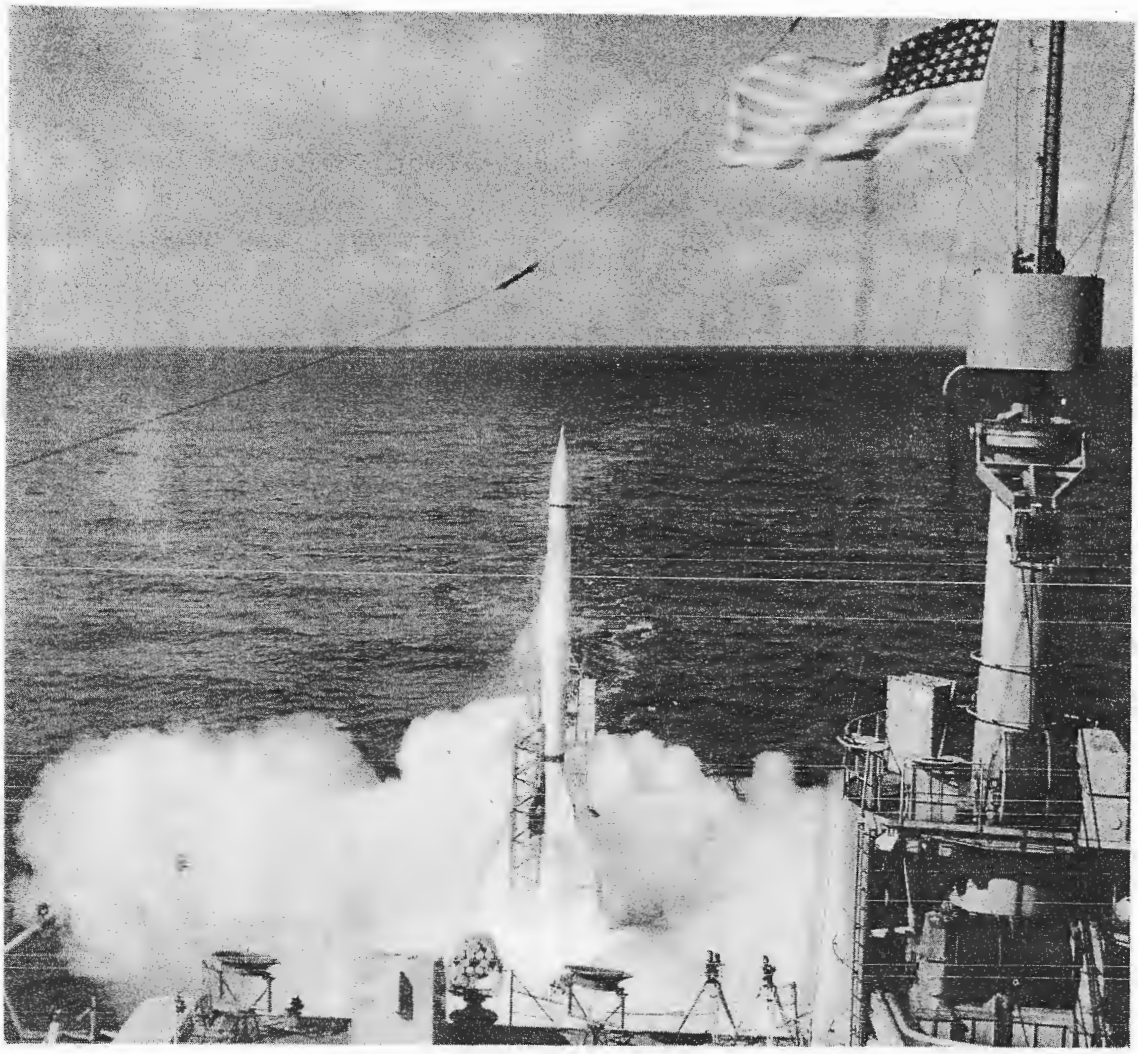
Naval Research Laboratory

CAPTAIN F. R. FURTH, USN, DIRECTOR

Washington, D. C.



The NRL Viking, the largest American-built single-stage rocket, leaves the deck of the USS NORTON SOUND at sea to reach a height of 106 miles. Being engaged in most all branches of basic and applied scientific research, The Naval Research Laboratory pursues an active program in the physics of the upper atmosphere using rockets as the instrument vehicle.

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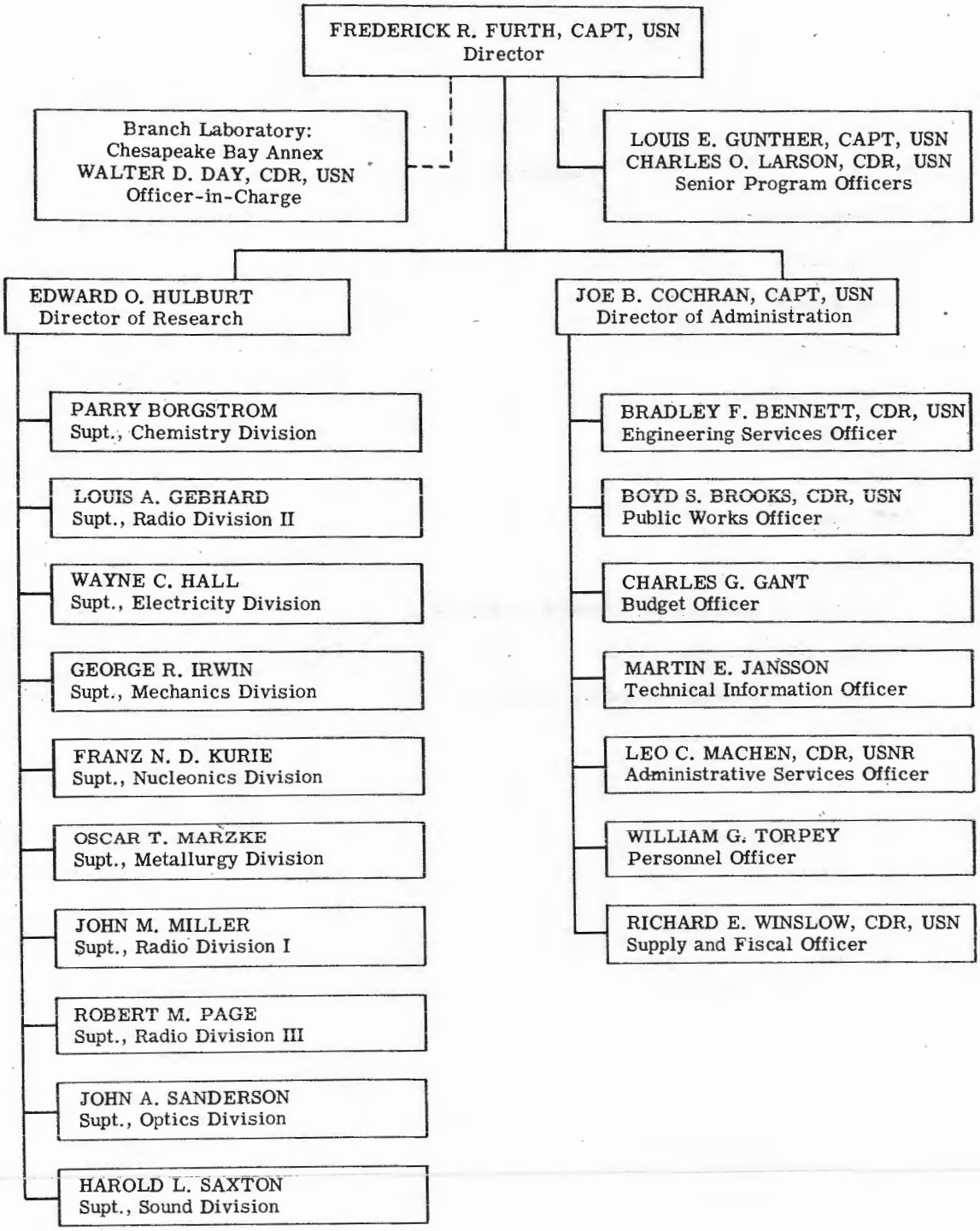


NAVAL RESEARCH LABORATORY

INTRODUCTION

The mission of the Naval Research Laboratory is to support the Chief of Naval Research in his effort to preserve national security by initiating, planning, and conducting in the physical sciences, applied research and development to meet the immediate needs for equipment and materials to increase the combat effectiveness of the Navy, and fundamental research and experimentation in anticipation of future requirements.

Fiscal 1950 was NRL's twenty-seventh year of service to the Fleet, but the research program during that year showed little or no deviation from the traditional pattern. As in fiscal 1949, the most notable characteristic of the work has been continued change in emphasis, begun after VJ Day almost five years ago, from applied research of purely wartime application to long-term, basic investigation. While in general the broad research programs remained unchanged, more and more effort has been devoted to acquisition of fundamental knowledge in several hitherto unexplored areas.

Work for the year was again conducted by ten scientific divisions—one each for chemistry, electricity, mechanics, metallurgy, nucleonics, optics, and sound, and three for radio. For purposes of administration, the Laboratory continued to recognize nine arbitrarily defined "fields" of science. Problems in eight of these fields are generally assigned wholly to the division bearing the corresponding name. The field of "physics" is considered as a special case, responsibility for problems so classified usually being shared by one or more of the scientific divisions.

For the second consecutive year there has been an over-all decrease in the total number of problems. Beginning with 445 research, development, and test problems on 1 July 1949, the Laboratory during fiscal 1950 accepted 103 new problems and closed out 152 existing problems, a net decrease for the year of 49 problems. At year's end, 30 June 1950, a total of 396 problems was under active prosecution.

Although the scientific program is constantly in a state of flux to meet changing needs, and although problems vary in size and complexity, a rough average for the twelve-month period gives a breakdown by scientific division as follows:

DIVISION	AVERAGE NO. OF PROBLEMS 1 JULY 1949 - 30 JUNE 1950
Chemistry	76
Electricity	29
Mechanics	39
Metallurgy	29
Nucleonics	13
Optics	35
Radio Division I	48
Radio Division II	70
Radio Division III	46
Sound	23

For those interested in detailed results on any aspect of the scientific program, attention is directed to the formal NRL technical reports, of which 190 appeared during fiscal 1950, available upon request by authorized persons. This report, consisting wholly of "unclassified" material and hence reflecting only a portion of the effort, is intended as a concise review of such of the Laboratory's recent accomplishments as may be offered publicly without prejudice to national security.

CHEMISTRY

The Naval Research Laboratory has long maintained broad, basic, and continuing investigations covering all the major chemical aspects of naval requirements. During the fiscal year ending June 30, 1950, the chemistry program followed its normal trends of research and development, except for special emphasis on certain immediate problems of strategic importance.

Problems of lubrication, always demanding a major share of attention, have continued under attack via basic research in colloid and surface chemistry, but with intensive efforts toward development of high-temperature greases. New fuels have continued to be sought through continued development of some new compounds. And other important aspects of the program have included continuing work in protective coatings for men and materiel, in electrochemistry and power generation, in rubbers and other elastomers for special applications, in fire extinguishment by foams, and in electrical insulants.

LUBRICATION

Constant research in lubrication is necessary to meet the varied and increasingly difficult requirements of naval equipment. One part of the lubrication program comprises basic studies in colloid and surface chemistry—studies of adsorbed films on surfaces, friction and wear, mechanisms of antioxidant, and rust-inhibitive agents. The other, based upon results of the first, is the actual development of lubricants for specific naval applications where commercial products fail. The field explored at the Laboratory has been largely confined to nonpetroleum lubricants (diesters, polyethers, silicones, etc.) because these materials offer greater possibilities for use at very high and low temperatures.

Improved lubricating greases in which the usual soap gelling agent is replaced with copper phthalocyanine were developed and are being distributed for performance tests. The high melting points and stability of these compounds as compared to those made with soaps point to unusual potentialities for applications over the range -100° to $+450^{\circ}$F. A useful instrument known as the worker-consistometer was developed for studying the flow properties of greases, the effect of shearing stresses during flow, and the ability of a grease to function as a lubricant. It has been shown that high-temperature lubricants for turbo-jet and turbo-prop engines can be prepared from certain synthetic diester oils combined with a heat-resistant antioxidant of the phenothiazine type.

The state of dispersion of lubricant additives (antioxidant, antirust, antiwear) is of particular interest. Recent research demonstrated that often the additive is present in organized clusters called micelles, and progress was made in observing the relationship of micelle formation to the nature and concentration of the additive. It has been proved that many of the soap-type additives are extended association polymers when pure but that the presence of small traces of water causes a remarkable reorganization into smaller compact micelles. The state of dispersion of the additives may be as important as chemical composition.

Research has been in progress on the basic mechanism of operation of various rust inhibitors and on the most appropriate methods of measuring and comparing relative effectiveness. Study of rust inhibition when steel is immersed in water or in oil containing water proceeded with emphasis on the equilibrium between the rust-inhibiting molecules dissolved in the liquid and those adsorbed on the metal surface. A new experimental approach was found for the quantitative study of the adsorption of rust-inhibiting compounds from aqueous solutions.

This stick-slip machine has been developed at the Laboratory by rebuilding a standard machine tool. With it the lubricating action of lubricants on various metal surfaces can be examined and, by the use of electronic and optical-photographic methods, records are obtained for later study and comparison with other lubricants or metal surfaces.

FUELS

The Jentzsch tester, designed by the Germans and used by the German Navy in World War II to determine ignition characteristics of hydrocarbon fuels, was made the subject of a critical evaluation at this and other naval laboratories. Tests on a number of widely different fuels indicated a qualitative but not quantitative relationship between the Jentzsch comparison number and the cetane number. A series of cooperative tests on eight selected fuel cuts conducted at the Engineering Experiment Station (Annapolis), the Naval Boiler and Turbine Laboratory (Philadelphia), and at NRL failed to indicate satisfactory reproducibility. Differences in construction of the individual testers appeared to account for the inconsistencies.

A study was made of contaminants in liquid alkali metals which can contribute to corrosion in metal containers. Special emphasis was placed on oxide contamination, and the solubility curve of oxygen in sodium against temperature was determined. Lower temperature values were determined in glass apparatus by filtering the oxide from the metal and determining it as such. Higher temperature values were determined in stainless steel with the aid of radioactive Na^{24}. The data from the two methods corroborate each other and produce a single solubility curve from the melting point to 500°C.

PROTECTIVE COATINGS

In the field of protective coatings, the problem of tropical deterioration of materiel by moisture and fungi has had continuous study. Exposures have been made of a wide variety of finished items and materials at the Naval Research Laboratory exposure site in Panama and under simulated tropical conditions at the Laboratory. A method is being developed which allows separate evaluations of the respective contributions of moisture and fungus to degradation.

Fungus control by chemical agents is being studied primarily in terms of the physiological responses of the fungi to chemical structure of the added inhibitors. A comprehensive screening program on growth inhibition is in progress and has thus far included about 2500 chemical compounds. On the basis of promising leads disclosed by this screening, specific classes of toxic agents were prepared and their effects upon fungus growth studied in detail. Thiocyanoacetates have proved of particular interest and merit further study. Organic stereoisomers and cis-trans isomers are currently being investigated since little is known about the effect of these molecular rearrangements on fungus growth. Microrespiration experiments are becoming a useful adjunct of the assay data by providing fundamental information on the mechanisms of the various toxic actions.

In the study of protective coatings for magnesium and its alloys, changes in the organic primer have been recommended whereby all or part of the zinc yellow is replaced by calcium chromate. Sufficient quantities of these materials have been prepared for submission to the Naval Aircraft Factory and to several Bureau of Aeronautics' contractors for service application. In addition to the change in pigmentation, it was shown that protection was improved by the use of 100-percent phenolic vehicles.

The problem of organic linings for fuel storage tanks is being actively prosecuted. During the war the Bureau of Yards and Docks constructed several hundred large concrete storage tanks in the various theatres of war and lined them with Thiokol and other organic coatings to protect the gasoline from deterioration by the concrete. While these tanks have given very good service over a period of five or six years, occasional complaints of deterioration prompted an extensive survey and re-evaluation of the entire lining problem in the fall of 1949. Thiokol linings were found to be still serviceable with some exceptions, but deterioration occurred where jet fuels had been stored. An experimental program is being conducted at this Laboratory to improve the formulation of these latex coatings, and the properties of other lining materials are being studied. A number of Saran and vinyl-base compounds have shown remarkable resistance even toward jet fuels, and recommendations will soon be made to the Bureau of Yards and Docks for revisions in the current specifications for fuel-tank linings.

ELECTROCHEMISTRY

Studies in electrochemistry during fiscal 1950 centered on batteries, both secondary and primary. Basic research on lead-acid storage batteries included a study of the corrosion mechanism of the positive grid. As one phase of this study, pure lead was anodized at constant potentials in sulfuric acid. It was found that PbO_2 forms a protective film over a limited range of potentials above the equilibrium potential for its formation and that above this range the film breaks down and PbO_2 is continuously formed at a higher rate. At rates below the equilibrium potential, tetragonal PbO was shown to be formed, and an equation for its rate of formation was worked out. The rate of attack was found to increase with increasing temperature and decreasing concentration of electrolyte.

As another approach to this corrosion problem, specific etching techniques were developed for use in metallographic studies of lead and its alloys, and, when coupled with special X-ray and optical methods of detecting and identifying various portions of the structure, especially after corrosion, it is believed that considerable progress can be made in understanding the physical manner in which this corrosion takes place. This information should be of considerable value in attempting to prolong the life of any storage battery, particularly of the submarine type.

In connection with the problem of protecting steel hulls from electrolytic corrosion by the use of sacrificial zinc anodes, a method was evolved for the study of polarization decay and build-up at the electrode surfaces. This was made possible by a new dc interrupter technique developed at the Laboratory. Such a method permits the calculation of the capacity of the double layer, thus making it feasible to obtain true potential measurements at the electrode surfaces. The method may find a wider application in the study of many electrochemical reactions.

GAS ANALYSIS

In the development of a composite gas analyzer for submarine use, considerable progress was made by outside contractors in the development of the positive filter method for infrared absorption to determine concentrations of carbon dioxide, carbon monoxide, and hydrocarbon vapors. This equipment is being evaluated at the Laboratory, and it is likely to prove suitable. A modified Pauling instrument appears to offer a satisfactory basis for the determination of oxygen by its paramagnetic properties. A newly developed method combining thermal conductivity and convection effects appears to have considerable possibility for the determination of hydrogen and possibly carbon dioxide.

The possibility of using a single instrument exists in the new radio-frequency mass spectrometer being developed by the National Bureau of Standards. At the present time the Bureau, at the request of NRL, is determining the sensitivity of this new instrument for the negative ion of carbon monoxide. In the conventional mass spectrometer the high sensitivity required for carbon monoxide is not possible because of the presence of large quantities of nitrogen (which has the same molecular weight as carbon monoxide). Since carbon monoxide forms a negative ion and nitrogen does not, it may be possible to determine CO by this method.

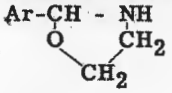
HIGH POLYMERS

In the field of high polymers a broad investigation of organo-phosphorus chemistry was continued because of interest in such compounds as resin intermediates, rubber compounding materials, lubricant additives, plasticizers, fire retardants, and other materials of naval interest. Exploratory research led to a new synthesis of alkyldichlorophosphines, previously unavailable without the use of tedious and dangerous procedure, by the reaction of dialkyl cadmium compounds with phosphorus trichloride. A long homologous series of such compounds was made and characterized. The synthesis of aryldichlorophosphines via the Friedel Crafts reaction was made practical by improvements which increase the usual yields of 3-20 percent to approximately 80 percent.

Work on the problem of relating ozone concentration to rubber deterioration led to the development of equipment for the determination of very low concentrations of ozone in air. It was subsequently used in a survey of the so-called "standard" Navy rubber aging equipment (National Eveready X-1A). From measurements at the Mare Island, Puget Sound, Philadelphia, New York, and Portsmouth Naval Shipyards, and at NRL, it was concluded that, because of the large number of

variables affecting ozone concentration (arc current and voltage, carbon alignment, air leaks in test chamber, rate of exhaust gas removal, and the laboratory atmosphere), it would be difficult, if not impossible, to get all X-1A units installed and operated in such manner as to give comparable results in accelerated weathering tests on rubber.

Further work in rubber chemistry led to development of new formulations to fill military requirements. Basic research was directed toward an understanding of factors affecting physical properties and deterioration rates. An extensive survey was made on the use of elastomers in high-vacuum systems, and suitable materials for particular uses in such systems were developed. New vulcanization accelerators were prepared, and a beginning was made on the complex problem of relating accelerator structure to the properties of the vulcanizate. In the course of investigation of aldehydeamine condensation accelerators, it was shown by infrared absorption spectra that, contrary to views previously expressed in the literature, the reaction of ethanolamine with an aromatic aldehyde has a Schiff base structure, Ar-CH=N-CH_2-CH_2OH, rather than the oxazolidine ring structure,



INFRARED SPECTROSCOPY

Infrared spectral methods for structural determination and identification have also been utilized in other problems in fuels, lubricants, and polymers, particularly in connection with silicone fluids and synthetic rubbers, and the applicability of the methods was extended by further research on hydrocarbons, fluorinated compounds and phosphorus compounds. From data for 121 liquid hydrocarbons there have been found useful bands for the characterization of 18 different molecular groups, including isobutyl, 3-methylbutyl, 3-ethylbutyl, 4-methylamyl, 2,3-dimethylamyl, neopentyl, vinyl, benzyl, benzal, etc. Infrared spectra of over forty fluorinated compounds, mostly hydrocarbons, were obtained and, in cooperation with contract work in Raman spectroscopy at the University of Oklahoma, nearly complete vibrational assignments have been made for eight compounds, and partial assignments for at least ten others. From the data, characteristic bands were derived for the identification of fluorinated olefinic structures and aromatic structures with fluorine or CF_3 substituents. In phosphorus chemistry, the infrared and Raman spectra of trimethylphosphine oxide were completely interpreted, and new spectral methods were demonstrated for the identification of organophosphorus compounds including phosphonic and phosphinic acids, phosphites, phosphonites, phosphonates, and phosphinates.

FIRE EXTINGUISHMENT

The Navy's vital interest in fire extinguishment has been the continuing concern of a specialized group at the Laboratory. Seven years of research and development has recently resulted in the first naval installation of the subsurface foam injection method of oil tank fire protection at Jacksonville, Florida. The redesign of carrier large-capacity foam systems was completed and installed on several ships. Trial shipboard tests have shown the benefits gained by NRL analysis and study of the systems. Immediate operation of the foam nozzles is now possible through reliable push-button operation.

Additional research was conducted to elucidate the mechanism of fire extinguishment by mechanical foam. Results show clearly the prominent role played by the water in the foam in combating hydrocarbon fires, even in the case of gasoline where it was generally believed that vapor transmission prevention was the most important factor in the process.

ELECTRICAL INSULATION

In connection with electrical insulation studies, the logistically unsound dependence of electrical equipment manufacturers on asbestos from Africa and mica from India and Madagascar has led to research on the beneficiation of native ores. The presence of large quantities of asbestoses in New England, Georgia, and California, together with voluminous deposits of micaceous ores in North Carolina, warrant such studies.

A novel method of cleaning asbestos was developed which consists of water-dispersing the raw material in a paper-beater, passing the slurry through a Vortrap (a pipe-like apparatus which creates a vortex in a cylinder, centrifugal action separating the light asbestos fibers from the heavier rock-like impurities), and filtering off the soft fibers mechanically. The resulting product proved to be of much greater purity than that obtained by the conventional processes involving either fluffing with air or screening.

The refining of native mica was found feasible by dispersing books of low-grade ore in water, floating the microscopically thin plates over a riffle box (trapping the magnetite therein), and re-consolidating the particles into a continuous, purified, paper-like, totally micaceous sheet. Utilization of this material in most electrical applications where imported mica is now employed including capacitors, seems likely.

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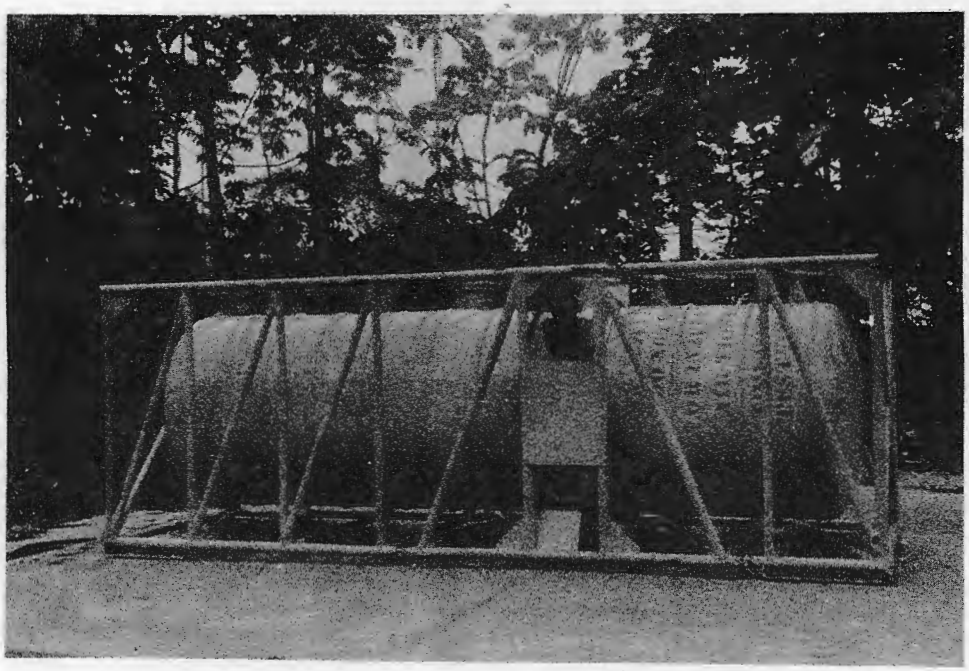


The Laboratory maintains a testing station in Panama where the effects of tropical temperatures and humidities on naval and military equipment are studied. An experimental sealed container for a jet engine is being weathered to note the effects, if any, of the tropical climate on the interior temperatures and humidities. Among tropical exposure stations, NRL is outstanding for its ability to handle items as large as this.

ELECTRICITY

The program in electricity, formulated at the Laboratory five years ago, involves research and development in electrical engineering devoted primarily to three categories: (a) shipboard electrical systems; (b) airborne electrical systems; and (c) operational devices for all branches of the Navy.

Facilities for research and development in electrical engineering are being expanded. Drive stands capable of generating 400 horsepower will soon be installed for investigations on high-powered airborne generators. Altitude and weather chambers are available for making these investigations over a wide range of altitude, temperature, and humidity.

VOLTAGE REGULATION

A typical aircraft electrical system contains one or more carbon pile voltage regulators which are subject to wear and, consequently, misadjustment in normal service. Research is required to improve the stability and reliability of such equipment in military aircraft. Investigations are going forward at the Naval Research Laboratory to devise techniques permitting a better theoretical study and analysis of dc voltage regulators and transients in dc generator-regulator systems. Emphasis was placed upon the analysis of a system consisting of a single generator with an associated carbon pile voltage regulator.

The approach to this problem has been through the application of the basic principles of feedback amplifier theory, and assumptions were made so that the system may be considered linear. Using these assumptions, it was possible to express mathematically the stability and transient characteristics of the system. The transfer function of the carbon pile regulator was derived, and a method evolved by which this function can be measured. In addition, the entire system was analyzed as a closed-loop control system. When full load is removed from the generator, the calculated and measured terminal voltage transient responses are found to be essentially in agreement.

PERMANENT MAGNET ALTERNATORS

Electrical systems in aircraft are subject to malfunctioning of sliding contacts such as brushes on commutators or on slip rings. This malfunctioning may be due to excessive filming of the commutators or slip rings during sea level operation or due to excessive brush wear when operating under altitude conditions. The permanent magnet alternator operates without slip rings or commutators; therefore, a research program is under way to investigate the characteristics of such machines.

In the past, one of the major problems involved in the application of permanent magnet alternators has been the demagnetization of the magnets on sudden application of overload or short circuit and their failure to recover on removal of the overload or short circuit. The type of permanent magnet machine being studied deliberately provides for magnetic shunt paths around the field magnets as well as high-current-capacity short-circuit paths around the magnets to limit the demagnetizing effects of short circuits and overload.

An additional problem encountered with permanent magnet alternators, particularly the above type, is the inherently poor regulation of the units. Consideration is being given to the design of static regulators that will provide continuous control of the terminal voltage for conditions of variable load and variable speed.

The development of such a generating system would make possible an aircraft electrical system entirely free of sliding contacts, thus eliminating the source of excessive brush wear, reducing the problem of conducted and radiated radio noise, and resulting in improved performance.

ARCING FAULT PHENOMENA

Failures in aircraft electrical systems are being studied with particular reference to the intermittent faults which may occur in the system causing severe damage to the aircraft structure without a corresponding heating of the faulted conductor or without tripping a conventional protective system. Data have been gathered on the more common 30-volt dc systems now used in aircraft and on other systems less commonly used, such as the 120-volt dc and the 120/208-volt, 3-phase, 400-cycle ac systems.

An analysis of the data collected while investigating the 30-volt dc system indicated that although 25 percent of the faults became welded 75 percent were intermittent or arcing in nature and could result in extensive damage to the aircraft structure. With further analysis on the magnitude and time characteristics of the faults which are a hazard to the structure, it will be possible to state the operating requirements of protective devices which will reduce or eliminate this hazard.

Investigations on the faults which might be encountered in 120-volt ac systems were confined to single-phase faults since these seem most likely to occur in aircraft. Here, too, it was found that the large percentage of faults established under laboratory conditions resulted in intermittent faults. Wide variation in fault current magnitude was found for a particular conductor size, although maximum peak currents decreased as the faulted conductor cross section became smaller. The fault current was found to be determined primarily by the contact resistance and the arc resistance. Vibration frequency, direction, and displacement had but little effect on the current magnitude of the first fault pulse.

The duration of 98 percent of the first fault pulses established in the investigation of the 120-volt ac system was less than 0.01 second. This time factor is less than that for 30-volt dc faults and accounts for the fact that more structural damage resulted from the 30-volt dc faults than from the 120-volt ac faults. No correlation was observed between vibration frequency, direction, and displacement, and the fault duration. Further studies will be made on the various systems now in use or under proposal to determine the contribution of environmental conditions found in aircraft to the phenomena of arcing faults.

DETERMINATION OF MINIMUM LEAKAGE AND CLEARANCE DISTANCES

The design of electrical systems for high-speed submarines requires exact knowledge of the limitations of the materials which are used, and specific data are required on the minimum leakage and clearance distances permissible for insulation. At the present time, no sound engineering basis is available for specifying these distances. Existing data and values are based entirely on industrial experiences which have been found to provide minimum safe values for certain special applications, but which are often not applicable to naval installations.

Experimental work has been completed in establishing techniques for determining the safe leakage distance, determining shipboard environmental conditions for insulation, and compiling a table of values setting forth minimum values for leakage and clearance distances. A new technique was developed for determining the minimum safe value of leakage distances for several types of insulating materials being employed on shipboard electrical systems. The criterion that was established based this distance on what has been termed "tracking voltage," which is the maximum permissible voltage that may be impressed across a given piece of insulating material without producing visual signs of damage to its surface. This technique in conjunction with a knowledge of the surface contaminants that exist in submarines was used to produce a set of tables showing the permissible values of spacing for the various contaminant conditions found where the equipment is installed.

It was shown that the leakage distance is dependent on water, sodium chloride, and many other conducting contaminants, and that the presence of such contaminants as carbon, bits of fibre, etc., are of secondary importance and need not be considered. The electrode geometry and the angle the insulating material makes with the horizontal have also been analyzed for effects on leakage distance.

The soundness of the technique in arriving at leakage distance through the use of tracking voltage was clearly demonstrated through an extensive study that included all factors effecting an ultimate breakdown of the insulation. Design data resulting from measurements made by this method need not be modified with a safety factor.

TRANSIENT CHARACTERISTICS OF DIRECT-CURRENT MACHINES

The performance of direct-current machinery and lead-acid storage batteries under transient and fault conditions is extremely significant in shipboard dc systems where freedom from commutator flashover and reliability of circuit breaker operation are necessary. This is especially true in large-capacity systems where excessive fault currents make the attainment of circuit breaker selectivity a difficult matter. Accordingly, a study is under way to determine the current supplied by dc rotating machinery and submarine batteries to system faults; to investigate such variables as machinery rating and operating conditions, battery condition and fault circuit resistance; and to determine the rate of rise and decrement of the fault currents. Furthermore, studies are being made to determine flashover characteristics of dc machinery as the result of overloads.

Using a mock submarine electric system, an investigation was made of the short-circuit characteristics under various operating conditions of the motors, generators, and batteries employed in submarines. Not only were the short-circuit currents experimentally determined, but also existing relationships were evaluated to describe the transient behavior of dc machines. Observations indicate that existing theoretical relationships do not possess the accuracy necessary for obtaining the optimum design for shipboard power systems. In general, there is no adequate reflection of the influence of initial conditions of load, voltage, and speed on peak currents; and the buildup and decay of armature and field currents are not predicted with design accuracy.

It is furthermore indicated by these studies that a better fundamental knowledge of the internal phenomena of rotating machinery is required before relationships may be formulated to calculate the transient response of dc machines with the required accuracy. Work is now in progress to study the several factors such as air gap flux behavior, changes in armature, field and mutual inductance, and the effects of reactance voltage during large transient currents. A study is being made, also, to describe accurately the phenomena of flashover and to determine methods which will reduce the susceptibility of dc machines to flashing in the case of large overload currents.

Since dc machines in submarines are associated with lead-acid storage batteries, studies have been made on such batteries to determine their effect on transients in these composite systems. The battery internal resistance, internal voltage, short-circuit voltage, and recovery voltage are all important under conditions of battery operation. For the first time, it was demonstrated that overvoltage which exists during the charging of a lead-acid battery is capable of contributing to transient currents and hence existing overvoltage must be taken into consideration in making fault current calculations.

* * *

MECHANICS

Mechanics programs at the Naval Research Laboratory include research on shock and vibration, strength of solids, and penetration ballistics. The ultimate aim of the shock and vibration project is to evolve design criteria for shock-resistant shipboard equipment and machinery and for vibration-isolation devices. The strength of solids program has under consideration (a) determination of the mechanical strength properties of materials under mechanical shock typical of combat; (b) basic analysis of the development of cracks and the mechanism of brittle failure; and (c) study of the stress-strain-time relations involved in plastic flow. The aim of penetration ballistics problems is to discover what happens when a missile strikes a target. Answers are sought to such questions as:(a) Can penetration of fragments be represented by a penetration law and, if so, what features limit this procedure? What new factors influence deformation resistance at very high straining speeds? (b) If fuel vapors are present, under what conditions will the impact flash cause an explosion? (c) Can one demonstrate a rational, quantitative method of assessing gunfire damage to components and produce data which will be useful in aircraft design?

SHOCK AND VIBRATION

It would be helpful in safeguarding structures against the effects of shock and vibration to understand the propagation phenomena of such mechanical effects. A completed experimental study of transverse waves in plates under centrally applied impulsive loads showed the considerable magnitude of error made when displacements are large and one assumes zero "middle surface" strain. Stress amplitudes, waveforms, and propagation rates were also determined quantitatively. Vibration investigation in the solid state made use of low- and ultrasonic-frequency techniques to probe the influence of permanent strains on the velocity of longitudinal, shear, and Rayleigh waves.

Trends noted in preliminary work indicated that tensile strain lowered the velocity of longitudinal waves in tool, mild, and hot-rolled 1020 steel; that compressional strain affected the velocity of longitudinal waves similarly in 25 aluminum, copper, phosphor-bronze, and stainless steel; and that strains have an effect on shear-wave velocities opposite to that on longitudinals. Strained copper and tool steel were found to affect wave velocity more than strained aluminum and hot-rolled 1020 steel. Refinements of ultrasonic pulse-time techniques were found which permit wave-velocity measurement to an accuracy of 0.2 percent.

Efforts were extended to improve devices which produce and measure shock and vibration. Shock-generating machine characteristics were studied to determine whether they properly simulate field conditions. Calibration of the medium-weight, shock-generating machine involved mounting a given load perpendicularly to the anvil table and subjecting it to different conditions of applied load, hammer height, and table displacement. Reed gauges, velocity meters, accelerometers, strain gauges, and the "Mirragraph" were employed to record shock motions and to determine the velocity of load-peak acceleration, initial anvil-table velocity, and peak accelerations. A velocity meter with 4-inch travel and one-fourth the weight of existing types was designed, constructed, and evaluated.

During the summer of 1948, in cooperation with other Navy groups, there was conducted an extensive series of trials of shock effects propagated through a ship's structure. Noncontact underwater explosions near the USS NIAGARA (APA87) were employed. During the past fiscal year data from these explosion trials were treated statistically to find if peak-reading gauge measurements are representative of those obtained by velocity meters. For these tests, it was found, reed gauges give a good approximation of maximum velocity, but for underwater explosions of long duration both reed gauges and putty gauges do not respond properly to maximum accelerations. In conjunction with vibration studies of solid bodies, there was developed an ultrasonic inferometer using surface waves, which permits a point-to-point inspection of wave phenomena in cylindrical samples.

An evaluation of shipboard shock mounts was made using rigid and flexible loads for comparison. As a result, specifications in terms of load rating, travel, and initial height were proposed. Four sample mounts, developed jointly with the Rubber Laboratory at Mare Island Naval Shipyard were subjected to impulsive forces. For 150 pounds per mount the shock spectra were found to be identical radially and axially.

The Centralizing Activity for Shock and Vibration (under the cognizance of the Research and Development Board) is centered at the Naval Research Laboratory and, during the past year, conducted three symposia, as follows:

"Mechanical Shock and Vibration Problems in Various Types of Aircraft and Their Influence on Personnel" at Wright-Patterson Air Force Base, Dayton, Ohio, September 8-9, 1949.

"Mechanical Shock and Vibration Problems Pertaining to Missiles and Rockets" at California Institute of Technology, Pasadena, California, December 13-15, 1949.

"The Effects of Mechanical Shock and Vibration upon Military Shipments Conveyed by Common Carriers" in Washington, D. C., March 23-24, 1950.

Results of these meetings showed that shock and vibration hazards impinge upon all fields. The growth and sustaining interest in this project are reflected by over 300 participants at each of the meetings and the expressions of interest from other Research and Development Board Committees for starting similar functions patterned along the work of the Centralizing Activity. A nation-wide survey of all shock and vibration projects under the cognizance of the Department of Defense was conducted, and its findings have been published and distributed.

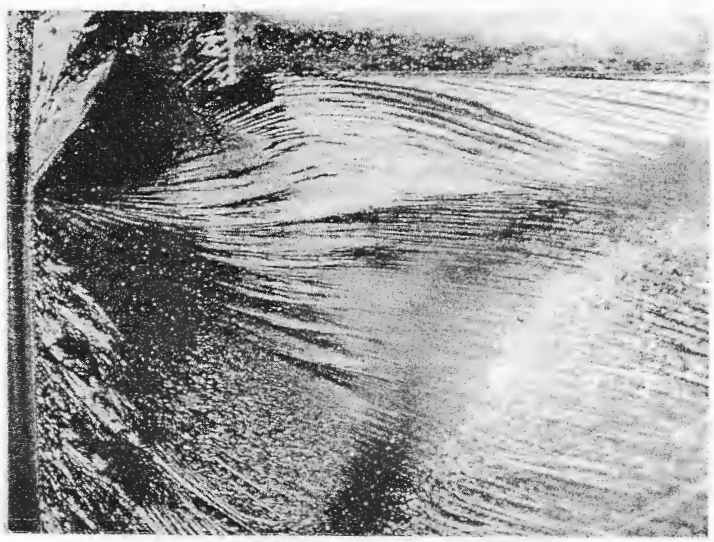
Much research remains on projects begun during the past year. In progress is the design of a new-type accelerometer consisting of one small indicating unit that gives acceleration values in each of the three normal axes. Modifications are planned on the present reed gauge. The performance of the light-weight shock-generating machine will be investigated to check if it properly simulates field conditions. Work toward a rational shock-mount evaluating method is progressing and work was initiated to scale down the size of shock mounts and experiment with stiffer and softer rubber stock. In dynamic response of strength of equipment subjected to shock, the effects of ratio of the mass of a simple system to the mass from which it obtains its energy has been investigated, and an extension of this project to complex structures is in progress. Noise isolation studies on capacities of mounts, measurements of shock and vibration on shipboard, and tests under existing specification of sonar, radar, and other shipboard gear are continuing.

STRENGTH OF SOLIDS

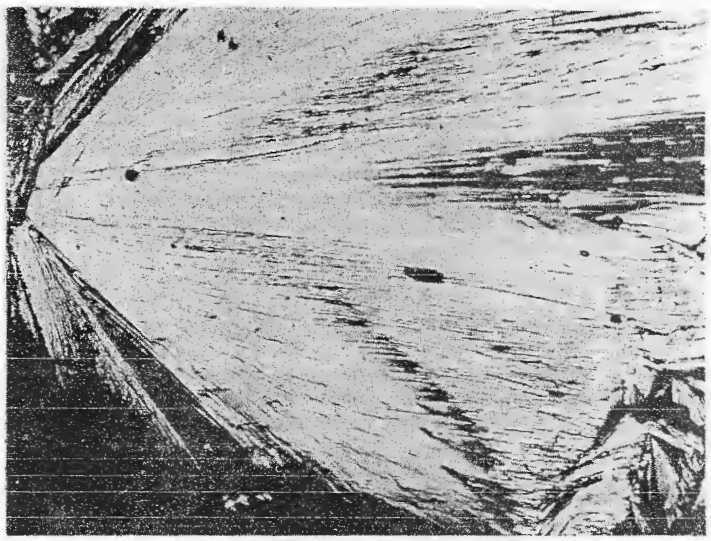
Methods were developed for evaluating the relative mechanical-shock resistance of structural materials to shipboard-type shocks probable under field conditions, and an evaluation was made of some cast aluminum materials. A study now under way on the process of failure in selected materials subjected to a small number (0 to 20,000) of cycles of large strain, seeks to determine the role played by energy loss per cycle, stress, deflection or strain, and cycles to failure. A rotating beam, a cantilever deflection method, and a Navy high-impact shock machine are currently used for these studies.

By utilizing the difference in magnitude of electrical-resistance changes per unit of elastic as compared with plastic strain, an attempt was made to determine the stress-strain relation of a wire specimen. This method, which necessitates measurements of only the change of electrical resistance with strain, was found feasible for some but not for all metals.

The mechanisms and development of cracks which result in both slow and rapid fracture were studied in model systems that generally consisted of foils and thin metal or plastic sheets. Cracks or notches were introduced initally by a knife edge, although ballistic impact was also used. Observations of slow crack propagation were made microscopically; rapid fractures were observed by using high-speed moving pictures (up to 14,000 frames per second). Relations were determined showing energy to propagate a crack versus the crack length. It was shown that, when the specimen crack suddenly developed to complete failure, the energy available and required was contained as stored elastic energy in the specimen. This energy was small compared to that required for slow crack propagation and the failure corresponded to brittle fracture.



Bakelite 15 X



Molybdenum 100 X

Plastics can serve as models for studying fracture mechanisms in metals. These photomicrographs show fan-shaped fracture patterns produced in a bakelite and molybdenum specimen as a result of the same type of fracture initiation in each.

Stress-strain relations were studied for wires and fibers for constant-strain rates, variable between 10^{-6} per second to 10^{-1} per second. Experiments with dead-weight loading of unoriented nylon and polyethylene films showed a delayed yielding analogous to that which occurs in some metals. This phenomenon exhibits itself as a sudden yielding which may occur in the order of minutes after the application of a constant dead-weight load. Studies of X-ray line broadening as induced by deformation have been made to show changes in crystallite size and other structural factors. Possibly the most important feature of these works is the model demonstration of a generally valid concept for failure as consisting of the extension in size of the region or regions which have become unstable relative to plastic flowing. The size of the smallest flow units or domains in certain nylon films was found to be about 10^{-4} centimeter in linear dimensions.

Plans for the immediate future include additional research on these problems. A direct, tension-compression fatigue machine for large strains as well as a machine for momentarily applying large stresses to tensile specimens is under design. Construction of a machine to extend constant-strain-rate measurements for wires and fibers to 102 per second is planned. An additional tool of considerable value for studies of plastic flowing will be established through installation of a high-intensity X-ray source and diffraction camera.

PENETRATION BALLISTICS

Experimental force-penetration data from the optical chronograph were subjected to searching and powerful analyses, confirming the opinion that greater precision would be necessary to reveal velocity and strain-rate effects. One variable, previously uncontrolled, was the friction between penetrator and target. A study of some of the promising lubricants was made and means found to reduce the frictional variation enough for the desired degree of precision. Soft metal platings and certain extreme pressure lubricants both reduced the energy expended for a given volume of indentation by about ten percent. Further reductions appear attainable.

Rectangular target plates had generally been used with the optical chronograph. The difficulty of observing and computing the behavior of this plate under impact constituted an uncertainty. It was decided to reduce this and to make a fundamental alteration in technique simultaneously. These ends were accomplished by introducing a long back-up bar, the impact reaction of which can be more accurately anticipated and measured through wire resistance strain gauges. In several trials force-time curves obtained with this method gave good agreement with force-time curves obtained from simultaneous optical chronograph film records. Support for development and extension of these new measurement techniques was established by a contract with the University of North Carolina.

The impact-flash question necessitated extension of the investigation into the high-velocity range. This entailed construction and installation of a heavy gun mount and a high-speed counter chronograph responsive to light screens; adaptation of a Fastax camera for recording at 14,000 frames per second; and development and standardization of explosive fuel vapor mixtures which would distinguish among impact flash intensities in this high-velocity range.

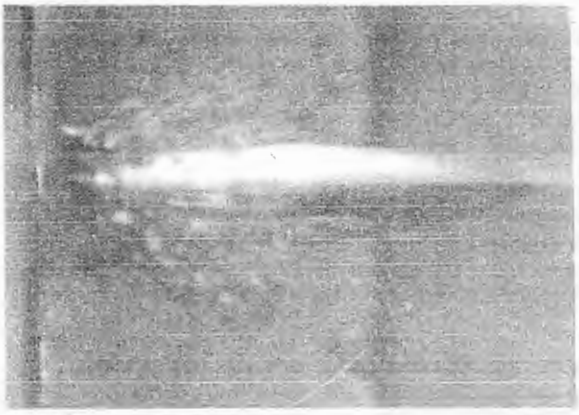
Estimates of the vulnerability of aircraft and of the gunfire damage actually observed have, in general, been empirical, largely subjective, and productive not of measurements but of rough rankings by assignment to such classes as (a) kill, (b) just capable of return to base, and (c) worth repair. A series of high-strength box-beam specimens constructed of aircraft alloys with representative design features was made available for an attempt to demonstrate approach to the more difficult goal of a quantitative and rational method.

Roughly, damage is defined and measured as the decrease in static load to collapse. The collapse load of one specimen is measured. An identical specimen is subjected to carefully controlled gunfire damage simulating combat hits, the relative probability of which can be estimated satisfactorily. The damaged specimen is then loaded to failure and the difference between the collapse loads is taken as the damage to the structural component. Most of the gunfire damage has been applied and enough of the damaged specimens have been tested to indicate it will be possible, in this way, to show significant and quantitative differences between five types of box-beam test structures provided for these trials.

* * *

(a) Bullet in free flight

(b) Early stage of penetration, showing impact flash incandescence



(c) Late stage of penetration

Photographic facilities and techniques are being used to permit the scientist to see action that escapes the eye. By microflash photography, a caliber .50 bullet is seen in flight at 2700 feet per second and in two stages of penetrating a thin aluminum sheet.

METALLURGY

The metallurgy program includes problems in physical metallurgy, melting and casting, and welding. Physical metallurgy problems are established to (a) study effects of chemical composition, structure and processing on physical, chemical and mechanical properties of metals and alloys of known or potential military importance; (b) investigate various solid-state reactions — such as phase changes, precipitation, and ordering — which strongly influence properties; (c) study effects of external conditions on properties, particularly on flow and fracture at low, room, and high temperature; and (d) formulate principles to assist the development of improved alloys or of alloys using less critical materials for various military applications such as ship-plate, armor, aircraft and power plant components, and electronic gear — and when feasible to develop such alloys.

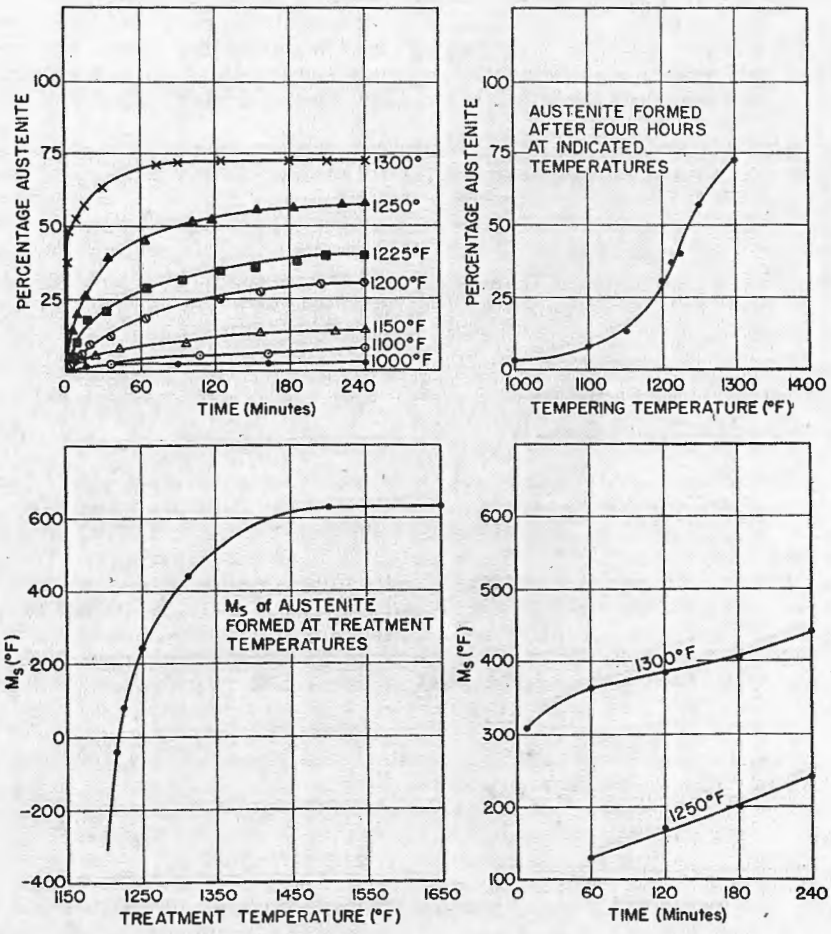
Melting and casting problems aim to investigate methods to improve the properties and reliability of castings for critical service in structural and ordnance components of military equipment; and to study all aspects of the casting processes, including mold materials, liquid-metal quality, flow of metal in molds, mechanics of solidification, and liquid-solid transformation reactions. Under the welding program a basic study is being carried out on the metallurgical, mechanical, and performance characteristics of welds, aimed at improving the joint efficiencies of high-strength structural materials — high-strength, notch-tough steels required for ships and submarines; high-strength aluminum alloys for aircraft; and high-temperature alloys for gas turbines, reaction motors, etc.

PHYSICAL METALLURGY

It has been known for some time that certain alloy steels show erratic physical property changes when tempered at fairly high temperatures close to the generally accepted critical temperature, and it has been theorized that these changes result from formation and decomposition of austenite. A study conducted on a 0.10 percent carbon, 3.5 percent manganese, 2.5 percent nickel steel which had a critical temperature of 1225°F, determined by slow heating, showed that holding for four hours resulted in the formation of some austenite at 1000°F. The amount of austenite formed increased with increasing temperature. Austenite formed at low temperatures, 1200°F and below, did not transform on cooling to room temperature, in fact, did not transform at liquid nitrogen temperatures. Austenite formed above 1200°F transformed to martensite, and the temperature of formation of martensite, M_S, increased with increasing tempering temperature. See curves, page 18.

Tensile and impact tests were made on alloy steel specimens having various percentages of austenite, and tempered and untempered martensite. It was found that austenite lowers yield strength and affects other tensile properties depending upon whether or not it transforms during testing. If it does, tensile strength is raised and elongation and reduction of area are lowered. Austenite has little effect on impact properties unless it transforms during testing. If it transforms to martensite during testing, transition temperature is raised and maximum energy lowered. Likewise, martensite formed during cooling from the tempering treatment increases yield and tensile strengths, lowers elongation and reduction of area, raises transition temperature, and lowers maximum energy.

Considerable information has been gathered on the effects of various alloying elements on the transition temperatures of pearlitic (killed) steels having a base analysis of 0.30 percent carbon, 1.00 percent manganese. Aluminum, boron, carbon, cobalt, chromium, copper, manganese, molybdenum, nickel, phosphorus, silicon, sulfur, titanium, and vanadium were added separately in increasing amounts. Grain size and microstructure were held as constant as possible. It was shown that phosphorus, carbon, silicon, and molybdenum increase transition temperatures; that cobalt, copper, chromium, and boron have little effect on it; and that manganese and nickel lower it, with manganese being the most effective. Aluminum, sulfur, titanium, and vanadium show no consistent trend which, it is felt, is due to the manner in which these elements are distributed between the



Rate of austenite formation and the amount formed after four hours

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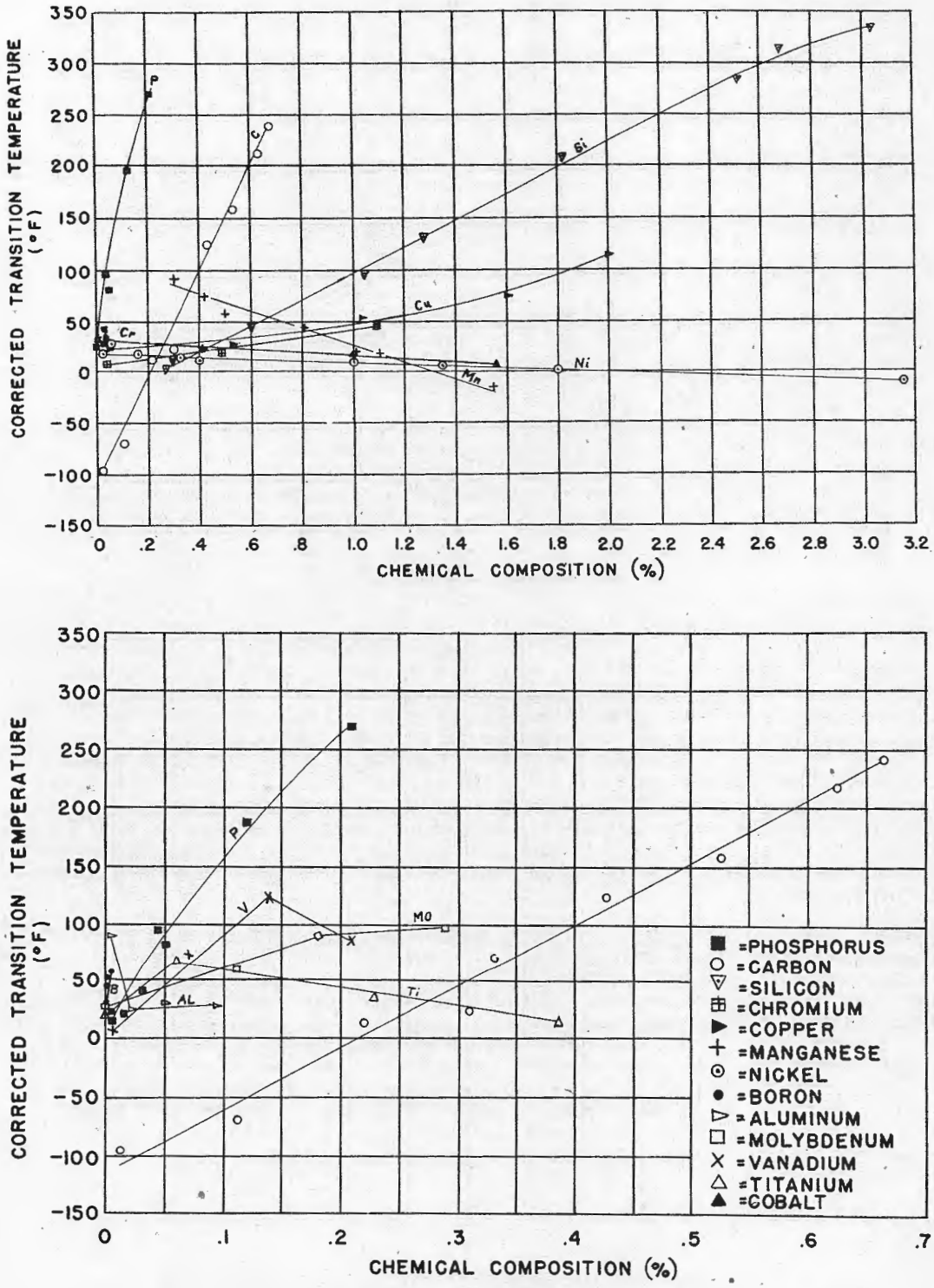

Effects of elements on transition temperatures

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ferrite and precipitated phases. A few tests in which more than one element was varied showed that effects of carbon, manganese, and nickel were approximately additive. See curves, page 19.

The various alloying elements were found to change the shape of the transition curves in different ways. Some caused the curves to be displaced uniformly to the right or left, some affected only the top portion, some only the bottom portion, while others changed the entire shape. Studies are currently under way to determine the significance of these changes.

Room-temperature tensile tests were also made on each of the compositions for correlation with impact data. A good correlation was found between maximum energy in the impact test and reduction of area in the tensile test; a fair correlation was obtained between transition temperature and reduction of area; but a very poor correlation was found between all other impact and tensile properties.

Studies of the electrical transients formed upon interrupting an electric current were made on approximately ten different contact materials. It was found that for "strikeover" or relaxation oscillation transients, these materials fell into two groups. One group composed of the higher-melting metals such as platinum, silver, and iron showed these transients to have peak potentials rising from 300 volts initially to 1000 volts finally, and a relaxation frequency of about 3000 times per second, which decreases as the discharge continues. The second group of materials composed of carbon and low-fusing metals such as cadmium, zinc, and bismuth have an almost constant peak voltage of about 300 volts and a relaxation frequency of about 6000 times per second. If a contact pair is made up of a member from each of the two groups, the type of discharge is determined by the positive member. An investigation of the correlation between contact-separation distance and transients showed that these initial "strikeover" transients begin before the contacts have separated 0.001 inch.

MELTING AND CASTING

Important data on the freezing of simple shapes, as obtained by thermal analysis techniques, indicate that "bleeding" or "pour out" data, which have been the only data available on freezing rates, may be erroneous. The thermal data point out that solidification does not proceed at a constant parabolic rate as given by the formula: $\text{Wall Thickness} = K\sqrt{t}$, where K is a constant and t is time. This relationship is valid for the first part of solidification, but during the last stage, solidification proceeds at a rapidly increasing rate in contradiction to the formula. Thermal gradients determine how the last stage of solidification proceeds and thus play an important role in controlling soundness. Superheat retards the rate of initial skin formation and therefore increases time for complete solidification; it has no effect on the last stages of solidification. Mold size affects only the final stages of solidification. Small, "insufficient" molds retard solidification in this range so that time for total solidification is increased. Surface-to-volume relationships, rather than a shape factor, control final solidification time.

Studies of the flow of liquid metal in gating systems were analyzed in terms of hydrodynamic principles, and casting soundness and surface quality have been correlated with known conditions of flow. The behavior of the metal as it enters the mold cavity and the resulting casting quality vary markedly with the momentum and pressure conditions imposed by the design geometry of the gating systems. With exit-to-inlet channel ratios of less than one, the systems are pressurized and there is obtained a uniform flow which is a desired feature for horizontal gating. Ratios of more than one result in partly filled channels with consequent dependence on momentum effects for proper metal distribution. Appropriate design and momentum control can produce uniform or sequential flow. Pressurized systems by virtue of excluding atmosphere from the gating system improve casting quality for dross-forming metals. Overpressurization, however, is harmful in that excessive deterioration of the sand wall results with consequent trapping of sand in the casting. This is particularly true with high-fluidity metals.

WELDING

A comprehensive investigation was completed of various small-scale laboratory tests which have been used or proposed for predicting large-scale performance of welded structures. Tests

were conducted on ship-structure steels to determine the contribution of mechanical and material variables to the performance of laboratory specimens. It was found that the temperature of transition from ductile to brittle behavior of the various notch specimens is specific to the specimens. It was also found that the elusive material factors which characterize steel quality such as strain-rate sensitivity, strain-aging susceptibility, etc., which, it is known, do change from steel to steel and heat to heat, vary considerably even in a single plate of supposedly homogeneous steel. The various specimens were likewise found to be specific to variations in material properties. Extremely complicated interrelationships of material and mechanical factors therefore determine performance of specimens or structures, and a rigorous correlation between simple laboratory specimens and structures is not feasible except in an approximate sense which is subject to wide chance fluctuations and requires statistical analyses.

* * *

Pouring an experimental ingot in the Naval Research Laboratory Foundry. By the use of thermocouples and automatic potentiometer recorders, complete temperature records are made of the metal and mold throughout the pouring and solidification period.

NUCLEONICS

Nuclear science involves studies of the interactions of high-energy particles with themselves and with other matter. Two sources of such particles are available: those devices known as particle accelerators of which there are many different forms for different specific uses, and the radioactive isotopes which are made artificially in particle accelerators or nuclear reactors. The Naval Research Laboratory, in developing its program in nucleonics, has, of necessity, concerned itself with particle accelerators. At the beginning of this reporting period the Laboratory possessed two accelerators, a 20 Mev betatron which had been constructed for radiographic applications during the recent war, and a 2 Mev proton Van de Graaff machine which was purchased commercially in 1949.

Because of lack of proper upkeep and other circumstances, the betatron was in very poor operating condition. As a result of a complete and successful overhaul during the fiscal year, the instrument is now operating at 120 roentgens per minute at one meter from the target. Preparations are being made to use it in the study of the energy dependence of nuclear reactions produced by high-energy gamma rays.

The operating characteristics of the 2 Mev Van de Graaff machine were studied in detail, some faulty design elements were corrected, and a number of calibration curves were prepared. This machine is now essentially ready for use.

Construction work has started on another Van de Graaff machine, a 5 Mev horizontal type instrument. It is anticipated that it will be completed within the next fiscal year and that it will be moved into a new building specifically designed and built for it. Now being assembled in a small room in an existing building, it can be operated only up to something under one million volts, thus to a great extent limiting its capabilities.

Work continues on the compact design for an electron synchrotron. It is expected that this device will be given a tryout during the next fiscal year.

A one Bev proton synchrotron and the necessary building facilities have been designed by the Laboratory. Pending approval of its construction, some of the magnetic and radio-frequency design problems for the machine have been pursued. The proposal has been critically examined by the University of California and by the Brookhaven National Laboratory, both reporting favorably on the fundamental soundness of the design.

A Nier type of abundance-measuring mass spectrometer has been modified in an attempt to determine the practical limits of the precision with which isotopic abundances can be measured with present techniques.

Because of the great interest which attaches to phenomena initiated by particles of extremely high energy, various studies have been undertaken in the field of cosmic rays where such high energy particles are observed. The tools in these investigations are stacks of ultrasensitive photographic emulsions exposed in stratosphere balloon flights and at mountain elevations at different geomagnetic latitudes. During the past year emulsions of greater and greater thicknesses and greater sensitivities became available. The photographic processing of these emulsions, nearly one-half a millimeter thick, is a task of severe technical difficulty and much time during the past year was spent in mastering these techniques. Numerous balloon flights, arranged by Project Skyhook, were made to study the nucleonic cascade, the mechanism of meson production in hard showers, and the general study of the heavy nuclear primary component. Because improvement in the methods and techniques during the year were so gradual, no conclusive results have yet been reached in any of these problems.

On February 15, 1950 radio astronomers reported a solar flare. The Laboratory was fortunately able to have a balloon in the air within two hours which rose to over 90,000 feet before recovery.

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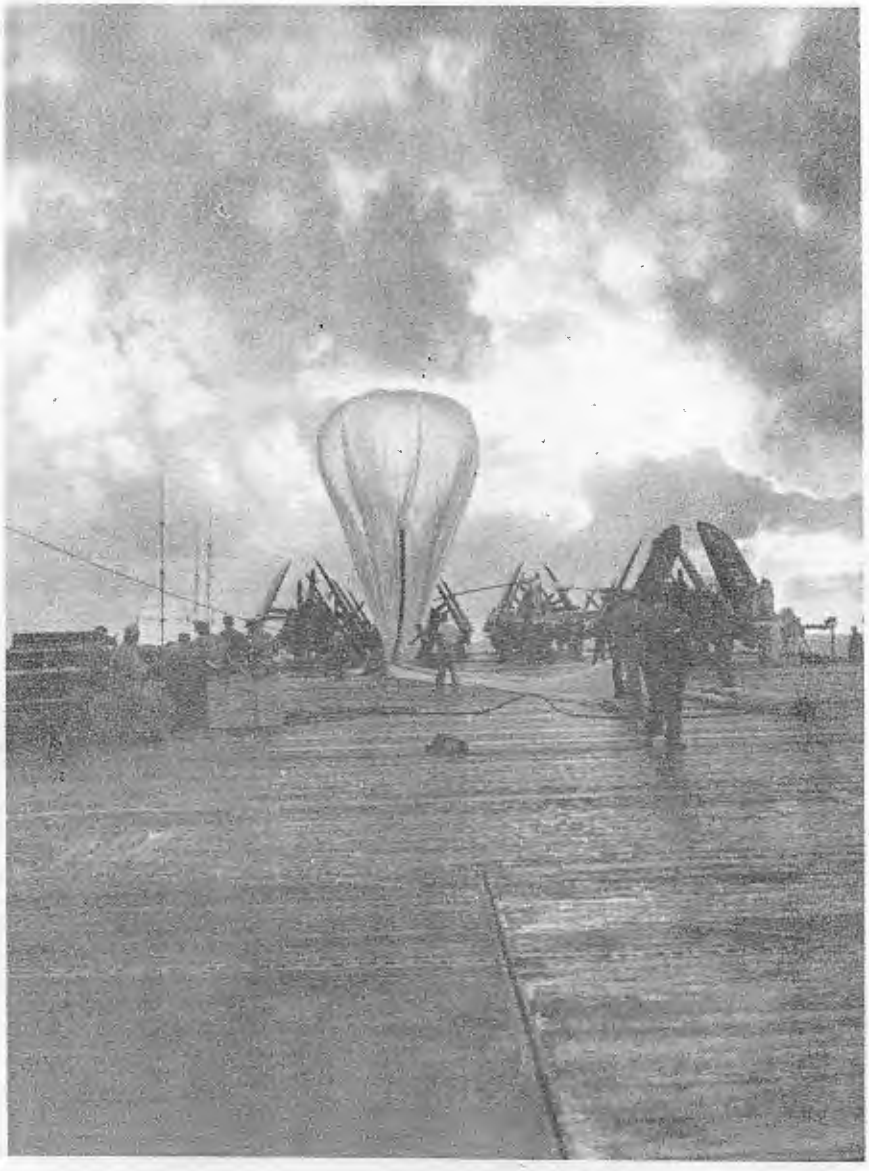

Project Skyhook polyethylene balloon being inflated on the deck of an aircraft carrier prior to launching for cosmic-ray experiments

Preliminary study of the cosmic events recorded in the photographic plates carried by this balloon suggest that the flare had no appreciable effect on cosmic-ray phenomena in the earth's atmosphere.

A series of measurements was made to test the theory of multiple Compton scattering developed previously at the Laboratory. These experiments were designed specifically to eliminate the effects of extraneous scattering from the shielding measurements carried out previously. A source emitting nearly monochromatic gamma rays was mounted outdoors on a high light pole in an uncluttered portion of the station. A few feet away, also on a high pole, was mounted a Geiger counter and immediately before it successive layers of shielding material, either lead or aluminum. The results obtained were in good agreement with the theory.

A large and versatile beta-ray spectrograph, containing a magnet and either of two vacuum chambers, was built. One of the chambers has been completed and, together with the magnet, constitutes a double-focusing beta-ray spectrograph of large luminosity and high resolution. The other vacuum chamber is now being designed and will permit the instrument to be used in three fashions — as a standard 180-degree instrument, as a beta-gamma coincidence instrument, or as a pair-spectrometer - with simultaneous use of photographic and counter recording. It is believed that this is one of the most versatile instruments of its type ever to be constructed.

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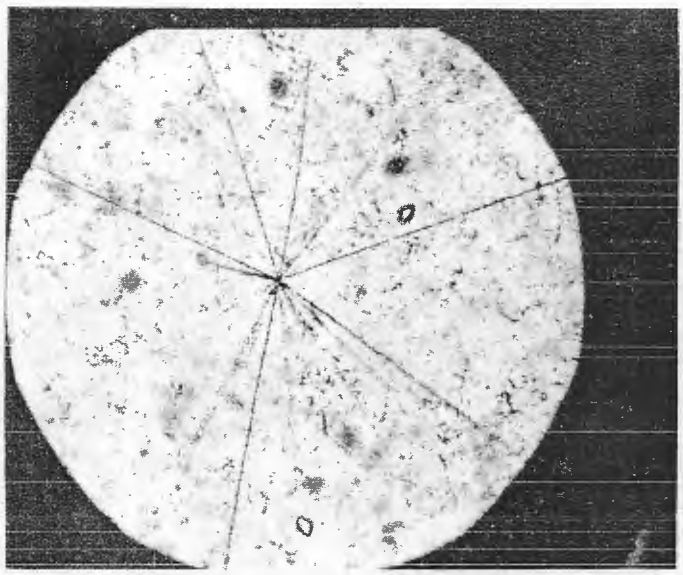

Photomicrograph (600 X) of a nuclear disintegration which occurred in a photographic emulsion during a balloon flight at a 20-mile altitude. An energetic cosmic-ray particle from space penetrated the emulsion, passed through a silver or bromine nucleus, and excited some of the nucleons to such a level that they escaped. These particles then passed through the emulsion and left sensitized paths which appear as tracks on development. This "star" contained 26 branches in its three-dimensional form, but only those in focus of the microscope are shown here.

OPTICS

The field of optics at the Laboratory covers a broad program of basic and applied research. A large portion of the research is conducted in the field and experimentation has been carried on from rockets, aircraft, airships, surface vessels, and submarines.

Research continues in the field of optics of the atmosphere both at high altitudes and near sea level. Other portions of the program seek to improve the optical properties of materials, design new optical systems for laboratory and naval use, conduct basic spectroradiometric research throughout the infrared and visible down to the extreme ultraviolet, and advance the science of photometry. The work in electron optics is concerned with problems involving photon and particle counters, radiac instrumentation and other nuclear research, and includes research in X-ray and electron diffractions.

PHYSICAL METHODS OF PHOTOMETRY

Visual methods of photometry, especially at low levels of illumination where the Purkynje phenomenon* becomes effective, are somewhat unsatisfactory; the accuracy of measurement is not high and there is poor reproducibility. The work of this problem has as its object the application of photoelectric methods to photometric measurements in order to gain accuracy and reproducibility.

The interest in low level photometry arose from the demand for a greater understanding of vision at reduced light levels in order to design more effective aides to military activities under the cover of darkness. Closely allied to these interests is a desire to study more completely the properties of phosphorescent and fluorescent materials since these have been found to be valuable aides to night operations.

A photoelectric photometer was developed which duplicates, quite accurately, the sensitivity curve of the average human eye at various light levels within the Purkynje region. By using suitable optical filters, the sensitivity curve of the photomultiplier tube was corrected to that of the eye. With suitable modifications this instrument was used to measure and record photographically the growth and decay of the luminescence of phosphors. Methods were investigated and developed for measuring the chromaticity of optical filters and phosphorescence and fluorescence at low light levels.

During the past year the design and construction of a stabilized power supply for the photometer when used on ac circuits has further extended its usefulness. A logarithmic recorder was developed to make the instrument more compact and portable and to avoid the necessity of incorporating two or three meters to cover the entire range.

The success of physical photometry depends upon accurate calibration with the present system of photometric standards, which involves all the difficulties of heterochromatic photometry. Progress was made on a method of calibration which promises to be fairly satisfactory. Five colors about equally spaced through the visible spectrum were selected, and surfaces of suitable brightness were made by using tungsten lamps and the selected optical filters. These will serve as standards of brightness for the physical photometer and are to be calibrated by a large group of observers.

Future work on the problem of physical photometry will consist of perfecting the techniques of heterochromatic measurements and studying their limitations.

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*The phenomenon known as the "Purkynje effect" occurs at low intensities where the characteristics of the human eye change. As the eye becomes dark-adapted, the maximum point on the sensitivity curve shifts toward the blue region. Also the shape and magnitude of the sensitivity curve undergo changes.

ATMOSPHERIC FLUCTUATIONS

In the Navy's need for varied communication systems to cover all types of operations, attention has been directed to the development of communications which employ optical systems. Since 1948, the Laboratory has been investigating those limitations imposed on optical communications by atmospheric turbulence which produces twinkling of light originating at a distant signalling lamp, and by background illumination such as moonlight reflected by the sea.

The major portion of the measurements were made during the past year with equipment installed at the Chesapeake Bay Annex of the Laboratory. The apparatus as set up consisted essentially of a mirror and photocell receiver system which was operated to measure the twinkling of light sources at distances of 4400 and 17,750 yards. The amplitude of the fluctuations in twinkle intensity was measured as a function of the frequency. It was established that twinkling is much more pronounced at low frequencies than at higher frequencies; for example, at 10 cycles per second the twinkle was two and one-half times greater than at 25 cps and ten times greater than at 100 cps.

Twinkle of stars was found to vary inversely with the frequency. Fluctuations in moonlight reflected from the sea did not depend as markedly on frequency as in the case of light from distant sources.

The analysis of these data yielded information required in designing optical communications systems in such a way that atmospheric turbulence will produce minimum disturbances in them.

SKY BRIGHTNESS MEASUREMENTS

A program of observations of the brightness of the daylight sky at various altitudes was finally completed by a series of observations from a B29 airplane flying up to 40,000 feet. Data of sky brightness and polarization were obtained at several altitudes above the surface for several points in the sky for several altitudes of the sun.

A survey of the brightness of the night sky with no clouds or moon was carried out by observers in Maryland, Alaska, Canada and Greenland. On nights with no visible aurora there were some unexplained variations in the sky brightness, but no pronounced variations with latitude, although the sky at Saskatoon seemed brighter at times than the sky in other places. The survey is being continued.

EXTREME ULTRAVIOLET RADIOMETRY

The objective of the extreme ultraviolet radiometry studies is to exploit these spectral regions making use of recent advances in techniques using photomultipliers, high-speed pumps, and automatic recording systems. The results will aid in the solution of theoretical problems connected with the solid state, semi-conductors, surface layers, and molecular structure, and, it is expected, will also offer new possibilities in spectrochemical analysis. Further use will be made of this new tool for studying the mechanism of the electric discharge. Knowledge of the absorption and ionization processes in gases for the spectral region under study is important in connection with the ionosphere and the physics of the upper atmosphere, where solar ultraviolet radiation becomes absorbed.

During the early part of 1950 a vacuum monochromator designed by the Naval Research Laboratory and The Baird Associates, and constructed by the latter, was placed in operation together with a high-intensity hydrogen-discharge-tube light source constructed at the Laboratory. The equipment functioned very well and progress was more rapid than expected. Six separate and important pieces of research were largely completed and the success of the first two of these was necessary for the entire program.

(a) A sensitive and simple photoelectric means of measuring relative intensities in the vacuum ultraviolet was developed. This equipment, consisting of a photomultiplier with a fluorescent material coated on the envelope, is necessary for and makes possible the rapid measurement of reflectances and transmittances in this spectral region.

(b) The energy emerging from the exit slit of the monochromator was measured in absolute units by means of a thermocouple. This is the first time that absolute spectral intensities have ever been measured in the vacuum ultraviolet. These measurements permit carrying out a number of important research problems, particular applications having been made and described in items d, e, and f below.

(c) First use was made of the vacuum monochromator in measuring the spectral response of the ultraviolet photon counters being developed by the Laboratory for the measurement of solar ultraviolet radiation from rockets.

(d) By means of the thermocouple measurements it was shown that certain fluorescent materials, in particular, pump oil and anthracene, have constant quantum efficiencies in the vacuum ultraviolet. This makes possible the use of the fluorescent-sensitized multiplier instead of a thermocouple for measurement of relative spectral energy distribution.

(e) The absolute sensitivity to ultraviolet excitation of the $CaSO_4$:Mn phosphor flown in several rockets was measured. This phosphor was used to measure extreme ultraviolet radiation and X-rays from the sun. By means of the calibration performed with the vacuum monochromator, it was possible to place values on the absolute energy emitted by the sun in the spectral range 1040A to 1340A. The total solar radiation in this range was found to be approximately that of a 5000° K black body sun.

(f) Special photomultipliers with quartz envelopes were manufactured by the Radio Corporation of America for the Naval Research Laboratory. Their spectral sensitivity was studied and they were found to respond to 1550A.

* * *

PHYSICS

In addition to research in the familiar specialized fields of physics, such as mechanics, electricity, and optics, which are described in other portions of this report, there is much which cannot be so readily delineated. Such, for instance, is the work on electrical and magnetic properties, in meteorology, on the physics and research of the upper atmosphere, in mathematics, and several other subjects discussed in the following sections. Each of these "physics" projects serves to provide not only specific and important data for the "fundamental research" efforts of the Laboratory's program, but also, ultimately, equipment and ideas for naval use. As they are all grouped under the catch-all expression "physics," they all have the further common denominator of being those research subjects that help fill out the scientific program and accomplish the objectives of the Laboratory.

ELECTRICAL AND MAGNETIC PROPERTIES

An extensive program of theoretical and experimental research in the fundamental electrical, magnetic, thermal, and mechanical properties of matter is carried on. The studies are concentrated in the fields of low-temperature research, surface phenomena, and the interaction of the nuclei and electrons of solids with their surrounding lattice. Progress during the past year included the construction and installation of specialized cryogenics apparatus and the measurement of numerous low-temperature properties of tin, aluminum, and copper as well as the measurement of ferromagnetic properties of metals at radio frequencies.

The Cryomagnetics Laboratory

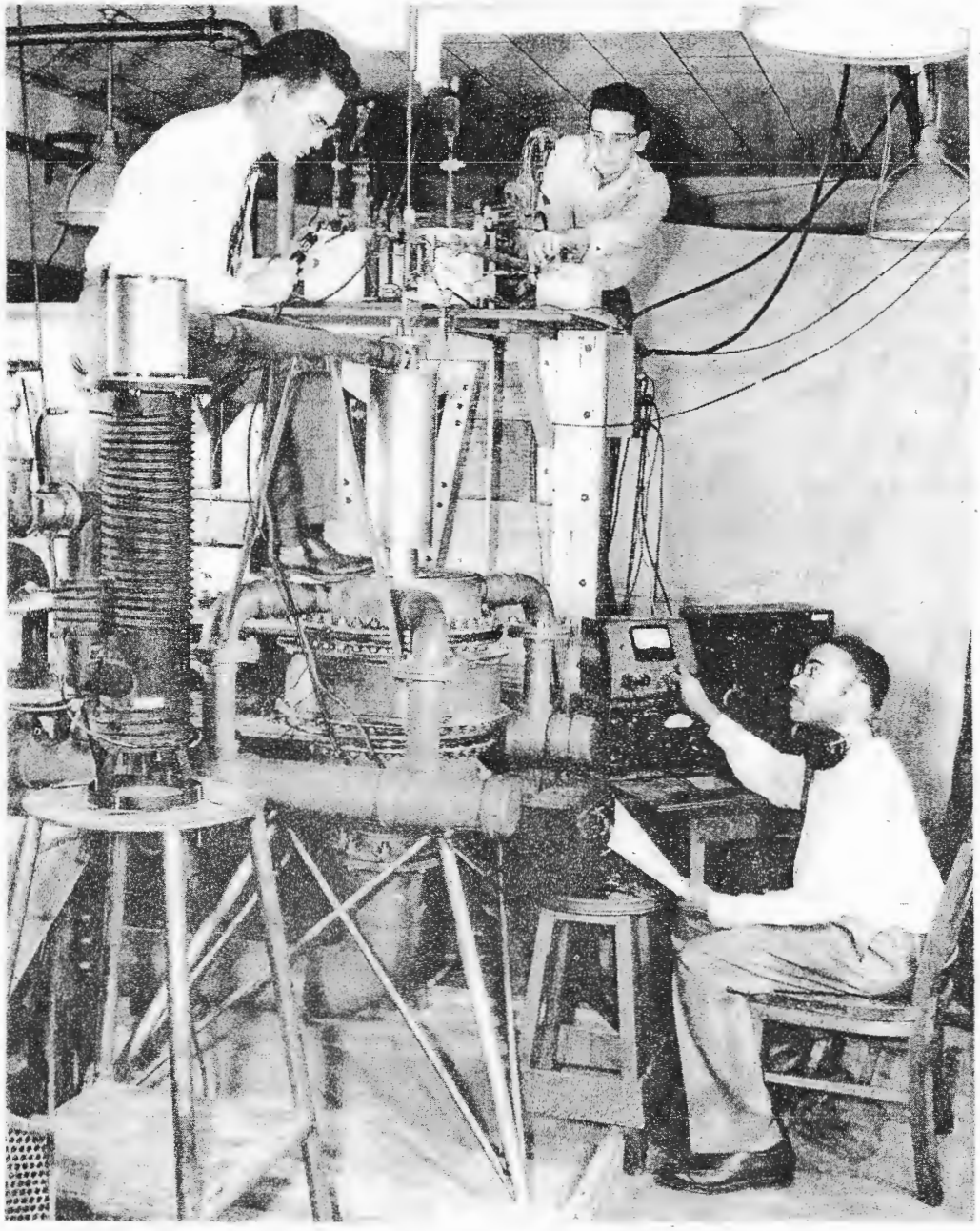
By studying the properties of matter at temperatures approaching absolute zero, new knowledge of molecular and electronic interaction can be obtained. Such studies require the development of techniques for the production and measurement of temperatures of order 0.001°K and, at present, the only practical method for producing these extremely low temperatures utilizes the cooling of a paramagnetic salt under adiabatic demagnetization. The temperatures produced require study of the extension of the thermodynamic temperature scale.

A cryomagnetics laboratory in which a magnetic field of 100,000 oersteds will be continuously available is now being installed to conduct cryogenic research below 1.0°K. Pending the completion of the motor-generator power supply, the magnets have been temporarily connected to battery-charging generators and operated at reduced power. With this arrangement, demagnetization experiments were conducted successfully, and, in a field of approximately 15,000 oersteds, temperatures of 0.04°K were reached. Satisfactory thermal insulation at this temperature was achieved, the temperature drift being in the order of 0.003°K per minute.

When the installation of the large motor-generator is completed, work will be undertaken on the production of temperatures of order 0.005°K and on the establishment of the thermodynamic temperature scale below 1.0°K.

Thermal Conductivity at Very Low Temperatures

Existing measurements of the thermal conductivities of metals at liquid helium temperatures are scattered and very incomplete. The temperature dependence of the thermal conductivities of single-crystal specimens of metals can yield information on the effect of the lattice and of impurities on the behavior of free electrons in metals. Measurements extending throughout the temperature range of 1° to 25°K would be of particular interest; hence experimental apparatus employing helium gas thermometers for measuring the thermal conductivity of metals at liquid helium and hydrogen temperatures was constructed.



Equipment is being prepared for research at temperatures as low as a few thousandths of a degree absolute. Such low temperatures, produced in the metal dewar shown in the center of the picture, are obtained from a solenoid-type air-core magnet capable of producing extremely intense magnetic fields. By the use of this equipment studies will also be made of the magnetic properties of materials.

Measurements of thermal conductivity in this temperature region have been made on six highly pure metal specimens; three were of aluminum, two of tin, and one of copper. The majority of these specimens were in single-crystal form. The specimens all showed the same general type of temperature dependence of thermal conductivity. At the lowest temperatures the thermal conductivity rose approximately linearly with the temperature until a maximum conductivity was reached and then decreased for further temperature increase, in general accord with theory.

For those metals, such as tin, which become superconductors at low temperatures, measurement of the thermal conductivity in the normal and superconducting state at the same temperature should lead to valuable information regarding the behavior of the normal electrons in superconductors, as well as to an estimate of the proportion of free electrons which go into the superconducting state. Preliminary measurements of this sort, in which the superconductivity was quenched with a magnetic field, were made on the two tin specimens. It was found that, when the superconductivity was quenched with a magnetic field, the thermal conductivity was strongly dependent upon the magnitude of the magnetic field applied. Further study of this dependence of thermal conductivity upon applied magnetic fields will be made.

Magnetic Resonance

A fundamental study of physical phenomena in solids is going forward through work on (a) resonance of nuclei in solids, and (b) paramagnetic resonance. Measurements of magnetic resonance can be used to obtain information on the structure of solids and on the internal electric and magnetic fields in solids.

Nuclear magnetic resonance constitutes a fine probe for investigation into the structure of materials. In particular, it is possible to obtain direct information about the location and motion of light nuclei, especially protons, whose magnetic properties are ideal for resonance absorption experiments.

Materials under investigation by analysis of absorption line widths due to the nuclear magnetic resonance of protons include metal hydrides such as titanium hydride, tantalum hydride, calcium hydride, lithium aluminum hydride, sodium hydride, lithium boron hydride, and sodium boron hydride. The first two are of greatest interest since the extreme width of the titanium hydride and the contrasting narrow width of the tantalum hydride are indicative of the quite different behavior of hydrogen in each.

Special equipment was constructed for studies of paramagnetic resonance which will permit measurements to be made at two selected frequencies, 10,000 megacycles and 25,000 megacycles, at liquid helium temperatures. Studies are under way on copper sulphate, manganese salts, and manganese activated phosphors. The work is expected to yield information on the couplings between the paramagnetic ions and the surrounding lattice as well as information on the manner in which the paramagnetic ions are distributed through the material.

New techniques were developed for the study of paramagnetic resonance. A simple, easily adjusted system using a standing wave detector and a modulated magnetic field was used for detection of resonance and for preliminary investigation of line shape. A much more sensitive detection scheme using a lock-in detector was built and is being used for precision measurement of very weak signals.

Low-Temperature Phenomena at Microwave Frequencies

The dielectric constant of liquid helium was measured over the temperature range of 1.6° to 4.2°K in a superconducting cavity operated in the TE_{111} mode at 9100 Mc. The measured values ranged from 1.0492 to 1.0574; the maximum value and a discontinuity in the slope of the dielectric constant vs. temperature curve occurred at the lambda point, 2.2 degrees. These results are in agreement, within experimental error, with optical data and with measurements made in 1928 by Wolfe and Keesom at 500 kc. Measurements made with the same apparatus indicated that the loss tangent of liquid helium at 9100 Mc is less than 5×10^{-6}.

A study of the superconducting properties of tin at microwave frequencies yielded identical results for both solid and electro-deposited tin cavities operated in the TE_{111} mode at 9100 Mc. The

cavity Q rose sharply from a value of about 40,000 at 3.72°K to 120,000 at 3.62°K and thereafter continued to rise more slowly, reaching 5×10^5 at 3°K and 1.5×10^6 at 1.6°K.

Ferromagnetism at Radio Frequencies

In carrying out the research program on ferromagnetic properties of metals at radio frequencies, equipment was prepared to measure the reversible complex permeability of samples in a stress-free condition, and to allow variation of the polarizing magnetic field along the normal, rather than virgin, magnetization curve. Satisfactory results obtained on electro-polished nickel at 50 and 200 Mc indicate that similar modifications for measurements at 1000 and 3000 Mc will be equally successful.

Progress in research on the ferromagnetic properties of ferrites included measurement of the real and imaginary components of permeability of a ferrite over the frequency range of zero to 10,000 Mc. Two regions of pronounced dispersion were found, and the fundamental mechanisms of domain rotations and wall displacements were separated by a new method involving r-f studies of remanence and of single-domain particles. Effects due to inertia of domain walls were found for the first time. These results are believed to be of considerable importance for a sound understanding of magnetic properties of the ferrites.

PULSE-JET ENGINES

For the past few years experimental work on pulse-jet engines has been conducted at the Chesapeake Bay Annex, Naval Research Laboratory, where facilities recently underwent expansion so that the nature of the experimental work changed from a static to dynamic character through the use of whirlstands. The original whirlstand was supplemented by one of larger rotor diameter. Thus it is planned to use one whirlstand for valve and engine-endurance studies while the second stand is devoted to engine-development work. The two whirlstands are mounted in adjoining pits with a wall between so that preparations for tests can be made safely while the other whirlstand is in operation. Facilities for measuring air consumption of these engines have been enlarged.

Life-endurance studies demonstrated that one 6-inch diameter, 32-inch length engine, operating at a frequency of 165 cycles per second, fuel rate 125 pounds per hour, rotor at 155 revolutions per minute had a valve life of 38 hours. With two engines operating at opposite ends of the rotor, the speed recorded at 220 revolutions per minute or 309 feet per second tip speed, the valves ran 15-1/2 hours with the valve box still in operating condition.

Another accomplishment in pulse-jet engine life was improvement in engine mounting. The use of reinforcing rings made possible the operation of engines for over 100 hours without tube failures and helped maintain the original shape of the engine when subjected to operating conditions involving heat and vibration as well as rotational forces of approximately 300 g.

An application of this research on valve endurance was in the development of helicopters powered by pulse-jet engines mounted on the tips of the rotors. This use requires an engine service life of at least forty hours. Design drawings and the valve box embodying valves which had demonstrated this service life were supplied to an Air Force contractor to guide his development.

Pulse-jet wave propagation studies were made utilizing a shock tube and explaining pressure-peak reflections from the open end of the pulse-jet engine. Progress in measuring the arm-airfoil drag torque facilitated the measurement of the net thrust of engines run on the whirlstand. Changes in the fuel distribution improved starting of the engine at normal operating velocities.

METEOROLOGY

Special electronic equipment was devised to utilize the microseismic method of detecting and tracking hurricanes or typhoons at sea. This method attempts to obtain a bearing on a distant storm by determining the direction of propagation of the earth motions which originate in the vicinity of the storms. During the 1949 hurricane season two experimental stations using the new equipment were operated—one at Chesapeake Bay Annex, and the other near Miami, Florida. The analysis of the data emphasized the need for studies designed to determine the mechanism of generation of microseisms

by a storm over the water, as the maximum practical range for operational detection and tracking of storms is still open to question. During the 1950 hurricane season it is planned to operate experimental stations along the Atlantic Coast to determine the maximum range of detection of storms over open ocean.

Work was undertaken to develop improved methods and equipment for more accurate aerological measurements under Arctic conditions. New type humidity, temperature, and wind equipment as well as modified wind equipment were installed at Point Barrow, Alaska, where arrangements were made for a continuous program of evaluation of Laboratory work.

Studies employing a whirling arm which can provide velocities up to 400 miles per hour are in progress to determine the accuracy of new methods for measuring true air temperature in flight. These and other studies will be extended to higher velocities upon completion of a larger whirling arm.

Methods and materials are being investigated to develop a constant-level balloon with major efforts centering on materials such as plastic-aluminum foil laminates and various rubber compounds. Special attention is being given to the low-temperature properties of certain rubber compounds in an attempt to produce a rubber balloon which, with appropriate flight-control equipment, will perform as a nonextensible or fixed-volume balloon.

UPPER ATMOSPHERE RESEARCH

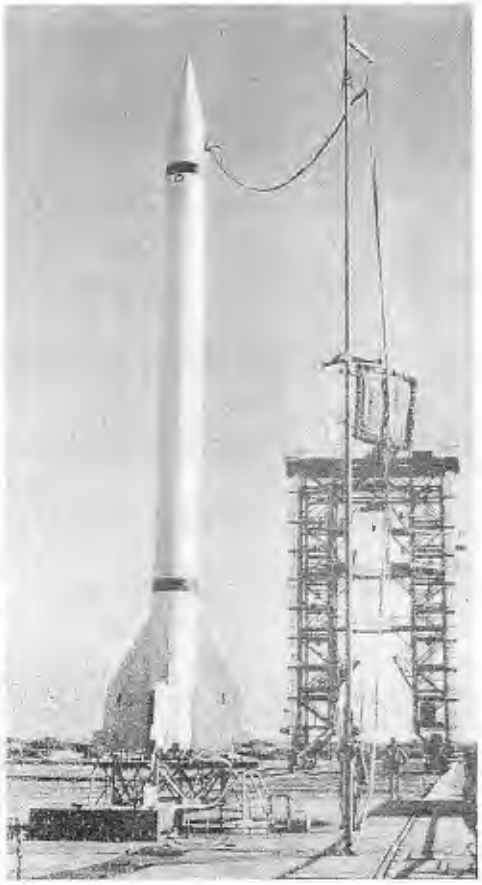
During the fiscal year, upper atmosphere research efforts were centered primarily on three Viking firings, two V-2 flights, and several Aerobee flights. Of outstanding importance to the Navy and to upper atmosphere rocketry was the successful launching and flight of a Viking rocket from the deck of a ship at sea. Research equipment in this rocket was carried to a peak altitude of 106 miles. Studies of atmospheric physics at rocket altitudes were continued and a new highly sensitive wide-range pressure gauge for upper atmosphere measurements was developed and used successfully in a number of flights.

Shipboard Launching of Viking

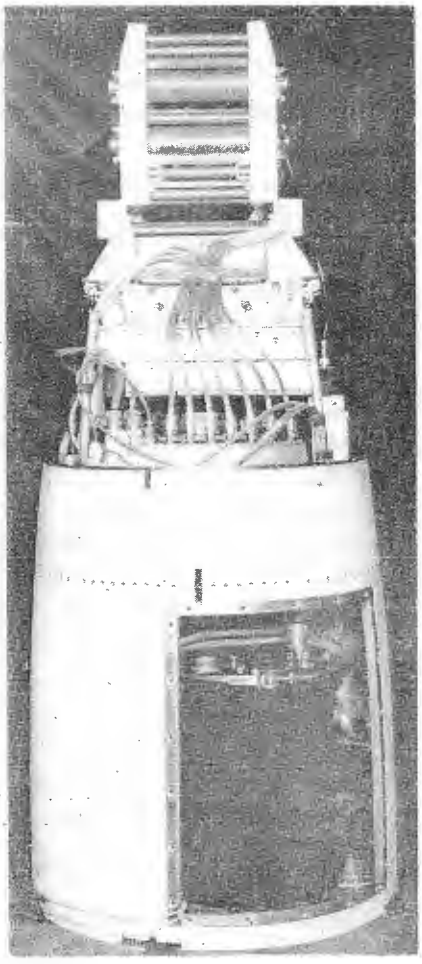
Viking No. 4, an upper atmosphere rocket 32 inches in diameter and 46-1/2 feet long, was fired at sea on May 11 and reached a peak altitude of 106 miles, the highest yet reached by any American single-stage rocket. This was the first successful firing and flight at sea of a large stabilized rocket. Known as Project Reach, the operation was conducted aboard the USS NORTON SOUND, AV-11, in the Pacific Ocean near the intersection of the geographic and geomagnetic equators. Powered flight lasted 74 seconds at which time a velocity of 3500 miles per hour and an altitude of 26 miles had been attained; the rocket then soared as a free missile to its peak height. Impact splash occurred 7-1/2 minutes after take-off at a point 7 miles astern of the ship. A fixed guiding tower, specially designed and constructed, was erected on the deck to launch the rocket and guide the airframe until it had attained sufficient velocity to clear the ship. The successful use of these fixed vertical rails considerably advanced the technique of launching large rockets from shipboard. Prior to the operation, the influence of the ship's motions on launching was studied at the Laboratory and was also determined experimentally by firing a full-scale dummy Viking at sea.

Viking 4 carried almost half a ton of research equipment for the study of primary cosmic rays, atmospheric pressures and temperatures, and rocket performance. The NRL matrix telemetering system, employing two new receiving stations installed on the ship, recorded data during the flight.

During the coming year, the Viking will be increased in diameter to between 40 and 45 inches to provide greater ease of instrumentation layout and to enlarge the propellant capacity. From additional fuel capacity there will result a considerable increase in payload-altitude capabilities. The final objective of the current Viking development program is a rocket which can carry 500 pounds to 190 miles in stable vertical flight.



A Viking rocket emplaced at White Sands Proving Ground for launching. The structure in the background is used for final assembly and testing procedures and is then wheeled to a safe distance. Preflight contact with the rocket is obtained through the cable which is automatically released as the propellant ignites.



Nose section of Viking No. 4 showing the cosmic-ray telescope in the upper half and the telemetering transmitter in the lower half. This cosmic-ray telescope identified primary cosmic-ray particles and the transmitter radioed this and other data to the ship.

Cosmic Rays

In an effort to learn more about the constitution of cosmic radiation at rocket altitudes, the ionization and range of cosmic rays were measured by Geiger counters and recorded simultaneously during the flight of Viking 4. Similar records were made in a V-2 flight at White Sands Proving Ground on February 17. To understand the significance of these measurements more fully, the fluctuation phenomena of the type of proportional counters used were studied both experimentally and theoretically prior to the flights. From V-2 data, primary protons and soft secondary electrons were positively identified in the cosmic radiation, and alpha particles were also detected. Quantitative values of the intensities of the various components will be forthcoming from both these flights.

Experiments designed to detect diurnal variations in the total ionizing, soft gamma, and fast neutron components of the cosmic radiation were performed with Project Skyhook balloons at Camp Ripley, Minnesota, in June 1949. No diurnal variations within the statistical uncertainty of the experiment were detected. This shows that the solar magnetic moment must be considerably less than has been postulated to explain the knee in the cosmic-ray latitude curve.

Solar Radiation Studies

Since 1946, the Laboratory has been studying solar radiations as a part of its upper atmosphere research program, using the high-flying rockets as vehicles for instruments. These investigations, concerned specifically with the ultraviolet and X-ray regions, are pursued to help develop a complete knowledge of the physical structure of the ionosphere.

For studying the ultraviolet region, rocket-borne spectrographs have been used and have provided spectra extending down to 2000A. Such data, obtained in June 1949, provided excellent resolution to half an angstrom unit and are now being analyzed. Ozone densities to an altitude of 70 kilometers have already been plotted from these spectra.

For the shorter ultraviolet regions (spectral bands 2000A-1750A, 1700A-1450A, and 1350A-1150A), absorption-altitude curves have been plotted from photon counter studies made in a rocket flight on September 29, 1949. The maximum rate of absorption of solar energy for the first three of these bands occurred respectively at 10, 70, and 100 kilometers altitude. The radiation below 1350A is almost completely absorbed in the 75 to 110 kilometer altitude region. In the same rocket flight, photo-emission experiments confirmed discoveries of high altitude X-radiation made by the Laboratory in 1948, and gave good altitude resolution of the radiation absorption in the wavelength region from 1350A down. All these radiations were shown to be predominantly of solar origin.

The ultraviolet photon counter tubes used in the above studies were especially developed for the purpose. The long wavelength limit to their response was in the extreme ultraviolet and its exact position was controlled by the gas filling. Lithium fluoride, sapphire, and quartz windows determined the short wavelength limit.

Measurements of the X-radiation were made with photon counters, ionization chambers, and photographic emulsions covered by suitable filters. The softer X-ray component was shown to be of solar origin and to vary in intensity from flight to flight. Variation of X-ray absorption with altitude as determined by the photon counters, and the intensity measured by the photographic emulsions, indicate that these rays are one of the principal sources of E-region ionization.

These solar radiation data are expected to contribute a great deal in establishing a sound theory of the ionosphere.

Instrumentation

An argon-nitrogen ratio measuring mass spectrometer, developed for upper-atmosphere rocket flights, was completed and tested and will probably be flown in a rocket shortly. According to the tests, this instrument should provide reliable data on the argon-nitrogen ratio to an altitude of approximately 65 miles.

3700

A new pressure gauge having a very wide range of operation was developed. This instrument, capable of measuring pressures in the range from one atmosphere to 10^{-8} atmospheres, was used to conduct pressure and temperature studies in three Vikings and one V-2 rocket. The data obtained during these flights and in previous rockets indicate that the NACA tentative standard pressures and temperatures are much too high in the regions between the balloon ceiling and 62 miles altitude.

X-RAY ANALYSIS

For the past several years the application of X-ray analytical methods has been receiving renewed attention because of the development of highly efficient Geiger-Muller tubes and photomultiplier scintillation detectors. These new detectors have put X-ray absorption and emission spectroscopy on a practical basis, comparable to optical spectroscopic analysis.

In particular, the development of X-ray fluorescence analysis has been pursued intensively, and several classical analytical problems were solved successfully. Analyses of hafnium-zirconium and tantalum-columbium mixtures were carried out with an accuracy of a few percent for concentrations down to a fraction of a percent. Uranium in solutions could be determined with comparable accuracy. Gasolines were analyzed for tetraethyl lead and ethyl bromide with a speed and accuracy well beyond that possible by any other techniques. These newly developed analytical techniques have been adopted by many other laboratories and the general picture is one of rapidly expanding utilization of X-ray analysis in all types of analytical laboratories.

APPLIED MATHEMATICS

Theoretical Studies

An investigation of plane stress systems was made. For the case of plastic stresses, a complete classification of yield conditions compatible with isometric stress trajectories was achieved. Corresponding to each such yield condition, an infinite number of simple exact solutions of the equation of plasticity may be obtained. For the case of purely elastic stress systems a characterization of the stress in terms of the stress trajectories was attempted. Since photoelastic measurements yield only the stress trajectories, not the stresses themselves, this characterization enables one to state precisely what subsidiary data must be taken in the course of a photoelastic experiment in order to ascertain by calculation the internal stresses in the specimen.

The phenomena of nonlinear viscosity in fluids and of large elastic strain in solids were studied in detail. In the case of fluids, the objective was primarily to ascertain the correct and most general nature of the forces and heat exchanges experienced by a body flying at high altitudes. The dependence of these forces and heat exchanges upon observable qualities of the airflow was discovered, enabling a precise determination of the equation governing high-altitude aerodynamics. At the same time, various other theories describing nonlinear viscous effects and the various theories of finite elastic strain were contrasted, compared, and correlated. A certain general unity in the two fields was obtained by showing that two major classes of new phenomena not predicted by the classical linear theories will generally appear in any sort of nonlinear theory, whether intended to describe elastic, fluid, or plastic behavior. It was decided to name these two types of phenomena Kelvin effects and Poynting effects after the discoverers of special cases occurring in elasticity. The mathematical equations describing these effects are closely analogous even when the physical phenomena are quite diverse. The simplest form of the Kelvin effect in fluid dynamics consists in the fact that a fluid when sheared will tend to expand or contract slightly. The corresponding simplest form of the Poynting effect consists in the fact that a fluid when sheared will tend to force apart or to draw together the shearing surfaces. A general survey of the nonlinear theories of elasticity and fluid mechanics was compiled emphasizing the diverse forms which Kelvin and Poynting effects may assume.

The perturbations in the earth's magnetic field arising from motions of ionized air were studied. Attention was restricted to disturbances of relatively slight extent, so that a simplified theory could be constructed. The field induced by such disturbances was shown to be equivalent to three ordinary gravitational fields. It was shown further that a centre and definite strength of disturbance exist, and that magnetic observations taken at four neighboring stations suffice to determine them.

Analog Computations

An analog computer was placed in operation during the fall of 1949 and has been in continuous operation ever since. Solutions obtained with this equipment contributed in a fundamental way to studies in physics of the upper atmosphere; the launching, guidance, and ballistics of missiles; the regulation of nonlinear systems; the dynamics of linear systems; and biophysics. In addition, techniques for stabilizing the solutions of algebraic equations and for evaluating determinants were perfected and reported.

SOLID-STATE PHYSICS

Role of Activators in Luminescence

A comprehensive study of absorption, excitation, and emission spectra of a series of lead-sensitized, manganese-activated phosphors proved that ultraviolet absorption bands situated to the long-wavelength side of the fundamental lattice absorption are due to the sensitizer alone, that the energy absorbed by the sensitizer is transferred to the activator by a nonradiative process, and that this transfer is possible when the activator is separated from the sensitizer by no more than 10A.

This information has helped to clarify the mechanism of a number of technically important phosphors, such as $CaSiO_3$:Pb,Mn, $Ca_3PO_4 \cdot CaF_2$:Sb,Mn and Ca_3PO_4:Tl,Mn used extensively in industry, as well as point the way toward the development of new sensitized phosphors such as both $n(CaO \cdot Na_2O) \cdot mAl_2O_3 \cdot pSiO_2$:Cu+Mn and CaF_2:Ce+Mn.

A knowledge of the functions of the sensitizer and activator, respectively, has presented the opportunity to operate on each impurity individually, resulting in the development of materials of possible use in X- and γ-ray radiography. The high-energy radiations render the sensitizer inactive and hence destroy the luminescence response of the phosphor where they strike.

Crystal Growth from Melts

Most crystalline materials of interest to physicists for their ultraviolet and infrared properties or for their response to high-energy radiation are obtained by a simple process of solidification from a melt of the same composition. Several recent contributions of the Laboratory promise to provide a better basis for efficient growth techniques and to broaden the scope of materials available by the melt process.

In connection with the crucible technique it was demonstrated that improved crystals are obtained by selecting crucible materials which minimize adherence of the crystal to the crucible wall and by maintaining the growth rate sufficiently rapid to avoid recrystallization induced by contraction stresses, which are inherent in the process if the crystal is confined during cooling.

Another step forward was made in demonstrating that the crucible technique can be used for high-melting mineral-like compounds. A series of tungstates, both pure and with luminescent activators, was prepared and followed more recently by single crystal molybdates. These high-melting compounds were also obtained by the Verneuille technique—a technique which, requires much more skill and attention to such details as adjusting the composition to compensate for unequal vaporization, but offers advantages in faster growth rate and lower heat costs.

The most promising investigation on growth techniques is concerned with exploiting the Kyropoulos technique, which involves forming a nucleus at the tip of a cool rod suspended in a melt and then slowly withdrawing this rod at a rate which permits a crystalline boule to form around the nucleus. The boule is not restrained by crucible walls and in some cases has even shown some development of natural crystal faces. Efforts to date have produced alkali and silver halides of appreciably better texture and purity than was ever achieved by the crucible technique. The Kyropoulos method, which offers advantages in speed and lower cost, may become an important factor in the event melt growth is required on a large scale.

Alkali Halide Color Centers

As part of a general study of the optical and electrical properties of solids related to radiation-sensitive phenomena, an investigation was made of the color center bands produced in alkali halides by X-rays.

The various trapped electron color bands (F, M, N, R, and S bands) were shown to be photoconductive and a model was worked out for the F-center which adequately explains the residual bandwidth at low temperatures. The investigation also revealed the existence of new ultraviolet bands which are associated with trapped hole centers. From data on the stability of the various ultraviolet bands to thermal and optical bleaching, it was shown that the centers responsible for these bands include holes trapped at positive-ion vacancies (G-centers), larger aggregates of holes and positive-ion vacancies, and halogen molecule centers (X_2-centers). Considerable progress was made on working out the nature and properties of these centers. It was shown, for example, that the extent of color-center formation in various alkali halides as measured by the amount of F-band formation is determined by the stability of the G-centers rather than by the stability of the trapped electrons as hitherto assumed. The activation energy of the G-centers is roughly the same as that of the positive-ion vacancies so that they are mobile at room temperature whereas the F-centers are generally immobile. At room temperature the migration of G-centers and positive-ion vacancies leads to the formation of larger centers as well as to the recombination of holes and electrons to produce permanent bleaching.

Fluorescence

Organic scintillators are being studied in an effort to clarify the physical processes involved in the emission of light under either particle or quanta bombardment. A new technique was developed for the measurement of the time of decay of these phosphors to an accuracy of about $\pm 2 \times 10^{-9}$ second, resulting in a comprehensive study of decay times under scintillation conditions. Measurements of these times for different crystal temperatures provided clues for the types of energy levels within the crystals.

Spectral studies were made on a number of crystals in an effort to accumulate more data for practical applications as well as to provide information on the fundamental process for conversion of incoming energy to energy emitted as light. Temperature studies were made on the variation of light output from crystals under constant gamma-ray bombardment, providing information of considerable practical and theoretical importance.

Additional detailed work on the temperature dependence of organic phosphors makes it possible to study more closely the characteristics associated with transfer of energy from one molecule to another. These studies are being extended to obtain new information on the quantum efficiency of energy transfer in organic lattices and increased knowledge of the molecular structures of organic phosphors.

Crystal Dosimeters

The application of effective medical treatment to large numbers of casualties in the aftermath of an atomic bombing would be greatly facilitated if all personnel were equipped with simple "dog tag" dosimeters to indicate the individual roentgen exposures. Perhaps the most promising dosimeters for coverage of the 50 r - 100 r range are activated alkali halide crystals that have been studied at the Laboratory for the past two years. Early work carried on at the time of the Bikini tests demonstrated that the degree of color induced in NaCl, KCl, or KBr was sufficient to indicate the dose by simple comparison with a calibration color chart. Unfortunately, the untreated crystals faded rapidly. Most of the past two year's work, therefore, has concentrated on the activation of the alkali halides to form a maximum of U-centers (solid solution of alkali hydride in alkali halide). F-centers produced in a crystal loaded with U-centers do not fade and satisfy the stability requirements over the operational temperature range. At the same time, the processing to form U-centers produces a more sensitive dosimeter.

In KBr the treatment, consisting of heating in the alkali vapor followed by heating in hydrogen, consistently yielded usable crystals with a concentration of 2 x 10^{18} U-centers per cubic centimeter. Such crystals are sensitive enough to be read in 25 r steps from 25 r to 500 r or higher (depending on size of the dosimeter) with a color chart and no visual aids.

It has been necessary in producing an atomic dispersion of excess alkali, to quench the crystal rapidly from the temperature at which diffusion of the alkali vapor into the crystal takes place; slow cooling produces colloidal aggregates rather than F-centers. It was discovered in recent experiments, however, that heating of colloidal dispersions in hydrogen produces normal U-centers. This result opens the possibility of using NaCl and higher melting point crystals which heretofore could not be quenched rapidly enough to avoid colloidal aggregations without fracturing.

X-RAY OBSERVATION OF THE HUMAN HEART

The Office of Naval Research established a project to develop an attachment for X-ray equipment to illuminate the heart stroboscopically thus providing visual examination of the heart at any selected point of its cycle. Having the technical skill and equipment required for successful prosecution of this development, the Naval Research Laboratory was called upon to collaborate and serve as a consultant. Involved in this problem are the development of a suitable form of triggering action from the heart itself, an appropriate pulse modulator, and a cathode-ray-tube display of the electrocardiogram to permit correlation between the electrocardiogram and the X-ray.

Inasmuch as the heart beats irregularly and the X-ray equipment must flash at any predetermined instant in the cycle of the heart action, it was necessary to provide for initiation of a complete timing cycle by each heart beat. Electrocardiac timing was selected in preference to acoustical pickup since the acoustic output lags the electrical impulses.

In application, two electrodes are attached to the extremities of the patient, usually the right arm and the left leg. An electrocardiac waveform thus obtained is amplified, displayed on a cathode-ray oscilloscope, and is also used to trip a delay timing circuit which in turn controls the source of power to ordinary X-ray equipment. Manual adjustment of the power level is accomplished by the conventional X-ray controls. In order to correlate the electrocardiogram and the X-ray image, a marking spike is superimposed on the cathode-ray display.

The extent of electrical disturbances produced in the electrocardiac pickups by the X-ray equipment is not known. Further work may be required to measure and minimize this effect. Work is continuing toward development of a long-persistence fluoroscopic screen to provide sufficient retention of the X-ray image.

* * *

RADIO

Since its earliest days, the Naval Research Laboratory has devoted the major portion of its efforts to the field of radio and electronics. The significance of developments in this field to the Navy, in peace and in combat, becomes obvious when considering the complexities of target detection and identification, of tracking and of guiding, and of radio communications among the many components of an active fleet. As a likely result of efforts in these pure military developments and studies come logical applications to civilian technological and welfare activities.

Research in radio at the Laboratory may be divided into three generalized programs of major efforts. The first is devoted to research in the fundamental science and theory of radio and electronics, with the primary purpose of providing a scientific basis for the design of new and improved electronic components and systems. Fundamental studies are made of radio wave propagation, antenna design and characteristics, microwave phenomena, and electron tube design and developments such as storage tubes, microwave amplifier tubes, and high-current-density cathodes.

The second program in radio research is devoted to analytical studies of naval electronics problems, both technical and tactical, and to the development and perfection of such naval electronic gear as radar, communications, and countermeasures equipment. The third of these programs comprises investigation and developments relating to gunfire control, missile guidance and control, and all-weather flying. Also under way are studies of the human element involved in operating naval electronic equipment, a problem of vital importance in building instruments to meet the mental and physical capabilities of an operator.

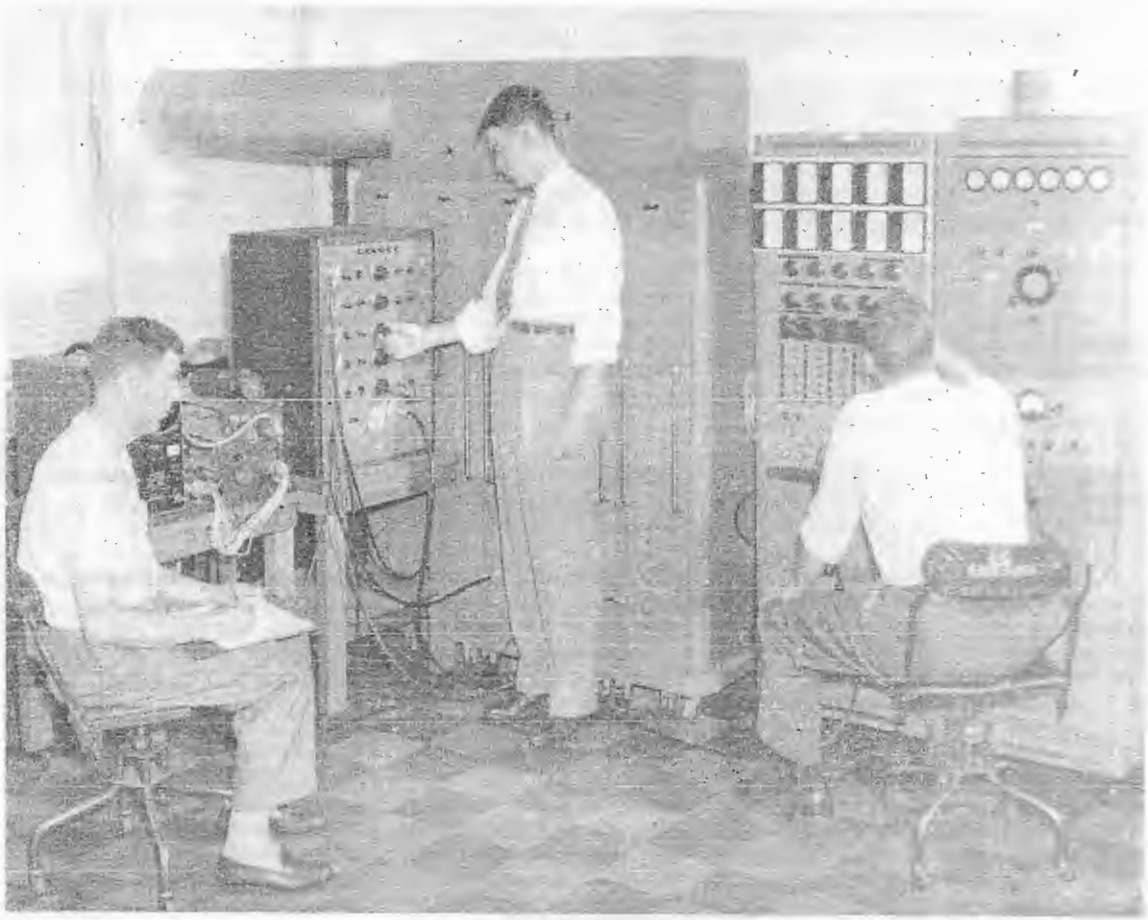
Though the over-all program in radio research constitutes almost one-half the entire efforts of the Laboratory, security considerations preclude a complete, and hardly even a representative, review of the year's accomplishments in this field.

The efficiency of naval communication, radar, navigational, and other electronic systems depends to a great degree on the influences of radio interference. Inasmuch as such interference originates from diverse sources, many of which are not under control of the military services, considerable coordination is essential, and the Laboratory participates in such activities by maintaining representation on committees of national and international organizations concerned with radio interference research, measurement, reduction, and regulation.

HIGH PULSE DENSITY STUDIES

The radio-frequency beacon, which transmits pulsed radio-frequency signals in response to triggering signals received from remote radio-frequency transmitters, is an important link in IFF, navigation, missile guidance, radio relay, and other pulsed communication systems. In these systems a radio beacon is frequently called upon to respond to triggering pulses from several independently operated remote transmitters. Obviously, if the number of remote triggering transmitters becomes too great, the beacon will be unable to respond faithfully to all the transmitters all the time. Under such conditions the beacon fails to reply or gives an apparent reply which is false in response to some of the triggering signals. In order to design such systems for maximum efficiency and reliability, a study was undertaken to establish the relationships involved between true responses, false responses, and no responses under overload conditions. These relationships have been quantitatively derived.

For the combined purpose of experimentally checking the theoretically derived relationships and for measuring the performance of actual beacon systems under known overload conditions, a pulse generator equipment was designed and built providing up to 300 independent triggering signal sources.



A multiple pulse generator is being used to check the performance of a Distance Measuring Equipment (DME) under high traffic density conditions. The multiple pulse generator, along with other equipment developed at the Laboratory, is capable of simulating the traffic conditions of as many as 300 separate interrogations of various pulse lengths (0.4 - 8.0 μsec) and repetition rates (22 - 350 pps).

This pulse generator, together with auxiliary target simulation and high-speed pulse-counting apparatus was used in the measurement of the performance of the airborne component of a high-capacity beacon equipment developed for the common air navigation system under high pulse density conditions.

MICROWAVE ANTENNAS

On the important problem of rapid-scanning antennas, principal effort was placed on moving-feed arrangements rather than on wide-angle-of-view focussing devices. One method devised at this Laboratory for producing feed motion along a straight line employs a wave guide located inside and along the axis of a circular cylinder, both wave guide and cylinder being slotted along their lengths. The cylinder slot is helical and the wave-guide slot is linear, so that uniform rotation of the cylinder relative to the wave guide produces a radiating slot feed which moves linearly at uniform speed. Developmental work on this device at the General Electric Company indicates that it may be practicable. Another general method for converting rapid rotational motion to rapid linear motion, also devised at this Laboratory, consists of revolving a feed horn on a circular path in front of an imaging reflector which is shaped to move the horn image along a straight line at some distance behind the reflector. One arrangement which utilizes this principle is now under test.

A theoretical treatment of the transmission modes of an infinite sheath helix was completed. Calculations, based on this theory, of the radiation fields of single and multiple finite wire helixes received excellent experimental verification.

The Equivalence Theorem of Schelkunoff was employed to obtain a more comprehensive formula for the radiation fields of dielectric rod antennas. For a rod of uniform cross section, excited in a single mode, the contributions to the radiated field from the side and ends of the rod were obtained in closed form.

Of basic importance to a proper understanding of metal lenses was a study of the transmission of electromagnetic waves through, and reflection from, an array of parallel metal plates. The Carlson-Heins theory was extended and made amenable to calculation. Theoretical results were confirmed experimentally by means of a microwave Michelson interferometer.

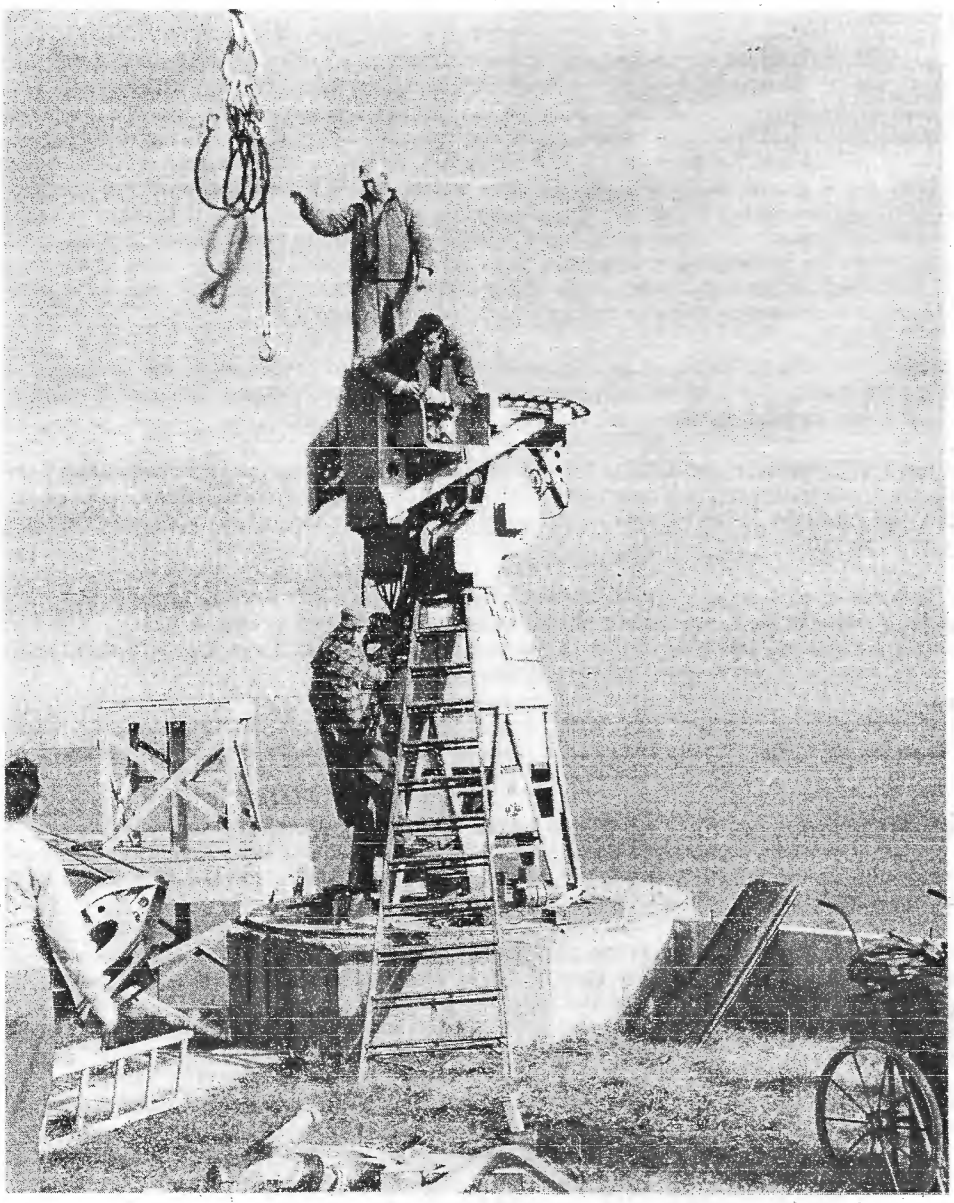
A series of horn gain standards covering a frequency range from 960 Mc to 39,000 Mc, fabricated for this Laboratory by the Sperry Gyroscope Company, is being calibrated to an accuracy of 0.2 db.

A specialized bolometer amplifier developed by the Laboratory for microwave use is now commercially available. Outstanding features of this completed amplifier are a continuously tunable variable-width pass-band, automatic normalization for correction of amplitude changes in the microwave energy source, and a fixed-law ratio expander.

A method for stabilizing reflex klystrons was developed; it emphasizes ease of operation rather than maximum stability, and permits an operator to select instantly either AM or c-w outputs. Stabilities of the order of one part in 10^6 are obtained for both c-w and AM outputs, over the range 8500 to 10,000 Mc. The principle of operation is valid for any frequency for which the necessary components are available.

Development of a mobile, compact, antenna pattern recorder, which operates satisfactorily over an 80-db range of input voltage, was completed. Another pattern recorder, also completed, eliminates the mechanical inertia inherent in conventional design and thus permits writing speeds in excess of 400 inches per second.

For the future it is planned to emphasize work on rapid scanning, axial mode radiators, and broadband antenna components.



"On location" at the Chesapeake Bay Annex, NRL's field test station, Randle Cliff, Md. Here a skilled construction crew, supervised by Laboratory technologists, erects an experimental radar antenna for trials over the seascape.

CIRCUITS, COMPONENTS, AND INSTRUMENTATION

Microwaves

For use in impedance matching of rotary joints at microwaves, an analytical expression was derived for the susceptance of a thin iris in a circular wave guide operating in the TM_{01} mode. Measurements of the susceptance of such irises were made for apertures of various size, ranging from 0.5 to 0.9 of the guide diameter, thus embracing values normally encountered in practice. The measured values were in good agreement with computed values.

A slide rule was developed which facilitates computation of wave-guide wavelength, reflection coefficient from standing-wave ratio, reflection coefficient for an attenuating transmission system, and the decrease in power absorbed by a load when it is mismatched. The slide rule is particularly useful when many computations of this sort must be made in connection with operation of coaxial lines, two-wire lines, and hollow pipe guides.

The NAREC

A general purpose NAval Research Laboratory Electronic Digital Computer (NAREC) is being designed for use in the reduction of the extensive experimental data gathered in missile-control research and in the numerical solution of the general mathematical problems arising in research programs. The types of problems that may be solved involve partial differential equations, systems of differential equations, integral equations, inversion of matrices of high order, and curve fitting by the method of least squares. Being designed as the parallel type, the computer will perform automatically the operations of addition, subtraction, multiplication, and division of binary numbers of 44 binary digit precision at the rate of 9000 operations per second. Input and output circuits will be operated from magnetic tape and will handle decimal numbers of 11-digit precision. An electrostatic storage for 1024 words (that is, either numbers or operating instructions) and an auxiliary magnetic drum-type storage for 2048 words will be provided. The computer, containing about 1800 vacuum tubes and 6000 crystal diodes, is expected to be in operation by July 1952.

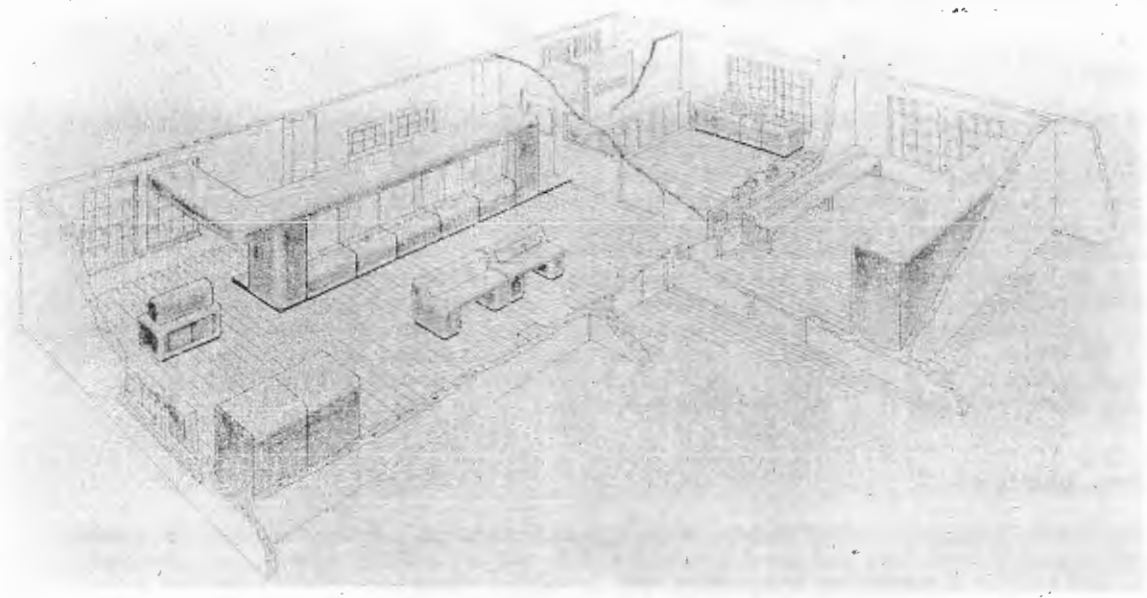
Frequency Control

The precise frequency control of radio-frequency oscillators has long been achieved by mechanical stabilization derived from piezoelectric crystals. Inherent in the design of such oscillators are a very small number of operational frequencies, and, in the past, many unsuccessful attempts have been made to build oscillators which could be varied over a wide frequency range and still retain the stability of crystal-controlled oscillators. A number of attempts have been made to stabilize an oscillator on a selected one of many sub-multiple and harmonic frequencies derived from a single crystal. Most of these attempts resulted in very complex apparatus, and none of them has led to practical applications.

A new principle of frequency control that may be applied to radio signal generators, transmitters, and receivers was developed in which a single crystal may be made to control any one of many frequencies which are selected by a decade series of control knobs, giving direct readings of the output frequency. It is based on frequency control of a variable oscillator whose frequency is divided down to a low, fixed reference frequency. Departure of the generated low frequency from the reference frequency generates a frequency correcting control signal which controls the frequency of the variable oscillator. A laboratory unit was designed covering the range 5 to 1400 megacycles.

LOW-LEVEL DUCTS

Measurements of overwater propagation in the Pacific at 3- and 9-cm wavelengths provided further information on the mechanism of propagation in low-level atmospheric ducts and helped to establish an explanation of a new propagation phenomenon which had been discovered earlier during tests in the Atlantic. The existence of stable ducts which are capable of providing extended ranges for microwave propagation at low heights was verified. At extremely long ranges on the 9-cm wavelength, a fluctuating type of signal was found having an unusually low attenuation rate. This was



The NAREC to be built at the Naval Research Laboratory. A general purpose electronic digital computer, this instrument will be used for the reduction of experimental data and the solution of complex mathematical problems. It will contain about 1800 vacuum tubes and 6000 crystal diodes and should perform about 9000 machine operations per second.

ascribed to possible scattering from turbulent atmospheric eddies at moderately high elevations; scattering from these eddies causes waves to follow the earth's curvature in much the same way as low-frequency "sky waves" are refracted by the ionosphere.* The scattering produced by turbulent air cells was formulated mathematically, and the results were used to find the polarization, the energy distribution of the scattered radiation, and the effect on propagation velocity. The Poisson transform and its meaning in two-dimensional propagation and scattering problems was studied and a simple physical interpretation was found which may be of general value. Work continued on theoretical methods for finding the influence of surface roughness on trapped modes in duct propagation, and the effective reflection coefficient of a rough surface was determined.

In order to forecast propagation conditions over the ocean, it is necessary to forecast the variation of the atmospheric humidity and temperature with height, time, and distance from land. These factors are governed to a large extent by turbulent eddies over the ocean surface. To obtain quantitative information on this largely unexplored problem, techniques were investigated for generating and observing the spread of smoke puffs produced by exploding small quantities of black powder at regular height intervals over the sea. From the areal spread of these puffs, which is measured photographically, the coefficient of eddy diffusion, the fundamental parameter sought, is determined.

RADIO ASTRONOMY

In the fall of 1949 a microwave radiometer with a clock-driven antenna mount was installed at the Laboratory; this apparatus has since continuously recorded the solar emission at 10,000 Mc. Several outbursts of emission have been noted which coincided with solar flares and radio fadeouts.

A critical survey was made of experimental and theoretical work on the radio emission from the undisturbed sun, and there was found reasonable agreement between measured values and a theory based upon thermal emission. Temperature and electron density distributions in the solar chromosphere were derived from an analysis of the radio-energy spectrum of the undisturbed sun.

The microwave radiation from the moon was measured continuously at 10,000 and 35,000 Mc during the lunar eclipse of October 6-7, 1949. No variation in intensity was recorded, confirming the plausible assumption that the surface of the moon is covered with a layer of dust of extremely good thermal insulating properties.

PRECISION LOCATION

In recent years there has been increasing debate as to the relative sensitivity of monopulse over sequential fire- and missile-control radar systems. To resolve this question, a comprehensive study was made of the effects of receiver noise in plausible monopulse and sequential systems on the signal-to-noise ratios appearing in the servo amplifier. The parameters such as antenna gain, beamwidth, and crossover, were so chosen for each system considered that tracking performance was maximized. It was concluded, as a result of the investigation, that, although the r-f monopulse system did exhibit a slight over-all superiority in signal-to-noise ratio the differences between the monopulse and sequential systems were not sufficiently large to warrant the choice of one system over another on the basis of receiver sensitivity.

APPLIED PSYCHOLOGY

The theory of communication networks is used to analyze the contributions of individual components of a system to the performance of the system as a whole. Many operational systems include human beings as components—instrument operators who receive data from one instrument and relay it into another instrument. A psychological study is being made to determine human transfer characteristics in terms of communication theory. Experimental research to date has furnished data directly relevant to (a) the use of pressure joysticks versus displacement joysticks for fire-control tracking devices and (b) the choice of optimum aided tracking time constants.

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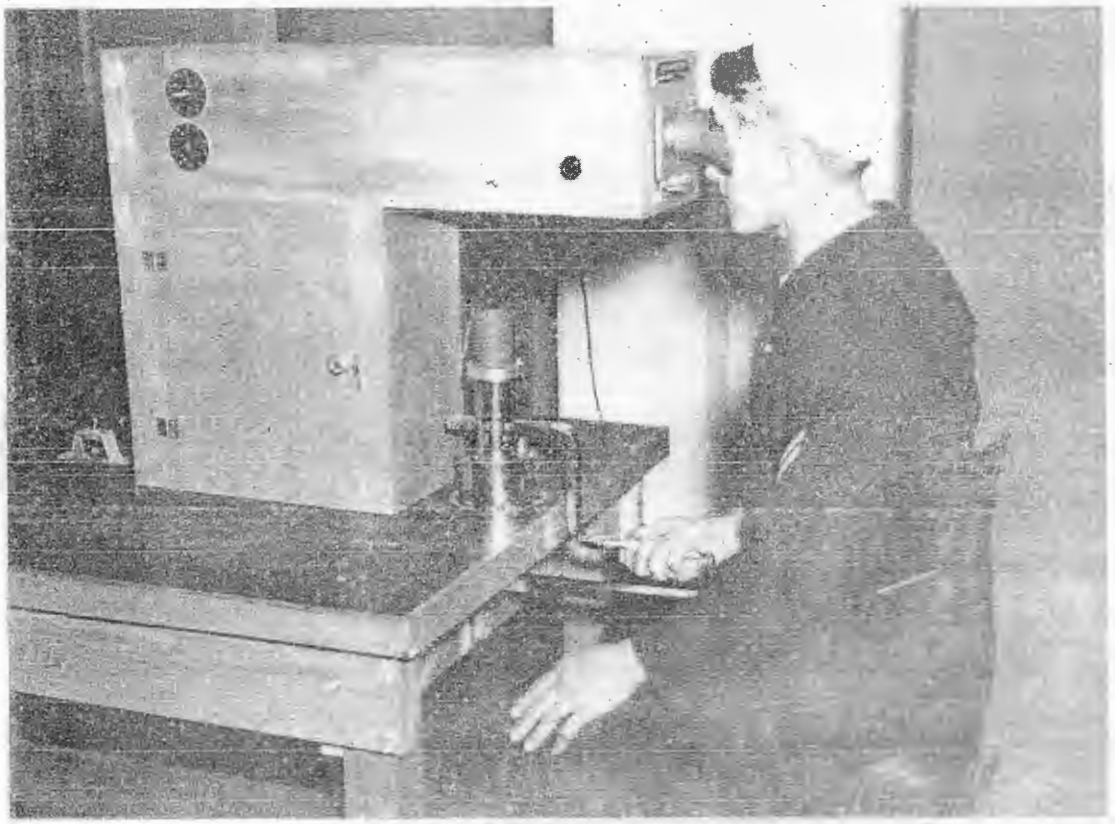
*A quantitative theory based on this scattering mechanism was developed by Booker and Gordon of Cornell University.



A typical subject being tested as part of the applied psychology program for measuring human reactions to various types of control situations.

Test apparatus has been constructed to measure and record reactions of personnel to various types of control situations. Results of such tests are then plotted to study the over-all effects on several subjects at various degrees of electromechanical rate and acceleration aiding.

THE ELECTRONICALLY DRIVEN RIPPLE TANK

An electronically driven ripple tank has been developed to study the phase fronts near two-dimensional models of antenna structures. In this instrument, electronically driven probe-vibrators excite the water surface in a shallow glass tank and produce a series of radiating ripples. Synchronously chopped light, directed through the tank to a ground-glass screen, shows the phase fronts of these ripples as stationary shadows. By using simple equipment, it is possible to visualize rapidly, or photograph, the changes in phase-front patterns brought about by changes in feed-point position and in reflector configuration, as well as by changes of as much as several hundred percent in exciting frequency. The equipment is simple, compact, easy to use, and is readily adaptable to many problems in wave analysis where simulations with water waves may be correlated with wave propagation.

* * *

The electronically driven ripple tank showing a typical phase-front pattern in the viewing screen.

A phase-front pattern made by the ripple tank. The probe-vibrator which excites the water is seen in the lower left.

APPENDIX A

Research and Development Reports

During fiscal year 1950, over 190 reports were published covering research of significant value, an increase of 42 over the preceding year. These documents, written by the scientists carrying out the investigations, serve as formal detailed accounts to the Navy Bureaus of progress on the active research problems. Distribution, however, is not limited to the Department of the Navy; all defense agencies known to have active interests in the problems are provided with the reports. In addition, the reports are filed with the Navy Research Section of the Library of Congress and the Central Air Documents Office at Wright-Patterson Air Force Base for indexing and availability to the broad audience of these two organizations.

There follows a listing of the 92 unclassified research and development reports issued by NRL during this past fiscal year.

CHEMISTRY

C-3452 "Effects of Moisture and Fungus Upon Electrical Insulating Material, A Laboratory Method," J. M. Leonard and C. E. Patouillet, April 15, 1949

C-3468 "Pyrolysis and Chlorinolysis of Some Perchlorinated Unsaturated Compounds," J. A. Krynitsky and H. W. Carhart, June 20, 1949

C-3475 "Ozone Measurements Made at Various Naval Establishments in National Eveready Weathering Units, Model X-1A," J. R. Britt, May 31, 1949

C-3481 "Phosphate Coatings on Steel Part I," J. B. Burbank, June 1, 1949

C-3489 "Reaction of Polyorganosiloxane Monolayers with Aqueous Substrates," H. W. Fox, E. M. Solomon, and W. A. Zisman, June 27, 1949

3508 "Rate of Reaction of Alkali Metals and Aluminum Borohydride with Water," T. K. Rice, F. J. Woods, and R. R. Miller, June 1949

3510 "Phosphate Coatings on Steel Part II - An X-Ray Diffraction Study of the Phosphates of Zinc, Iron, and Manganese," J. B. Burbank, July 28, 1949

3516 "Chemical Studies on Fungicides Part IV. Synthesis of Chloral and Butyl Chloral Amides," J. P. LaRocca and W. E. Weaver, August 15, 1949

3520 "Chemical Studies on Fungicides Part V. Synthesis of Propylene Oxides," J. P. LaRocca and W. E. Weaver, August 16, 1949

3545 "Further Research on the Hydrolube Fluids," J. E. Brophy, V. G. Fitzsimmons, J. G. O'Rear, T. R. Price, and W. A. Zisman, September 29, 1949

3546 "Phenothiazine-Type Antioxidants and Their Mode of Action," H. Ravner, C. M. Murphy, Jr., and N. L. Smith, January 18, 1950

3547 "Electrochemical Studies of Inhibitive Pigments," L. J. Waldron, September 20, 1949

3548 "Studies of Time-Potential Changes on an Electrode Surface During Current Interruption Part I Zinc-Steel Couple in Synthetic Sea Water," S. Schuldiner and R. E. White, October 5, 1949

3550 "Thermal and Oxidation Stabilities of the Polymethylphenylsiloxanes," C. M. Murphy, C. E. Saunders, and D. C. Smith, October 7, 1949

3567 "Spectroscopic Properties of Fluorocarbons and Fluorinated Hydrocarbons," D. C. Smith, J. Rud Nielsen, L. H. Berryman, H. H. Claassen, and R. L. Hudson, September 15, 1949

3602 "An Evaluation of the Jentzsch Fuel Tester," J. E. Johnson, R. H. Blizzard, and H. W. Carhart, February 20, 1950

3609 "Chemical Studies on Fungicides Part VI - Synthesis of Thiocyanoacetates," W. E. Weaver and W. Gillette, January 16, 1950

3615 "Synthesis of Phenothiazine Derivatives for Antioxidant Studies," N. L. Smith, October 30, 1949

3616 "The Cathodic Protection of Ships' Hulls in Sea Water - A Critical Review of the Problem," S. Schuldiner, January, 1950

3619 "Chemical Studies on Fungicides Part VII - Resolution of the Cis-Trans Di(Bromoacetate) of 1,4-Cyclohexanediol," J. P. LaRocca and W. E. Weaver, January 25, 1950

3628 "New Thermal Conductivity Methods in Gas Analysis," C. C. Minter, February 24, 1950

3632 "Chemical Studies on Fungicides Part VIII - Synthesis of α,α-Dichloroacetamides," W. E. Weaver and A. D. Swensen, March 9, 1950

3633 "Organophosphorus Compounds - The Preparation of Alkyldichlorophosphines," R. B. Fox, February 20, 1950

3645 "An Improved Method of Synthesis of Aryldichlorophosphines," B. Buchner, March 31, 1950

ELECTRICITY

E-3480 "Development of Equipment and Procedures for Calibration of Pitot-Static Type Underwater Logs," J. V. H. Allen, June 7, 1949

E-3488 "Remote Tank-Level Indicators," J. M. Marzolf, Jr., and W. K. Gardner, May 20, 1949

3519 "Dynamic Characteristics of Carbon Pile Voltage Regulators," R. L. Mills, September 10, 1949

3541 "Transient Analysis of Voltage-Regulated Aircraft DC Systems," D. G. Scorgie, September 26, 1949

3587 "Current and Temperature Rise in Aircraft Cables Part I - Single Cables Under Steady-State Conditions," M. Schack, December 14, 1949

3621 "Transient Characteristics of DC Motors and Generators," E. L. Brancato and A. T. McClinton, January 30, 1950

3637 "Measurement of Insulation Resistance on Energized Systems," E. L. Brancato and A. T. McClinton, March 1, 1950

3638 "A Thrust Computer for Turbo-Jet Engines," E. S. Van Valkenburg, March 16, 1950

3642 "The Design of Saturable Reactors," J. E. Hart, March 28, 1950

3643 "Investigation of Intermittent Faults in 30.0-Volt DC Aircraft Electrical Systems," M. Trbovich and P. E. Toomire, April 3, 1950

MECHANICS

F-3381 "Resistance of Cast Aluminum Alloys to Mechanical Shock First Partial Report," B. Goldberg, November 10, 1948

F-3476 "Propagation of Transverse Waves in Beams," I. Vigness, June 1, 1949

3581 "Harmonic Power Generation Using Unbiased Ideal Linear Rectifiers," R. L. Easton, December 13, 1949

3596 "The Determination of Shock Isolator Performance," J. P. Walsh and R. E. Blake, January 6, 1950

3597 "Proposed Shock and Vibration Requirements of Shipboard Mounts," R. E. Blake and J. P. Walsh, January 6, 1950

METALLURGY

M-3453 "High-Strength Cast Steel for Navy Anchors," R. H. Haring, April 26, 1949

M-3456 "Properties of Heavy Commercial Forgings of A Low-Carbon Iron-Manganese-Nickel Alloy," S. Toleman and W. J. Harris, Jr., September 1, 1949

M-3474 "Weldability of Cast Chromium-Molybdenum Steels for Service in Steam Lines at 950°F," M. A. Pugacz and J. A. Rinebolt, June 21, 1949

3525 "Contact Transients in Simple Electrical Circuits," F. E. Martin and H. E. Stauss, September 30, 1949

3560 "A Study of Mold Washes for Sand Molds," R. E. Morey and C. G. Ackerlind, October 28, 1949

3563 "A New, Safe, Graphite-Nodulizing Alloy," E. T. Myskowski and R. P. Dunphy, October 30, 1949

3577 "Determination of Oxygen in Titanium," D. I. Walter, November 18, 1949

3603 "Principles of Gating," W. H. Johnson, W. O. Baker, and W. S. Pellini, January 12, 1950

NUCLEONICS

3613 "Penetration of Gamma Radiation Through Thick Targets," W. R. Faust, January 18, 1950

OPTICS

N-3462 "The Measurement of Fluctuating Radiation Components in the Sky and Atmosphere. Part I - Equipment, Measurement and Analysis, and Initial Results," E. Goldstein, July 1, 1949

N-3484 "The Measurement of Slant Visibility," H. S. Stewart, L. F. Drummeter, and C. A. Pearson, June 15, 1949

3523 "Reflection Interference Filters for the Infrared," D. V. Estes and M. E. Barbour, August 22, 1949

3591 "Visibility of Navy Radioactive Self-Luminous Personnel and Deck Markers," L. J. Boardman and L. H. Dawson, December 28, 1949

3594 "Night Sky Brightness Measurements in Maryland and Greenland During 1949," M. Koomen and C. A. Pearson, January 4, 1950

3598 "A Logarithmic Recorder for Measuring Light Down to Low Intensities," W. S. Plymale, Jr., January 3, 1950

3635 "High-Voltage Stabilization by Means of the Corona Discharge Between Coaxial Cylinders," S. W. Lichtman, March 13, 1950

PHYSICS

P-3457 "A New Definition of A Fluid Part I, The Stokesian Fluid," C. A. Truesdell, April 26, 1949

P-3477 "Group Coincidence Discrimination," S. W. Lichtman, June 1, 1949

3522 "Upper Atmosphere Research Report No. IX A Sun-Follower for the V-2 Rockets," H. L. Clark, August 11, 1949

3535 "Upper Atmosphere Research Report No. X - The Matrix Telemetering System," J. T. Mengel, N. R. Best, D. G. Mazur, and K. M. Uglow, September 19, 1949

3553 "A New Definition of A Fluid Part II - The Maxwellian Fluid," C. A. Truesdell, September 20, 1949

3554 "A Form of Green's Transformation," C. A. Truesdell, October 11, 1949

3557 "A Note on the Analog Computation of Determinants," R. E. Roberson and W. McCool, October 18, 1949

3558 "Bernoulli's Theorem for Viscous Compressible Fluids," C. A. Truesdell, October 12, 1949

RADIO

3472 "Propagation of Electromagnetic Waves Through A Stratified Medium Part I General Analysis," B. Salzberg, August 3, 1949

R-3486 "Analysis and Calibration of Loop Probes for Use in Measuring Interference Fields," G. A. Morgan, Jr., June 17, 1949

R-3497 "Survey of Generalized Impedance Measuring Techniques for the Microwave Frequencies," P. A. Portmann, June 28, 1949

R-3498 "A Portable Servo Recorder for Antenna Patterns," O. A. Tyson and W. J. E. Edwards, July 6, 1949

3503 "Frequency and Bandwidth Tolerances for a Transpondor Go-No-Go Wavemeter," S. Paull, June 9, 1949

3504 "A Study of the Radio-Frequency Radiation from the Sun," J. P. Hagen, July 13, 1949

3506 "Application of Interstage RC Networks to Provide Selectivity in Low-Frequency Amplifiers," W. C. Whitmer, July 13, 1949

3511 "A Reciprocating Spaced-Line Sweep for Storage Tubes," W. A. White and D. A. Fluegel, June 28, 1949

3517 "A Method of Measuring Small Radio-Frequency Powers," J. P. Leiphart and W. E. Leavitt, August 9, 1949

3518 "Ratio Indicator," L. M. Wrye, August 16, 1949

3527 "Portable Precision Frequency Meter," G. K. Jensen and J. E. McGeogh, September 6, 1949

3530 "Antenna Wavefront Problems," K. S. Kelleher, September 19, 1949

3534 "Physical Optics of Metal Plate Media Part I, Theoretical Considerations," B. A. Lengyel, September 19, 1949

3540 "A Direct-Reading RF Wattmeter," W. E. Leavitt and H. F. Hastings, September 27, 1949

3559 "The Ripple-Tank as an Aid to Phase-Front Visualization," A. H. Schooley, October 15, 1949

3562 "An Interferometer for Microwaves," B. A. Lengyel and A. J. Simmons, November 3, 1949

3578 "Notes on Design, Construction, and Evaluation of Shielded Rooms," G. A. Morgan, Jr., December 9, 1949

3580 "Improvements in Regenerative Frequency Dividers," G. K. Jensen and F. E. Wyman, December 9, 1949

3588 "A Low-Inertia Recorder for Directive Antenna Patterns," O. A. Tyson, December 27, 1949

3595 "Computer for Radiation Patterns of High-Gain Antennas," B. I. Small, January 5, 1950

3599 "Physical Optics of Metal Plate Media Part 2, Experimental Studies," B. A. Lengyel and A. J. Simmons, January 3, 1950

3612 "Standing-Wave Measuring Equipment for Microwaves," P. A. Portmann, January 17, 1950

3614 "Frequency Stabilization System for Reflex Klystrons," O. A. Tyson, January 16, 1950

3624 "Variable Magnification - A Means of Increasing the Resolution of Television Transmitted Data," D. O. Collup, January 30, 1950

3639 "Signal Fluctuations in Long-Range Overwater Propagation," W. S. Ament and M. Katzin, March 17, 1950

APPENDIX A

SOUND

S-3444 "The Microthermal Structure of the Ocean Near Key West, Florida Part II - Analysis," R. J. Urick and C. W. Searfoss, April 12, 1949

S-3448 "Instrumentation for Magnetic Recording Research," R. H. Carson, April 14, 1949

S-3483 "Chemical Effects of Intense Ultrasonic Waves in Liquids," A. Weissler, June 15, 1949

3589 "Rotated Elastic and Piezoelectric Coefficients of Ammonium Dihydrogen Phosphate," B. J. Faraday, December 20, 1949

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APPENDIX B

Published Papers

As a means of stimulating professional advancement and development for its research workers, the Laboratory encourages the publication of papers on unclassified research problems in appropriate journals. Not only are the authors of these papers benefited by such publication, but all of science, and industry too, receives through the professional journals the important scientific information being uncovered and developed at the Naval Research Laboratory. The following list of nearly 100 papers published in the scientific press during fiscal year 1950 is indicative of the efforts made by the NRL scientists in this direction.

CHEMISTRY

Alexander, A. L. and May, T. P., "Spray Testing with Natural and Synthetic Sea Water. Part II - A Study of Organic Coatings," ASTM Preprint No. 26, 1950

Fox, H. W., Solomon, E. M., and Zisman, W. A., "Reaction of Polyorganosiloxane Monolayers with Aqueous Substrates," Journal of Physical and Colloid Chemistry 54, 723-731, May 1950

Merker, R. L. and Zisman, W. A., "Extreme Temperature Lubricating Greases," Industrial and Engineering Chemistry 41, 2546-2551, Nov. 1949

Murphy, C. M. and Zisman, W. A., "Nonflammable Hydraulic Fluids," Lubrication Engineering 5, 231-235, Oct. 1949

Murphy, C. M. and Zisman, W. A., "Nonflammable Hydraulic Fluids (Part 2)," Lubrication Engineering 5, 264-269, Dec. 1949

Saunders, R. A. and Smith, D. C., "Infra-Red Spectra and Structure of Hevea and Gutta Elastomers," Journal of Applied Physics 20, 953-965, Oct. 1949

Shafrin, Elaine G. and Zisman, W. A., "Hydrophobic Monolayers Adsorbed from Aqueous Solutions," Journal of Colloid Science 4, 571-590, Dec. 1949

Smith, D. C. (with Nielsen, J. R. and Claassen, H. H.), "Infra-Red and Raman Spectra of Fluorinated Ethylenes. I. 1,1-Difluoroethylene," Journal of Chemical Physics 18, 326-331, March 1950

Smith, D. C. (with Nielsen, J. R. and Claassen, H. H.), "Infra-Red and Raman Spectra of Fluorinated Ethylenes. II. 1,1-Difluoro-2,2-Dichloroethylene," Journal of Chemical Physics 18, 485-489, April 1950

Smith, D. C. (NRL), Pan, Chi-Yuan, and Nielsen, J. R. (University of Oklahoma), "Vibrational Spectra of the Four Lowest Nitroparaffins," Journal of Chemical Physics 18, 706-712, May 1950

ELECTRICITY

Askew, W. H. and McClinton, A. T., "Current Ratings of Aircraft Cable," paper 49-202, American Institute of Electrical Engineers Transactions 68, 988-992, Part II, 1949

Horton, Billy M., "Sliding Contacts to Transmit Small Signals," Review of Scientific Instruments 20, 930-932, Dec. 1949

Larson, L. R., "Philosophy of Protection of Aircraft Electrical Systems," (digest of paper presented at AIEE meeting held 23-29 August), Electrical Engineering 68, 884, Oct. 1949

Marzolf, J. M., "Inductance Meter," Electronics 23, 90-91, May 1950

Marzolf, J. M., "A New Inductance Method for Remote Indication of Tank Level," Instruments 23, 562-563, June 1950

McClinton, A. T. and Brancato, E. L., "Transient Characteristics of DC Motors and Generators," paper 49-229, American Institute of Electrical Engineers Transactions 68, 1100-1106, Part II, 1949

MECHANICS

Kauffman, J. and George, W., "Load Induced X-Ray Line Broadening in Nylon Filaments," Journal of Applied Physics 21, 431-434, May 1950

La Torre, R. and George, W., "Laboratory Techniques: New Methods for Holding Multi- and Single-Filament Tensile Specimens," Textile Research Journal 19, 830-832, Dec. 1949

Trent, H. M., "An Equivalent Circuit for a Vibrating Beam Which Includes Shear Motions," Journal of the Acoustical Society of America 22, 355-357, May 1950

Vigness, I. and Nowak, R. C., "Streak Photography," Journal of Applied Physics 21, 445-448, May 1950

METALLURGY

Baer, W. H. and Loring, B. M., "Effects of Melting Atmosphere, Time at Temperature, and Degasification on Properties of Valve Bronze," Transactions of the American Foundrymen's Society 57, 257-262, 1949

Berg, O. E., "The Focusing X-Ray Tube," Non-destructive Testing, 12-14, Fall 1949

Johnson, W. H., Baker, W. O., and Pellini, W. S., "Principles of Gating Design," American Foundryman 17, 4, 106-113, April 1950

Morey, R. E., "Standard Test Sand Selected," American Foundryman 16, 32, Sept. 1949

Myskowski, E. T. and Dunphy, R. P., "A Graphite Nodulizing Alloy," Iron Age 164, 78-79, Sept. 8, 1949

Myskowski, E. T. and Dunphy, R. P., "Economic and Safety Advantages Seen for Improved Nodulizing Alloy," Steel 125, 82-83, Sept. 5, 1949

Myskowski, E. T. and Dunphy, R. P., "New Graphite Nodulizing Alloy," Foundry 77, 72-75, Oct. 1949

NUCLEONICS

de Packh, D. C. and Birnbaum, M., "Theory of the Capture Process in a Betatron-Injected Synchrotron," Review of Scientific Instruments 21, 451-456, May 1950

Faust, W. R., "Multiple Compton Scattering II," Physical Review 77, 227-232, Jan. 15, 1950

Faust, W. R., "Specific Activity of Potassium," Physical Review 78, 624, June 1, 1950

3700

Johnson, M. H. and Lippmann, B. A., "Motion in a Constant Magnetic Field," Physical Review 76, 828-832, Sept. 1949

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APPENDIX C

Selected Laboratory Problems

The scientific program at the Laboratory changes in detail constantly as a result of varying needs of the Navy. New problems are introduced, completed ones are cancelled, others may be suspended or delayed. Though the requirements of the Fleet are foremost, other considerations in the acceptance or rejection of research problems are: Available personnel with suitable qualifications, available equipment, facilities and space, and the relative importance of one problem over another. Much thought is placed on these factors before new problems are accepted as part of the over-all Laboratory program

There follows a list of selected problems being pursued at the end of this fiscal year.

CHEMISTRY

Fuels
- Characteristics of New Aviation Fuel Blends.
- Jet Propulsion Propellants.
- Oxidation Stability of Diesel and Jet Fuels.
- Cetane Improvers for Diesel Fuels.

Lubricants
- Fundamental Investigation of Oxidation Inhibitors in Oils.
- Friction and Wear as Related to Lubrication.
- Aqueous Lubricants Research.
- Basic Research on Greases.
- Development of Special Purpose Lubricants.

Protective Surfaces
- Methods and Materials for Tropicalization of Navy Equipment.
- Fuel Storage Tank Lining Materials.
- Finishes and Treatment for Magnesium.
- High Temperature Organic Finishes.

Personnel Protection
- Development of a Submarine Gas Analyzer.

Electrochemistry
- Electrochemistry of the Silver Peroxide Cell.
- Basic and Operational Studies of Lead Acid Storage Batteries.

High Polymers
- Organic Phosphorus Compounds.
- Electrical Insulating Materials.
- Basic Factors Influencing Properties of Synthetic and Natural Rubbers.

Control of Fires
- Methods for Control of Fuel Storage Fires.
- "Pressurized" Mechanical Foam for Airplane Crash Fire Fighting.

Colloids
Colloidal Dispersion in Oils.

Surface Chemistry
Absorption-Desorption Equilibria as Applied to Oil Additives.
Corrosion Inhibiting Films.

Physical Chemical Properties
Liquid Alloys as Heat Transfer Media.

ELECTRICITY

Electrical Power Systems
Characteristics of Submarine Electrical Systems.
Characteristics of Aircraft Electrical Systems.

Electrical Power Equipment
Electrical Insulation Life Studies.
Studies of Electrical Brushes and Brush Life.
Servo Control Studies.
Magnetic Amplifier Theory and Application.
Permanent Magnetic Alternators.
Generator Rating at Altitudes.

MECHANICS

Elasticity

Shock and Vibration
Analysis of Materials by Use of Vibration Techniques.
Laboratory Reproduction of Shock and Vibration Phenomena.
Instrumentation and Measurement of Mechanical Shock.
Shock Mounts.
Dynamic Response of Strength Members of Equipment Subjected to Shock.
Shock and Vibration Tests on Miscellaneous Equipment as requested by Various Defense Activities.
Centralizing Activity of Shock and Vibration, RDB.

Strength of Solids
Strength of Materials Under Shock Conditions.
Fracture Studies in Ships' Plastic and Metal Structures.
Plastic Flowing.

Penetration Ballistics
Investigation of Incandescence Related to Impact and High Velocity of Missiles.
Gunfire Damage to Aircraft Structure.

METALLURGY

Physical Metallurgy
Titanium Base Alloys.
Properties of Iron Alloys.
Metals and Alloys at Elevated Temperatures.
Formation and Decomposition of Austenite.

Physical Metallurgy (Continued)
- Electrical and Magnetic Properties of Metals and Alloys.
- Corrosion Mechanisms.

Melting and Casting
- Aluminum Alloys for High Temperature.
- Graphite Formation in Cast Iron.
- Mold Materials at Elevated Temperatures.
- Principles of Casting Metals.

Welding
- Weldability of Alloy Steels.
- Fundamental Studies of Weld Joint Behavior.
- Weldability of High Temperature Alloys.
- Performance of Aluminum Alloy Welds.

NUCLEONICS

Nuclear Constituents
- Nuclear Theory.
- Heavy Particle Reactions.

Nuclear Structure
- Radioactivity.
- High Energy Electrons and Gamma Rays.
- Mass Spectroscopy.

Nuclear Motive Power
- Reactor Materials.

Nuclear Technology
- Radiation Shielding.
- Radiochemistry.

OPTICS

Optical Properties of Materials
- Optical Filters.

Optics of Atmosphere and Sea
- Atmospheric Transmission.
- Scattering of Light.
- Slant Visibility Meter.

Spectroscopy
- Spectroscopic Investigation of Fuels and Lubricants.
- Extreme Ultraviolet Spectroradiometry.

Physiological Optics

Photometry
- Properties and Characteristics of Luminous Material.
- Physical Methods for Measurement of Radiation.

PHYSICS

Electrical and Magnetic Properties
- Radio-Frequency Ferromagnetism.
- Superconductivity.
- Cryogenics.
- Magnetic Phenomena Research.
- Semiconductor Rectifiers.
- Solid State Investigations.

Engineering Physics of Materials
- Gaseous Conduction of Electricity.
- Conduction of Electricity through Sliding Contacts.

Meteorology
- High-Speed Bodies in Air.
- Meteorology Instruments.
- Microseismic Storm Detection.

Upper Atmosphere
- High-Altitude Spectroscopy.
- High-Energy Particles by High-Altitude Cosmic Ray Studies.
- Ionosphere Studies.
- Temperature and Pressure Studies.
- Composition.

Electron Microscopy, X-Ray, and Electron Diffraction
- X-Ray Fluorescent Methods of Chemical Analysis.
- Electron Diffraction Applications.
- High-Temperature X-Ray Diffraction.

Crystals
- Physical Investigation of Nonmetallic Solids.
- Preparation of Nonmetallic Solids.
- Crystal Processing.

Applied Mathematics
- Analog Computers.
- Theoretical Mechanics.

Luminescent Materials

RADIO

Communication
- Terminal System.
- Automatic Printing System.

Countermeasures
- Mathematical and Empirical Study of Intercept System Indicators for Radio Countermeasures.
- New Radio Countermeasure Recording Techniques.

Systems Integration
- Electronic Systems Interference.
- High Pulse Density Analysis.

Electron Tubes
- Cathodes for Ultra-High-Frequency Tubes

Antennas
- Microwave Components Utilizing Dielectric Elements.
- Helical Antennas.
- Physiological Refracting Media.
- Dielectric End Fire Antennas.
- Microwave Gain Standards.
- Automatic Microwave Impedance Recorder.
- Frequency Stabilized Microwave Power Oscillators.
- Antenna Measuring Equipment.

Circuits, Components, and Instrumentation
- Instruments and Measurements.
- Frequency Meters.
- Millimeter Wave Research.
- Visibility of PPI Signals.
- Electronic Digital Computers.
- Random Pulse Circuits.

Propagation
- Electro-Magnetic Wave Propagation.
- Effect of Upper Atmosphere on Radio Wave Propagation.
- Extra-terrestrial Radiation.
- Radar Properties of Missiles.
- Effects of Atmospheric Precipitation on Radio Transmission.

Applied Psychology
- Psychological Research.
- Application of Psychology to Design of Gun Fire Control Systems.

SOUND

Transducers
- Crystal Transducers.

Propagation
- Ocean Sound Propagation.
- Sonic and Ultrasonic Sound Propagation.

Recording and Reproduction
- Sound Recording.
- Sound Control and Measurement.

Sonar Electronics
- Ultrasonic Circuit Behavior.
- Ultrasonic Noise Behavior.

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