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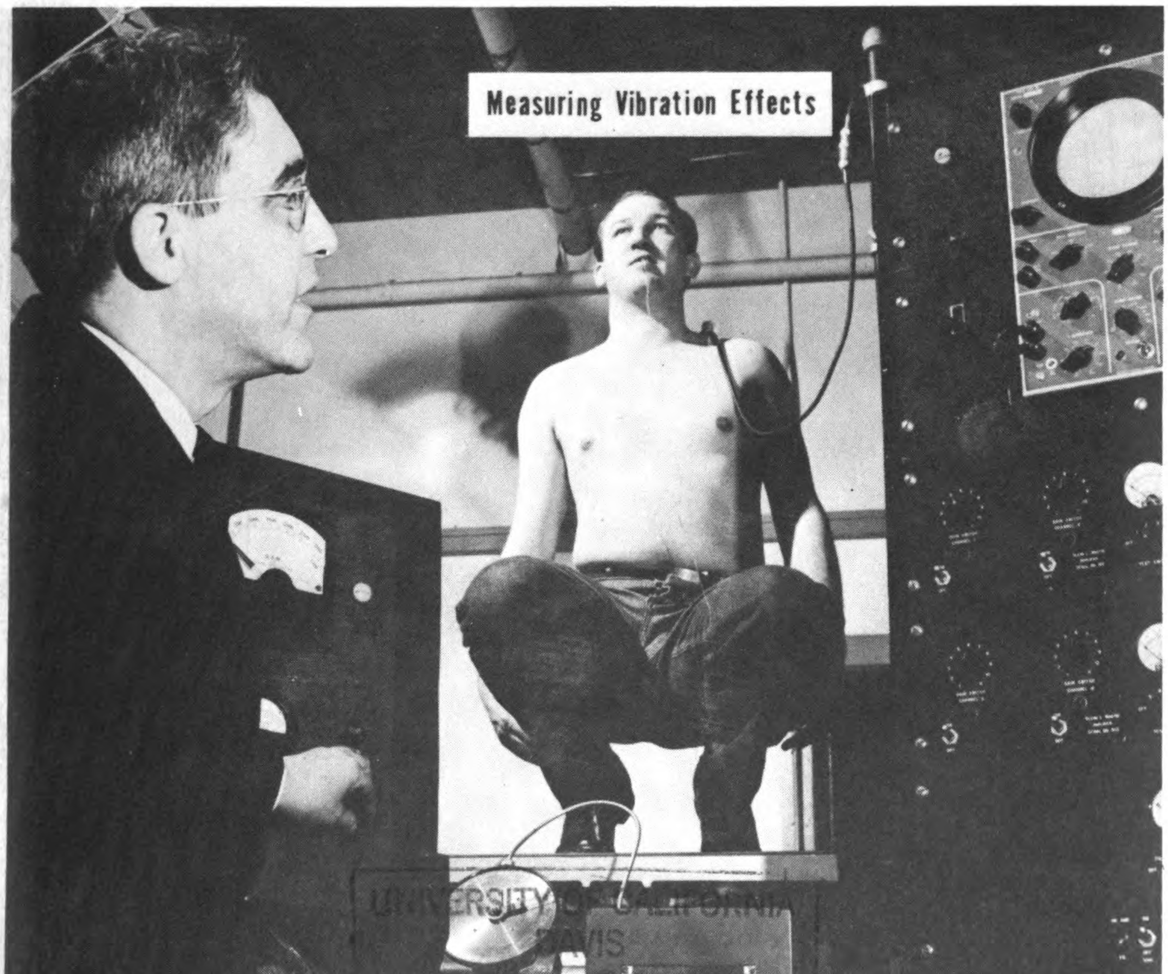
RESEARCH REVIEWS



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DEPARTMENT OF THE NAVY

WASHINGTON, D. C.

COVER PHOTO: LCDR David E. Goldman, Medical Service Corps, USN, is at the controls of the large displacement-amplitude vibration machine described on page 14 as a test begins. The subject, with accelerometer mounted on his shoulder, assumes a squatting position of the vibrating platform. These studies are being conducted by Dr. Goldman and his staff at the Naval Medical Research Institute, Bethesda, Md.

Research Reviews endeavors to report briefly highlights of technical progress in research by Navy laboratories and contractors and the development of important naval research facilities. Articles which meet these broad criteria and possess a good degree of readability are welcomed. Manuscripts and changes of address should be sent to Code 740, Office of Naval Research, Washington, D. C.

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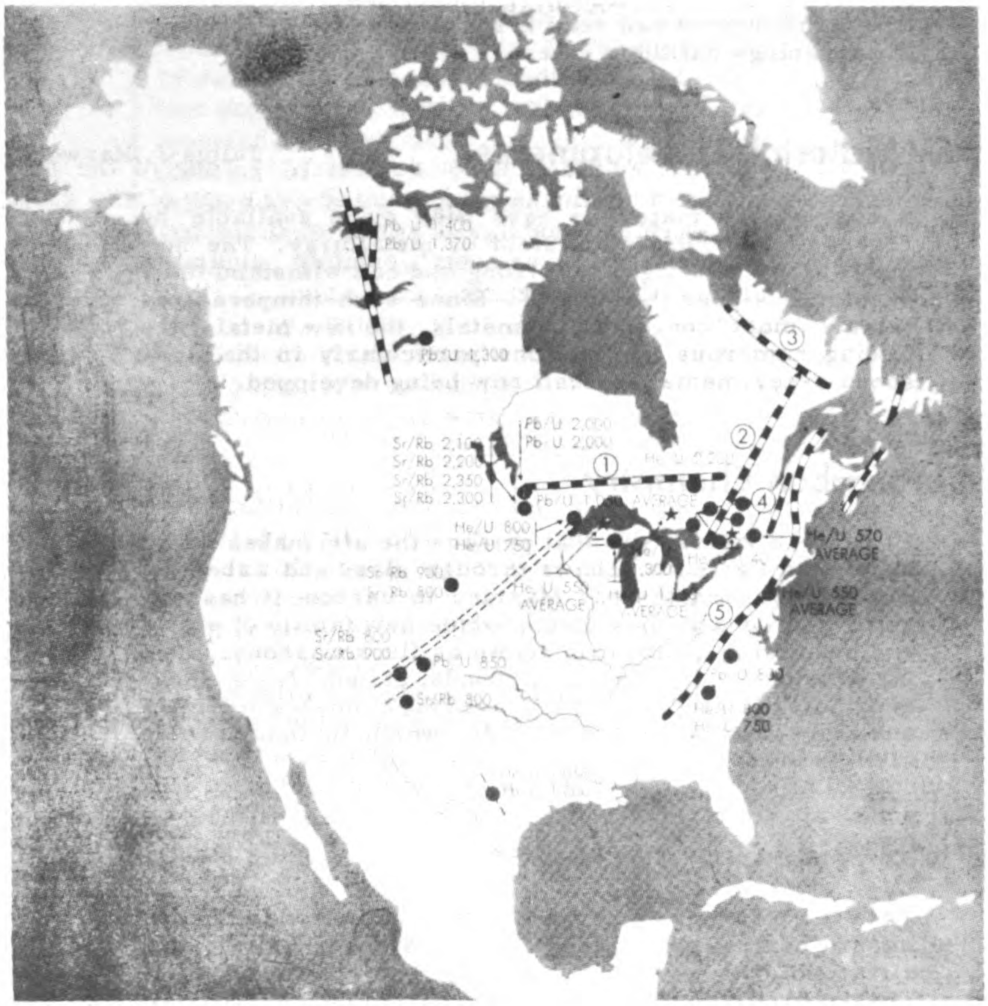
In This Issue



Ages of rocks in North America have been outlined by measurements based on radioactivity. Black and white strips indicate the roots of mountain belts, some of which are numbered in their order of development. Dotted lines denote possible mountain belts. Type of radioactive measurement is given by the ratio of one element to another, e.g., a lead-uranium ratio is indicated as Pb/U. Rock ages are given in millions of years.

Radioactivity and The Age of The Earth

by
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. . . Member of Light Particle
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Of all the recent applications of radioactivity, one of the most interesting is it's use as a means of determining the age of the earth. This problem has intrigued mankind throughout the centuries. Estimates have varied from the seventeenth century calculation of Archbishop James Ussher that the earth was formed at 9 o'clock on the morning of October 12, 4004 B.C. to an almost equally specific date of creation arrived at by the ancient Hindus which would lead to a present age of 1,972,949,054 years. The Hindus were amazingly accurate inasmuch as their estimate is of the same order of magnitude as the most reliable estimates of the present time.

Before the discovery of radioactivity, scientific estimates of the age of the earth varied between 20 and 90 million years. In 1931, Knopf summarized these early estimates pointing out that at the beginning of the present century the only apparent problem connected with the age of the earth seemed to be one of reconciliation of several independent estimates, all of which were of the same order of magnitude. These ranged from the 22 million years of Helmholtz, based on the source of the sun's heat, to the 90 million years of Joly, based on the rate of accumulation of sodium in the oceans, with intermediate figures such as Lord Kelvin's value of 40 million years based on the rate of cooling of the earth, and Darwin's value of 57 million years based on the separation of the moon from the earth.

The discovery of radioactivity with its extremely long decay periods necessitated a radical revision in man's concept of the age of the earth. Radioactive atoms are characterized by changes which occur spontaneously in their nuclei, transforming them into different elements. This rate of transformation, or decay rate, follows an exponential law, and is conveniently expressed in terms of a half-life, which is the time required for a radioactive material to be reduced to half its initial amount by these nuclear transformations. The half-life value for a given radioactive species is a constant which is characteristic of that particular species, and is often used as a means of identification. The decay chain may consist of only two members, radioactive parent and stable daughter, with only one transformation process taking place; or, as is more common among the naturally occurring radioactive materials, the chain may consist of several members, each successive member of which undergoes a radioactive transformation with its own characteristic half-life, until the chain finally terminates itself by producing a stable atom. Here at last was the perfect geological timepiece, a clock which was wound at the birth of the elements, and has been running at a constant rate ever since.

Referring to the three conditions given above, the half-life expresses the rate at which the decay process is occurring; the quantity of the stable end-product of the decay chain is a measure of the total change resulting from the decay process; the decay rate, it is reasonably certain now, has remained the same throughout time.

Of the naturally occurring radioactive elements, only uranium 238, uranium 235, thorium 232, potassium 40, and rubidium 87 have sufficiently long half-lives to be useful in age determinations.* It is comparatively easy to obtain an upper limit for the age of the earth by merely looking at the half-lives of some of these elements. From the half-life values for uranium 235 (7.1×10^8 yr) and potassium 40 (1.27×10^9 yr), and the fact that they still exist in appreciable quantities, it is improbable that the earth is older than 10^{10} yr. Another approximation to this upper limit may be obtained by considering the uranium 238 to 235 ratio, which at the present time is 138. Since with few exceptions odd isotopes are always less abundant than even isotopes, one can extrapolate back in time to the point when they were equally abundant, and thus obtain an upper limit of 6×10^9 yr.

A third approximation can be made if one makes the reasonable assumption that any system containing measurable amounts of a radioactive element cannot have been isolated longer than the time required to produce all of the observed stable daughter product resulting from the decay process. Thus, uranium 238 by a chain of successive transformations eventually produces a stable end-product, lead 206. Uranium 235, by a somewhat similar chain of decays, produces stable lead 207. If one examines the data on the known present day abundances of these four isotopes, and then makes the assumption that at zero time when our system (the earth) became isolated no lead 206 existed, then the maximum time that system could have remained isolated comes out to be approximately 5×10^9 yr. Of course, if some of the lead 206 or 207 is non-radiogenic in origin, the time necessary to produce the observed abundances by radioactive decay processes becomes smaller.

At this point it may be profitable to inquire as to just what "age" we are considering. Figures obtained in the above manner have been rather indiscriminately referred to as the "age of matter," the "age of the universe," the "age of the earth," etc. Actually, in the last example given above, the abundance data were based on samples taken from that portion of the earth's crust which was accessible to us for sampling. Hence the value obtained for the upper age limit should, strictly speaking, be regarded as an estimate of the maximum time elapsed since isolation of the earth's crust. The question then arises as to the magnitude

*Attempts to use radioactive samarium 152—half-life 2.5×10^{11} yr—for this purpose have not been successful due to scarcity of suitable samples; the stable neodymium 148 daughter does not occur in sufficient quantities to permit an analytical differentiation between radiogenic and non-radiogenic neodymium.

of the time interval between formation of the earth as a whole and solidification of the earth's crust. If the solar system originated in a cosmic dust cloud as centers of accumulation of matter, much of the accumulation would have an initial temperature well below the melting point. Calculations based on such an accumulation of potassium 40, uranium, and thorium from their present abundances and half-lives seem to indicate that due to the release of heat during the radioactive decay process, the earth would pass through a stage of liquefaction followed later by solidification of the crust. The time required for the liquefaction and subsequent solidification is estimated by cosmologists to be considerably less than 10^9 yr.* It seems reasonable then to disregard the time interval which elapsed between the formation of the earth and the solidification of the earth's crust, since the magnitude of this time interval seems small compared to the age of the crust itself. Hence, in a general sense, the age of the earth's crust may be taken as synonymous with the age of the earth itself.

An estimate as to a lower limit for the earth's age can be made by a measurement of the age of minerals, on the assumption that the earth must be at least as old as the rocks and minerals which form a part of its crust. Several methods based on radioactivity have been used for this purpose. In a mineral containing uranium the stable end-product of the decay is lead 206 (neglecting for a moment the lead 207 produced by the decay of uranium 235) which has been produced at a constant rate since the decay process started. A so-called "crude lead" method is based entirely on chemical determinations of the Pb/U ratio, ignoring any non-radiogenic lead which may be present. A refinement of this method includes—in addition to the chemical analysis—a determination of the lead isotope composition by mass spectrographic analysis; in this way the presence of the so-called "common" or "primeval" lead may be corrected for. A variation of this method involves a determination of the helium content of the mineral. In the chain of successive decays in going from uranium 238 to lead 206, eight helium atoms are formed by alpha decay. Because of the density of certain rocks and minerals, most of the helium remains entrapped therein. Thus, by determining the Pb/U ratio, or the He/U ratio in the sample, a calculation can be made based on the known decay rate of uranium which will give the length of time required for a given quantity of uranium to produce the measured amount of lead or helium.

However, both the lead clock and helium block methods suffer from serious disadvantages. For example, in both it is assumed that the only changes which took place in the past must have been through radioactive decay. But the geologic history of the samples used is often

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*There is considerable disagreement on this aspect of a liquid stage during the earth's early history. Jeffreys, although concluding that the interval of time from liquefaction to formation of a crust may have been from 10^4 up to 10^6 yr, disagrees with the ideas stated above concerning the effect of radioactivity. In his opinion, the contribution of radioactivity to the earth's surface temperature, even during early history, was negligible. Urey has recently suggested that the earth did not pass through any initial molten phase at all. However, such disagreement does not contradict the main point of the above argument, that the time since solidification of the crust is long compared to the previous intervals.

uncertain; the effects of leaching processes in past ages on the Pb/U or He/U ratios, or any other orogenic processes in the earth's crust at various times (sedimentation, weathering, mixing of two different ores through upheavals, etc.) cannot be estimated. Also there must be considered a possible contamination with ordinary lead ores (for example, pitchblende, a uranium ore, is often found in close association with galena, a lead sulfide ore). The escape of helium from all but very dense rocks by diffusion during geologic time is likewise a serious source of error in the helium clock method. However, if the rock or mineral sample is carefully chosen, reasonably reliable values may be obtained by either the Pb/U or He/U methods. For example, lead age measurements on uraninite samples from northern Karelia have yielded values of 1.8×10^9 to 2.0×10^9 yr.

Age measurements on the oldest rocks found thus far have been made by a method identical in principle to those described above, but different in detail in that it is based on the decay of rubidium to strontium. Rubidium 87, a naturally occurring radioactive isotope, decays to inactive strontium 87, the half-life for this process being 5.8×10^{10} yr. Because of this long half-life, the method is not too good for age determinations on comparatively young rocks, but is especially suitable for very ancient specimens. However, because of the extremely small quantities of radiogenic strontium formed, even over long periods of time, extremely sensitive methods of analysis are required, especially when the sample is contaminated with "common" strontium, when mass spectrographic analyses become necessary. Fortunately, in lepidolite about 99% of the total strontium is radiogenic, and no isotopic analysis is required. The usefulness of the method depends on the accuracy with which quantities of rubidium as low as .05%, and of strontium down to .01 - .002%, can be determined. According to Ahrens the oldest rocks on record average about 2.2×10^9 yr, as measured by the rubidium-strontium clock. Because of their similarity in age, and since they come from various parts of the earth's surface (Sweden, Canada, S. Africa, etc.), it is quite likely that these rocks are representative of the first major crustal disturbance in the earth's history.

By such methods as these, maximum and minimum ages of the earth have been established as approximately 5×10^9 and 2×10^9 yr, respectively. The method which has given the best results to date, however, is based on the determination only of the isotopic constitution of lead contained in a given sample. Lead as found in nature consists of four stable isotopes of masses 204, 206, 207 and 208. Of these, only lead 204 has remained unchanged throughout the earth's history and can therefore be taken as a measure of the quantity of primeval lead. Lead 206, 207, and 208 are the end-products of the radioactive decay chains starting with uranium 238, uranium 235, and thorium 232, respectively; they are therefore found in varying abundances. Material balance equations containing the age of the earth as an unknown can be set up for each of the three radiogenic lead isotopes, in which the amount of the isotope found now is set equal to the amount which existed at the beginning plus the amount formed by radioactive decay. If one knows the isotopic composition of the lead contained in the sample, it is possible to solve the equations for the age of the earth. Based on data obtained from twenty-five very carefully selected lead ore samples, Holmes has calculated this value to be 3.35×10^9 yr.

The most recent estimate of the age of the earth is based on a comparison of isotopic lead ratios in the earth's crust and in meteorites. Two assumptions are made here: first, that the earth and the meteorites were formed at the same time; second, that since in certain meteorites the amount of uranium is quite small compared to the lead, very little lead has been formed by radioactive decay. Hence, the isotopic composition of meteoritic lead is assumed to be the same as the composition of terrestrial lead at the time of the earth's formation. Thus, knowing the isotopic lead composition of several meteorite samples, one can calculate the length of time required for lead of this composition to change to values typical of present day terrestrial lead ore samples by radioactive decay processes. Such a calculation leads to a value of 4.0 by 10^9 yr.

In a similar manner, one can use the values for present day lead isotopic ratios found in samples from the Pacific ocean and compare them to the primeval meteoritic values. The calculated time interval in this case is 4.5×10^9 yr.

The results obtained by methods involving radioactivity with estimates made by other methods are compared in the following tabulation:

	Method	Estimate (10^9 yr)
Age of Earth's Crust	U 238/U 235 ratio	<6
	Pb/U (lead clock)	>2
	He/U (helium clock)	>2
	Pleochroic halies (alpha ionization effects in minerals)	>2
	Terrestrial Pb isotopic ratio	3.3
	Meteoritic Pb isotopic ratio	4.0 - 4.5
	Rubidium 87 - Strontium 87 decay chain	>2.5
	Cooling of earth's crust	2-4
Age of the Atmosphere	Potassium 40 - Argon 40 decay chain	~3
Age of Ocean	Salinity of oceans	1-7
Age of Solar System	Age of moon (tidal effects)	>2-4
Age of Galaxy	Age of sun	~5
	Star clusters	4-5
Age of Universe	Galaxy clusters	2-4
	Recession of nebulae (expanding universe)	~4

It is really remarkable that such a variety of methods should give results which agree so well in order of magnitude. As pointed out by Chandrasekhar, this time scale throughout the universe of the order of a few billion years does not seem to be accidental. Such a time scale seems to lead back to some common starting points for all these processes. It seems unlikely at the present time that any values radically different from those already quoted for the age of the earth will be found; efforts in the future will most likely be devoted to narrowing the interval between the minimum and maximum estimates by accumulation of additional data and refinement of the statistical methods used to analyze such data.

Symposium on Semiconductor Research

Definite trends to operation of transistors at higher frequencies, higher temperatures, increased power, lower noise levels, and longer operating life were indicated at an all-day symposium on semiconductor research at the Naval Research Laboratory in Washington, D.C., on February 11, 1954. As a feature of the meeting, William Shockley, Bell Telephone Laboratories, delivered the first Thomas A. Edison Lecture, sponsored by the NRL Branch of the Scientific Research Society of America, on the topic, "Present and Future of Semiconductor Research".

Improved characteristics are being obtained by continuing research on new and improved materials, geometry of the transistor itself, as well as circuit designs, according to the speakers at the meeting.

An experimental FM transmitter and receiver operating at 250 mc, and using multielectrode junction transistors, were demonstrated for the first time by R. L. Wallace, Bell Telephone Laboratories. The transmitter and microphone were small enough to be clipped to Mr. Wallace's shirt collar and the receiver was completely transistorized, except for the power amplifier.

New electro-etching and electrodepositing techniques, as used in the surface-barrier transistor, which is not a multielectrode type, are permitting production of transistors with operating frequencies in the order of 60 mc, according to W. E. Bradley of the Philco Corporation. Mr. Bradley revealed that Philco is experimenting with electrodeposited zinc, tin, and lead on n-type germanium as new surface-barrier materials.

Non-saturating transistor flip-flop circuits, designed for operation at one mc, but capable of operation at frequencies up to seven mc, have been developed, on an experimental basis, by A. W. Carlson, Air Force Cambridge Research Center. These circuits make use of non-saturating load lines and have been used by Mr. Carlson and others in the design of high-speed switching circuits, as used for digital computers, among other applications.

As an indication of a trend toward higher power transistors, C. L. Rouault, General Electric, reported the development of experimental 50-watt transistors, with current-carrying capacities up to one ampere.

Operating temperatures up to 250 degree Centigrade are possible through the use of semiconducting materials other than germanium, notably silicon, according to E. W. Herold, Radio Corporation of America. Research is continuing on the combination of non-elemental materials to form semiconductors, according to R. G. Breckenridge, Office of Naval Research. These include indium-antimony, aluminum-antimony, cadmium-sulfide, and lead sulfide. Current work on the physical properties of silicon and germanium was summarized by Esther M. Conwell, of Sylvania. Research in progress on noise in semiconductors, rectifiers, and transistors, was reported by R. L. Petritz, Naval Ordnance Laboratory.

In reviewing the current state of knowledge of semiconductors, Dr. Shockley implied the need for continuing investigation of the basic physical properties of transistors. As examples, he pointed out the recent discoveries of the "charge-carrier traps" and negative "resistance" phenomena of transistors at high electric fields --in the millimeter wavelength region and below.

New Materials Developments

by
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Office of Naval Research

Outstanding achievements since the close of the last war in the fields of metals and alloys, organic materials, metal-ceramics, and protective coatings lead one to view with excitement and imagination the future potential of materials developments and applications. The motivating forces responsible for the recent accelerated effort and emphasis on materials are by no means satisfied. Indeed, the over-all impact of some of these developments is almost autocatalytic in nature: the availability of superior materials has led to the consideration of still more severe design and performance characteristics and the demand for even better materials.

In addition to the normal needs of industry, the problems delineated by the present armament program and the new military developments in aircraft, ordnance and naval weapons and equipment have intensified greatly the search for new materials. The problem of conservation of critical alloying elements and materials runs as a central theme through most of the present materials research and development programs. Industrial expansion, technological advances, and military needs have all played their part in causing a transition from an "era of plenty to an era of insufficiency". The demands of our gas-turbine industry and related developments in rockets and missiles have imposed a serious burden on our available supply of alloying elements. This has been augmented by the increasing need and demand for higher strength, lighter weight, heat and corrosion resistant materials. These requirements often go hand in hand making the material choice more difficult. Of particular importance is the almost universal trend toward higher operating temperatures. Temperature requirements are being pushed higher and higher with the development of new weapons which depends on the availability of super high temperature materials. In fact, the term "thermal barrier" has come into use to define the present impasse in this field of research.

The fuels are available to provide the necessary operating temperatures for more powerful and efficient gas turbines but present high-temperature-alloy blading materials do not retain useful engineering properties at temperatures exceeding about 1650°F.

Finally, the specialized applications of our newest source of power, atomic energy, creates the need for materials with favorable nuclear properties. This requirement eliminates most standard engineering

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Condensed from a paper printed at the First Basic Materials Conference, New York City, June 16, 1953 materials from consideration. Another limitation is the specialized corrosion conditions encountered in nuclear reactors.

Let us examine, then, some of the recent developments in materials to observe how successful our efforts have been to provide solutions to these and other specialized demands for improved materials. I will attempt primarily to focus attention upon the directions in which materials research and development programs are heading, some of the more recent accomplishments, and their potential fields of applications.

The desirability of decreasing the weight of structures and components has resulted in a continuous, extensive search for new lightweight, high-strength materials. This is not only true for military applications but for industrial equipment and vehicles in which payload, performance, and economy of operations suffer from weight limitations. The most exciting and most publicized development in this field has been the production of ductile titanium and titanium alloys. Its light weight, excellent corrosion resistance to certain environments, outstanding strength-to-weight ratio and fatigue strength-to-tensile strength ratio, useful engineering strength properties at temperatures as high as 800°F and the availability of its ores delineate it as a metal of significant potentialities and applicability.*

An interesting Swiss development of a strong, high-temperature aluminum alloy called SAP (Sintered Aluminum Powder) recently has attracted much attention. It is produced from fine aluminum powder by a combination of cold pressing, hot pressing, and extrusion practice. This new product shows potentialities for use at temperatures up to 800°F, which represents a major temperature increase over the best commercial high-temperature aluminum alloy. Exposure to temperatures as high as 900°F for as long as 100 hours results in little or no change in the room temperature tensile strength of 50,000 psi. SAP is used as a compressor blade material and in engine components. Its development has led to research on other alloys utilizing the same principles from which may emerge a whole new series of sintered metal products.

In the class of high-strength, low-weight components, one must also consider the ultra-high-strength steels. Although, historically, steel is not considered a light alloy, nevertheless when heat-treated to provide tensile properties of 260,000 to 280,000 psi, it has a strength-to-weight ratio comparable to that of the strongest aluminum or titanium alloys, while exhibiting superior strength and modulus characteristics.

The high strengths are attained by quenching to a fully martensitic condition and then tempering between 400° and 475°F. To obtain maximum ductility and toughness, the carbon content is kept to a minimum, consistent with the strength requirements, with a sufficient alloy content to insure complete hardenability. Typical steel compositions are of the 4340 type with the new high silicon and boron steels also receiving much attention. Recent research indicates that silicon and boron serve to

*An article on titanium by the same author appears on pages 1 to 7 of the December 1953 issue.

increase resistance to tempering and shift the loss of impact resistance, which normally occurs in steels when tempered between 500° and 700°F, to higher tempering temperatures. Landing gears for aircraft are the primary application at the present time.

No discussion of high-strength, low-weight materials would be complete without mention of the rapidly expanding field of reinforced plastics. While in a strict sense, they are not new materials, nevertheless the marked progress in their development and use requires their consideration here. The use of plastics in body armor in the Korean War and in automobile bodies has been recently publicized.

In the broad sense, the term reinforced plastics covers any mixture of plastic and fibrous materials. The fibers provide the main strength characteristic and the plastic resin makes the material moldable and provides body. As would be expected, the properties of the reinforced plastic depend upon the type and amount of fiber, the particular resin, and the method of processing.

The main advantages of the glass-reinforced plastics lie in their high strength-to-weight ratio which is greater than most structural materials; their corrosion resistance to sea water, mild acids and bases, solvents and other chemicals; their weathering resistance; their excellent insulation and nonmagnetic characteristics; their dimensional stability over a wide range of temperatures; their resistance to moderate elevated temperatures (up to 500°F); their shock resistance (resiliency); their composition of nonstrategic materials; their low-cost forming processes involving low die costs; and their adaptability to making complex shapes.

Reinforced plastics in general are not cheap. Their prices range from $0.80 to $1.25 per pound for economical section sizes, but for any application, cost must be balanced against material properties. The more prominent uses of reinforced plastics are for radomes, electrical insulators, hardware in motors and generators, small boats, metal-forming dies, home appliances and industrial equipment parts, aircraft ducting, and other aircraft semistructural parts. It should be remembered that the moduli of elasticity and flexure of reinforced plastics is low. Low ductility and nonuniformity are other shortcomings.

In addition to their attractive physical and mechanical properties, the reinforced plastics are valuable in the unlimited sizes and shapes which can be readily molded. Their tooling costs are substantially lower than those for metals, which provides an economic advantage where short production runs or a variety of different shapes are desired. For quantity production, however, the high cost of the resin as compared to most commercial metals would offset the initial low tooling costs.

An increasingly popular method by which rigidity and low weight may be concurrently achieved is the use of sandwich construction. Progress in the development of adhesives and fabrication techniques has made possible a variety of metal-facings of nonmetallic nature. Sandwich construction may be used to compensate for the low modulus of the reinforced plastics where rigidity is required, but with some sacrifice in impact resistance and with increased fabricating costs. Metal-faced sandwiches bonded to cellular cores, which are generally corrugated metal foils or castable foam plastics, are finding use as rigid panels, contoured shapes in aircraft, tail or wing assemblies, fireproof doors, etc.

In the class of materials capable of withstanding highly stressed operating conditions at temperatures above 1800°F are the refractory metals, so-called because their melting points are greater than 3000°F; they include a group of elements which were formerly used mainly as steel alloying ingredients. Of the group listed below, molybdenum and its alloys have been selected as having the greatest potential for super-high-temperature service. Its abundance and availability in this country and its known high-temperature properties made it one of the most promising hopes for the solution of the difficult problems involved in gas turbines.

Refractory Metals

Metal	Melting Point (°F)	Density (g/cc)	Modulus of Elasticity (psi)
Tungsten	6170	19.3	50×10^6
Rhenium	5740	20.0	--
Tantalum	5425	16.6	27×10^6
Osmium	4900	22.5	--
Molybdenum	4760	10.2	45×10^6
Iridium	4450	22.5	--
Colombium	4380	8.57	--
Hafnium	3850	11.4	20×10^6
Chromium	3430	7.19	36×10^6
Zirconium	3380	6.5	14×10^6
Titanium	3140	4.5	15×10^6
Vanadium	3125	6.11	$21\text{-}22.5 \times 10^6$

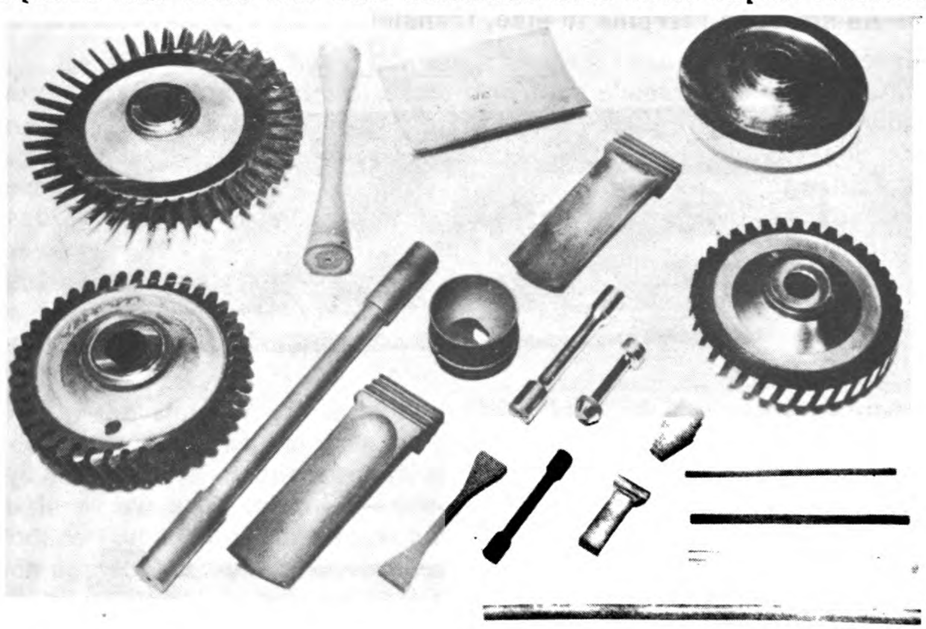
Several obstacles still must be overcome before molybdenum alloys can receive widespread military applications. Satisfactory protective coatings are urgently needed to prevent the rapid oxidation which molybdenum and its alloys undergo. Certain brittle characteristics which cause welding fabrication and service difficulties must also be overcome. Gas turbine manufacturers are now evaluating molybdenum alloy turbine blading and the opinion exists in some quarters that the only factor preventing their use is the lack of reliable protective coatings. Nickel and chromium coatings appear promising in this respect for use up to 1800° to 1900°F.

Aside from high-temperature applications there are other industrial uses for which molybdenum and its alloys may prove practical. Their use as die materials for die-casting brass and other relatively high-melting alloys appears most promising. Piping, tubing, liners, and valve applications in the chemical and related industries can take advantage of its corrosion-resistant properties.

Although not as extensive, parallel research and development are under way with chromium and its alloys. It has been known for several years that chromium base alloys exhibit good high-temperature properties at temperatures as high as 1800°F. Their extreme brittleness, particularly at room temperature, however, discouraged their use. Recent work by the Bureau of Mines and others has improved the ductility of chromium to the extent that it can be worked at moderate temperatures. Research programs are now trying to improve room temperature ductility characteristics.

As a result of research during the past few years, a completely new series of metal-ceramic combinations known as cermets, has emerged as potential structural materials. Although most of the development work was aimed at materials for the turbine end of the jet engine, as either turbine blades or nozzle stator blades, the properties of many of the cermets make them attractive for a variety of applications. Early investigations dealt primarily with oxide compositions, but the major current effort is on metal-bonded carbides, borides, silicides, and aluminides. These materials can be fabricated into a variety of shapes by direct pressing, extrusion, or machining. The picture below illustrates some of the shapes which can be produced. Of particular interest is the turbine wheel with integral blades and disc.

To date the most advanced cermet development is the cemented titanium carbide composition. A variety of compositions has been developed, the most interesting grades employing combinations of nickel, chromium, or cobalt as binder materials in amounts ranging from 25 to 60%. These metal-bonded titanium carbides exhibit strength properties up to 1800°F, oxidation resistance, and thermal shock characteristics which have led to their serious consideration and evaluation as turbine blade materials. The major problem confronting their possible use here is their lack of ductility. The probability of particles and fragments coming through the engine with considerable velocity requires that blade and vane materials have some impact resistance.



Shape, forms, and machine parts made from newly developed high-temperature materials

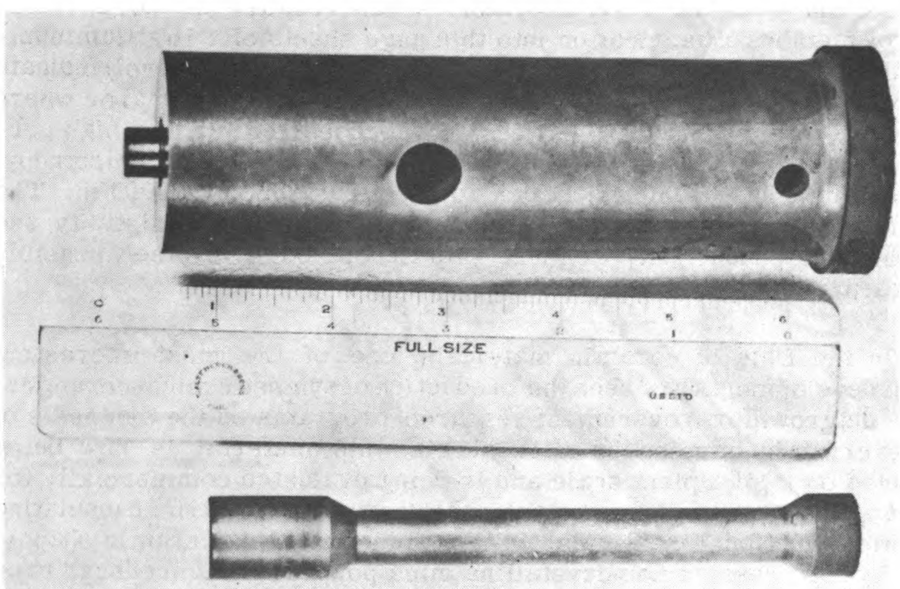
Increasing the binder content of the cemented carbides to provide such ductility causes a marked reduction in the high-temperature-strength properties. The prime effort in titanium carbides today is to develop compositions with a satisfactory compromise. Another mitigating factor has been the recent improvements in nickel-base alloys which may enable their use at temperatures up to 1650° or 1700°F.

Since the upper temperature limit of the titanium carbide is still not high enough, the metal-bonded borides, silicides, aluminides and the like are being investigated to extend this temperature range. Both military and nonmilitary potentialities exist for these materials.

In the field of boride compositions, it appears that zirconium-boride-base compositions may be extremely useful for applications involving contact with molten metals such as aluminum, copper, brass, magnesium, and tin. Their inertness to molten aluminum has led to the evaluation of zirconium boride as pump components for aluminum die-casting applications. Such a pump is pictured below. Zirconium boride also is being used increasingly as thermocouple protection tubes in molten brass and copper and for nozzles for spraying magnesium powder. A molybdenum boride composition, known as "Mo Braze," has been shown to be a satisfactory brazing material for molybdenum and tungsten. Research on the borides has resulted also in the development of compositions which exhibit attractive promise as cutting tool materials. If this development is successful, it will represent a significant step forward in the conservation of tungsten and cobalt.

The extensive materials work for nuclear reactor development has stimulated research on hafnium, vanadium and zirconium. The latter element was found to be an outstanding metal with low thermal neutron absorption for nuclear reactor purposes.

Germanium has found wide use in the recent development of transistors. As small as hairpins in size, transistors bid fair to revolutionize



Parts of pump made from zirconium boride many applications now utilizing electronic vacuum tubes. Their small size and weight, low voltage requirements, ruggedness and long life make it likely that a considerable percentage of small vacuum tubes will be replaced by transistors. The heart of the transistor is a semiconductor material, usually germanium. Silicon is another potential transistor material and recent research has introduced an aluminum antimony compound.

When one considers that a B-36 airplane contains more than 2000 vacuum tubes and that eventually use of transistors may result in a reduction of more than 90% of the total weight of an airplane's electronic equipment while at the same time providing increased reliability, the significance of transistors to the military becomes obvious.

Similar considerations apply to the radio and TV industries where transistors may permit an enormous reduction in the size of electronic computers. Small hearing aids employing transistors are now on the market and wrist watch radios have become a distinct possibility.

In the field of magnetic materials, an important recent development is a manganese-bismuth compound known as Bismanol. Perfected in a naval laboratory, manganese bismuthide appears to be ideally suited for applications requiring high magnetic flux density such as loudspeakers. The material exhibits a coercive force exceeded by no other known practical magnets. It can be used for almost all present applications of permanent magnets and its substitution for Alnico V and other magnetic materials may result in considerable savings of nickel and cobalt. Bismanol is stable magnetically to shock, vibration, centrifugal forces, and stray magnetic fields. It corrodes somewhat in humid atmospheres and may require protection by external coatings, such as nickel, under moist conditions. Bismanol magnets are made by powder metallurgy techniques from powdered manganese bismuthide.

Recent work in Navy laboratories has resulted in the development of methods of fabrication into thin gage sheets of a 16% aluminum-iron alloy. The magnetic properties of this alloy (called Alfenol) indicate its potentialities for applications as a laminated core material or where nondirectional magnetic properties may be desired. It has high permeability, rectangular hysteresis loops, and extremely low anisotropy. The material has been cold-rolled to sheets as thin as 0.0003 in. The high-temperature oxidation resistance, high electrical resistivity and low thermal conductivity of these thin sheets point to other possible applications.

In the field of ceramic materials, one of the most interesting recent developments has been the production of synthetic mica-ceramics. As an outgrowth of government research programs on the synthesis of single crystals of mica or mica sheets, this material is now being produced on a pilot plant scale and is being evaluated commercially for such applications as general machinable ceramics, electrical insulating ceramics, frictional materials, and for radomes. Mica ceramic shapes, made by hot-pressing polycrystalline mica powder, are soft enough to be conveniently precision-machined and precision-finished, after pressing, with conventional machining operations. They have low water absorption characteristics, temperature stability up to about 1500°F, and dielectric properties as good or better than most other ceramic dielectric insulators. The possibilities of incorporating other materials such as metals or refractor compounds are being investigated with the hope of extending the applicability of the mica ceramics for structural usage.

These and other new materials developments coupled with related progress in materials handling and processing have made available to the materials engineer, the designer and the production man, a varied choice for any given application. The full potential of these and future materials developments will only be realized by the coordination of components and materials from the start.

Effects of Vibrations on Man Studied

As machines with greater power concentrations are developed, the effects of vibration on operators and maintenance crews become more important. Aviators, operators of heavy construction equipment, operators of pneumatic tools, and of small hand-operated drills, buffing tools, etc., often complain of fatigue and discomfort. Occasionally there is interference with vision and the ability to perform fine handwork.

To study the effects of such vibrations on man, the Navy has designed and constructed a research instrument termed a large-displacement amplitude-vibration machine.

The Naval Research Laboratory cooperated with the Naval Medical Research Institute, Bethesda, Md., in the construction and testing of the instrument. Research studies are now being undertaken with it by Lt. Cdr. David E. Goldman, Medical Service Corps, USN, a Biophysicist.

The 2-ton instrument was designed to study low-frequency vibrations. It is capable of producing smooth vibrations from 2 to 50 cycles per second. Constructed to handle loads up to 200 lb, the table-top vibrating platform moves vertically through a maximum of 4 in at accelerations up to 15 units of gravity. Special built-in features allow the investigators to vary the cycles per second and the amplitude while the instrument is in operation, or to hold one and vary the other.

Little is known as yet of the effects vibration has on body tissue. Since the body is a very complicated mechanical system, the problem is extremely difficult. Investigators have found that different parts of the body respond maximally at different speeds.

Studies are now underway to map the mechanical structure of the body and its vibratory motion at various settings of the vibration machine. The data obtained will then be used to interpret physiological and psychological responses. With this information it will be possible to establish safety and tolerance limits as well as to devise protective measures when indicated.

Fluorocarbon Chemistry

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From the broad point of view of the welfare of human society, the discoveries that have led to the unfolding of fluorocarbon chemistry provide us with a most significant object lesson. Although fluorine was isolated as early as 1886, the bulk of the work on this element and its compounds has been conducted during the last two decades. The many useful materials and articles of commerce that have resulted from this research include paints, lubricants, plastics, rubber, cloth fibers, oils and solvents that defire fire and attack by organisms. The plastic "Teflon" alone has over 1,000 uses.

During the 1920's the structure of molecules and the force fields surrounding them were matters of importance to serious-minded scientists. A class of peculiar types of molecules called free radicals was given intensive consideration. These substances are characterized by a certain type of powerful magnetic field stemming from each individual particle. Important studies led to valuable knowledge concerning monoatomic free radicals, but experimental difficulties were encountered in studying polyatomic ones. Certain free radicals, whose atoms consist of carbon and hydrogen, were assumed to exist in attempting to account for certain chemical properties of substances. These were called the organic free radicals. Experimental attempts to determine the physical properties of these particles, particularly their magnetic fields, were unfortunately unsuccessful. The author of this article is one of the individuals who failed in this type of work.

In attempting to explore this matter further, it was thought that analogous structures composed of carbon and fluorine might be more useful for these experiments than the organic free radicals. Attempts were begun to construct chemical substances from which these fluorocarbon free radicals could be produced. Two lines of approach were initiated. Attempts were made to study the reaction between the elements, carbon and fluorine, and make compounds consisting of only these elements, and a new, more readily adaptable method of making trifluoroacetic acid was tried. Fortunately, laboratory investigations were finally successful in both of these efforts. The discovery of the mercury catalyst for the reaction between carbon and fluorine, which enabled fluorocarbons in homologous series to be isolated and identified uncovered an entire new field of chemistry dealing with very permanent and stable substances. The discovery of an electrochemical process gave an efficient method for preparing not only trifluoroacetic acid, but many other fluorocarbon carboxylic acids as well as other types of fluorocarbon derivatives.

The scientific cycle has thus been almost completed; in accomplishing this the so-called highly impractical academic scientist has created a whole new series of chemical substances, on which a new and very large industry may well be founded producing materials that will become common and everyday substances in everyone's life. More important, however, to the scientist and philosopher is the fact that the creation of these new substances gives us new materials for study upon which to build our theories and knowledge of our material universe. Already the detailed consideration fo the properties of these new substances has opened up new vistas in regard to the theories of the physical properties of substances.

The fluorocarbons are compounds whose molecules consist of atoms of the elements fluorine and carbon. A fluorocarbon derivative is a compound in which one or more, but not most of the fluorine atoms, are replaced by other atoms or group of atoms. A fluorocarbon carboxylic acid such as $C_3F_7CO_2H$ is a fluorocarbon derivative. A fluorocarbon radical is a portion of a molecule such as C_3F_7. Desirable substances have been made which contain such fluorocarbon radicals and are convertible to the free fluorocarbon radicals by heat, light or the impact of other free radicals. Not contained in this domain are the organic fluorine-containing substances, as distinct from organic compounds containing fluorocarbon radicals, as these substances have the essential characteristics of organic compounds rather than fluorocarbon compounds.

As the fluorocarbons are much more resistant to thermal decomposition as well as to attack by powerful chemical reagents than the hydrocarbons, there are potentially more individual fluorocarbons than hydrocarbons. Also, since fluorocarbons form as many, if not more, types of derivatives as hydrocarbons, the total sum of the fluorocarbons and their immediate derivatives should be greater than the total sum of hydrocarbons and their derivatives. The latter we commonly call organic chemical compounds, of which about one million are potentially available. As these two systems readily hybridize, the potential number of new pure substances is 1×10^{12}, or a million times a million. The term hybrid refers to molecules that are part fluorocarbon and part organic.

It is obvious that only an almost infinitesimal proportion of the total potential compounds have been identified in the very few years that we have had available since the discovery of the fluorocarbons.

It is fortunate that the elements, which in their combination form the fluorocarbons, are so plentiful on the surface of the earth. It is well known that carbon is readily available from coal, wood, and limestone, etc., but it is not generally appreciated that fluorine is even more abundant than carbon. It is found in a variety of minerals and is distributed widely over the earth's surface. There are a number of ways by which fluorocarbons can be synthesized from materials found in nature. They must be synthesized, as naturally occurring fluorocarbons have never been found. Fortunately, two relatively simple and direct methods appear at present to be the basis of the processes by which the primary fluorocarbon compounds will be made in large quantities. From these primary substances the numerous materials desired for special purposes will be synthesized after the manner that has been used by the chemical industry to produce all the present numerous articles of commerce. The first of these methods is the direct combination of the elements with the assistance of a mercury catalyst. Although this method is not used at present because it produces a great many different substances simultaneously in the form of a very complex mixture, it will eventually be used on a large scale because it is efficient and because the substances that are made in this way will be extremely valuable and difficult to prepare by any other method.

The other direct method is currently used to produce both inert and reactive fluorocarbon compounds in commercial sized units. It is called the electro-chemical process and involves the use of an electric current to cause a reaction between hydrogen fluoride and a carbonaceous-containing hydrogen. Elementary fluorine is not produced in this process, and although the mechanism is completely unknown, it is certain that it is not a process of fluorination. This is a continuous process of very high efficiency. It is ideally suited for large-scale use. Experience in its operation is leading to the production of desired compounds in satisfactory yields and amounts. As the mechanism is unknown, it is not possible by means of orthodox chemistry to predict the products that will be formed under a given set of operating conditions from any specific material, and considerable further experience will be needed before empirical rules can be laid down. We do know that occasionally the fluorocarbon product will be analogous in structure to the organic material reacted. This, however, is by no means the rule and frequently the desired product is obtained from a material having a different structure. This process was discovered prior to World War II in the same laboratory where the original demonstration of the fluorocarbons as a series of chemical substances had been made. Unfortunately, it was not used to produce the fluorocarbon materials that contributed to the war effort, because the process had not been developed for large scale use and also because the process seemed to be an unreasonable one. The processes that were developed and used during the war are extremely complicated and difficult to operate and are believed to be unsuited for economical commercial use.

The first important property of the fluorocarbons is their high stability. Most of them can resist decomposition at temperatures up to that which may be characterized as a dull red heat. This property will result in a permanence of materials made of fluorocarbons which cannot be had with materials made with organic chemical substances. Of equal or perhaps greater significance is the fact that the fluorocarbons resist chemical attack by even the most powerful reagents up to approximately the same temperature. As these include the oxygen of the air, it means that the materials are so resistant to combustion that they can be considered to be fireproof.

Another interesting and potentially useful property is the lack of stickiness of most fluorocarbon materials. We are frequently led to think that substances are of two kinds, water-like, and oil-like. We expect water-like substances to be compatible with other water-like substances, and similarly, oil-like substances are compatible with other oil-like substances. We know from experience that an oil-like substance is not soluble in water and has little tendency to adhere to it. We now must recognize that there is a third class which we may call fluorocarbon-like with little tendency to adhere to or be compatible with either water-like materials or oil-like materials. This means that neither a water-like or oil-like grease will adhere strongly to a fluorocarbon surface. As most of the materials that are plentiful in our environment are either water-like or oil-like, this means that it is most difficult to find anything that will stick to a fluorocarbon surface. Materials having a fluorocarbon surface, therefore, are very easily cleaned from common materials that soil them. This property is related to another important fluorocarbon property; that of low surface tension. Even a casual examination of liquid fluorocarbons in a glass container will show the almost complete lack of a meniscus at the boundary between the liquid surface and the glass wall of the container.

If a molecule is made, which has a fluorocarbon radical at one end which is very insoluble in water but a group at the other end which is very soluble in water, we have a material which can influence the surface properties of aqueous solutions. The fluorocarbon carboxylic acids are such substances. The carboxyl groups at the one end bury themselves in the water leaving the fluorocarbon tails projected above the surface. This imparts to the solution the surface properties of a fluorocarbon. This may lead to very important uses. By way of illustration, it can be pointed out that the hydrocarbon carboxylic acids behave in a similar manner and reduce the surface tension of water from the value it has as a pure substance to approximately half this value. This leads to the use of soaps as detergents and the use of similar materials as floating agents in certain mining operations, etc. If, instead of hydrocarbon carboxylic acids, we use an analogous fluorocarbon carboxylic acid, the surface tension of the solution is reduced by approximately half. The potentialities of this important fact are only beginning to be appreciated. Another related property of considerable significance is the low coefficient of friction between, for example, a piece of steel and a fluorocarbon surface. This is lower than has yet been found for any other substance. The potentialities of the use of fluorocarbons for bearings and lubricants are only just beginning to be realized. When it is appreciated that these same fluorocarbons used in the bearings resist both high temperature and chemical action, it is apparent that we can expect to hear more of their use for antifriction applications.

Other physical properties of the fluorocarbons that will be significant for their uses in the future are the high density, low refractive index, and high fluidity for the liquids and close approach to a perfect gas behavior for the vapors. In their chemical properties, the fluorocarbons are apt to give many surprises to the person basing his concepts on his previous knowledge of organic chemical substances, because the fluorocarbons and their derivatives, although similar in formula and structure to analogous organic compounds, are vastly different. In general, they do not enter into the chemical procedures that have been so useful in preparing all the various materials for organic chemicals from drugs and dyes to plastics and rubbers. A whole new set of chemical reactions and methods of synthesis will be needed to make correspondingly useful substances in fluorocarbon chemistry. A beginning in this direction has already been made, and we can be sure that the chemical profession has sufficient skill to create or invent whatever is necessary to take advantage of the very useful properties that have already been demonstrated in the fluorocarbon domain. A few examples of the difference between fluorocarbons and organic substances will suffice for illustration.

Fluorocarbon carboxylic acids are strong acids--hydrocarbon carboxylic acids are weak acids; fluorocarbon chlorides are very inert substances, organic chlorides are reactive substances that are useful as intermediates in chemical syntheses. An invention called the Grignard reaction has been extremely useful and versatile in organic chemical syntheses. Fluorocarbon Grignards are difficult to make and have not proven synthetically useful. Aliphatic hydrocarbon oxides are called ethers and are important solvents for many inorganic and acidic substances. They also undergo certain characteristic reactions. Fluorocarbon oxides of analogous structure have none of these properties. They are extremely inert chemically. Hydrocarbon nitrides are called amines because they are alkaline in nature just as ammonia. Fluorocarbon nitrides of analogous structure are not alkaline.

Because fluorocarbons and organics have such different properties, we can create substances of any desired character from the extreme fluorocarbon on the one side to the extreme organic on the other. An example of this is the location of a fluorocarbon radical in a molecule which would otherwise be organic. The fluorocarbon radical imparts to the molecule some of its properties of stability and resistance to reaction. The importance of this can be readily appreciated in the case of such items as dyestuffs where a fluorocarbon radical imparts stability and light-fastness.

Fluorocarbons give us most of the desirable properties of the organics without the undesirable. Oils, plastics, rubbers and paints composed of fluorocarbons can reasonably be expected, therefore, to replace organics in the future. How soon this will come will depend primarily on to what extent and how fast the basic research is done.

To date, fluorocarbons have not found extensive use. This is primarily because materials were not available. Another reason is because the properties are so different from previous known materials that we have had to begin learning about them from the very beginning and have often been led astray by our previously conceived notions. A beginning has been made with fluorocarbon plastics. Fluorocarbon oils have been made in limited quantities and have been found very useful for special purposes. The high cost of the early samples prevents large scale use, but this high cost is only a temporary thing which will vanish as soon as large scale use and production is assured. Rubbers containing fluorocarbon groups have been found with superior properties for certain purposes. When work along these lines is extended to elastomers containing no hydrogen, we can expect vastly superior materials. As an aid in electroplating and other large scale processing, certain fluorocarbons have been found to be very useful. Much more of this can be expected in the near future. Other fluorocarbons have been found to be the best fire extinguishers for gasoline fires. They are superior for this purpose not only because they prevent fire in smaller concentration, but also because of their much lower toxicity compared to other extinguishers both before and after use in the fire. With the above only as the first examples, we can expect this new branch of chemistry to become the basis of a large scale industry supplying a host of raw materials for all sorts of uses. We can expect fluorocarbons to enter into either the preparation or final composition of many consumers' goods of the future, particularly those that come under the heading of materials of construction.

World-Wide Gravity Program

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Increased knowledge of the earth's gravitational field is required for the determination of a more precise shape of the earth. Having determined this, we can prepare more accurate charts for navigational purposes. The accuracy of these charts is particularly important to navigation and control of guided missiles since these have no human pilot who can compensate for errors in our present charts by his control particularly near his target or destination. To use guided missiles effectively, we must know precisely the geographic position of launching site and target. In addition, knowledge of the earth's gravitational field is used for the solution of geophysical and geological problems, including the location of surface mineral and oil deposits.

Editor's Note: During the past five years, the author has travelled some 80,000 miles, taking gravity measurements at various points on the earth's surface. The purpose of the present report is to give the status of the development of the world network of gravity bases established by the Woods Hole Oceanographic Institution and to point out those problems which must be solved on an international level before a world-wide network of gravity bases can be achieved and before any larger mass of gravity data accumulates.

Since the initiation of this world-wide gravity program by the writer in 1948, most of the politically accessible countries of the world have been linked together in a common gravity network on the same datum. This datum is the Potsdam absolute gravity value for the U.S. Coast and Geodetic Survey national gravity base in the Department of Commerce Bldg. in Washington, D.C., as adjusted to fit gravity base values in England, Denmark, France, Sweden, Holland, Finland and Canada. This adjusted datum is 980.119 centimeter-gram-second (cgs) and is one milligal* (mgal) higher than the value used by the U.S. Coast and Geodetic Survey. Results appear to be fairly reliable with individual gravity determinations showing an accuracy of better than ± 0.5 mgal. The development of the global gravity network to date is shown on the back inside cover.

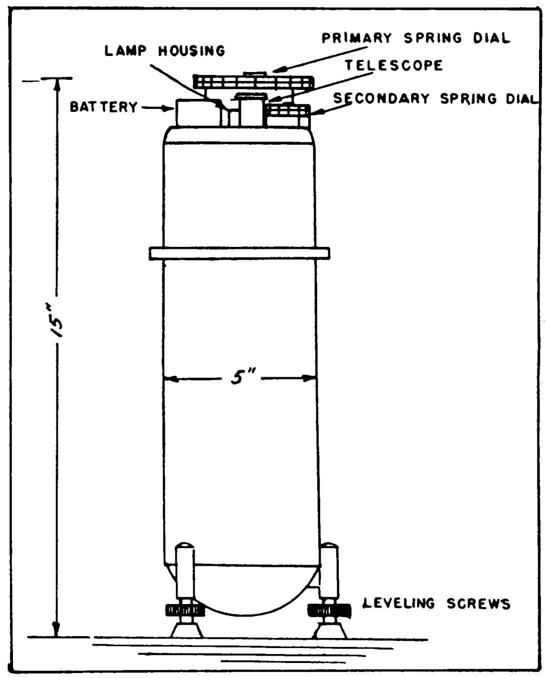
In addition to its world-wide gravity studies, the Woods Hole Oceanographic Institution is participating in the development of a reconnaissance network of gravity stations being established over the United States. This year the work is being confined to the northwest states—particularly the area in and west of the Rocky Mountains—where observations are being made at 15-km intervals along all of the principal highways.

As part of the present program, anomaly reductions are being made not only of the gravity observations now being taken but also of

*Gal after Galileo—1 milligal = $1/1000$ cm/sec^2

other gravity data, for example, that of the oil companies. These outside data are made available through the Special Committee for the Geological and Geophysical Study of the Continents of the American Geophysical Union. Duplication of previous work has been avoided wherever possible.

The development of gravimeters having ranges of 200 mgals or more during the past decade has made it possible to undertake gravity studies on a world-wide basis that ten years ago would have been regarded as impractical. In particular, the development of the Worden temperature-compensated gravimeter shown here has resulted in the making of more international gravity measurements during the past five years than had previously ever been made. The Woods Hole Oceanographic Institution alone in its gravity program has established during the past five years more than 2000 gravity bases in 78 countries embracing most of the politically accessible portions of the earth. Other organizations such as L'Office de la Recherche Scientifique Outre Mer have carried out similar studies. The number of submarine gravity stations has more than doubled during the same period principally through the work of the Lamont Geological Observatory of Columbia University. There are now about fifty high-range gravimeters suitable for inter-continental measurements distributed throughout the world.



Sketch of Worden Meter

To utilize successfully the large mass of gravity data now being accumulated, it is necessary that observations be referred to the same datum and that they conform to a fixed standard of accuracy both as regards individual station values and over-all value referred to absolute gravity.

Recognition of these requirements is not new. International adoption of the Potsdam absolute gravity base datum, with each nation tying its national gravity base to Potsdam by relative gravity measurements with pendulums, constitutes an attempt to satisfy the first of these requirements.* Uncertainties in pendulum measurements, however,

*About 60 years ago the gravity station in Potsdam, Germany, had the most consistent record of pendulum readings. Hence Potsdam was accepted, informally, as the international gravity base.

leaves much to be desired as regards their use for gravity standards. The degree of error in gravity measurements will depend upon the basis of calibrating the individual gravimeter used.

The adoption of an international gravity standard suitable for the calibration of gravity measuring instruments is at present the primary difficulty associated with making long distance gravity measurements involving changes of 1000 mgals or more. At the moment there is no set standard of calibration. The assumption that invariable pendulum measurements are adequate standards for calibration purposes is now definitely known to be in error. Comparisons were made last year, by this institution, of gravity values taken at the same sites using the Cambridge University magnetically compensated invar pendulums, the U.S. Coast and Geodetic Survey uncompensated invar pendulums, and the Gulf Research and Development Company's minimum-length non-magnetic-quartz pendulums. These showed differences in the observed value of gravity that amounted to as much as six mgals for a change of 1000 mgals. This deviation was systematic and related to change in latitude. Accumulatively between the Equator and the Poles, the difference in gravity interval measured with the Gulf pendulums and those of the U.S. Coast and Geodetic Survey would have amounted to more than 30 mgals.

The Cambridge University pendulums gave results intermediate between those obtained with the Gulf and the U.S. Coast and Geodetic Survey pendulums. They differed by two mgals for 1000 mgals change from the Gulf pendulums and by four mgals for 1000 mgals change from the Coast and Geodetic Survey pendulums.

These results are shown graphically on the opposite page; comparative results as obtained with the pendulums are plotted against those obtained with a gravimeter calibrated using the Cambridge pendulums as a standard. That the observed deviations are primarily related to the effect of changes in the earth's magnetic field on the period of the various pendulums involved is pretty well substantiated. For example, the gravimeter comparisons carried out in Australia, the British Isles and South Africa against the Cambridge pendulums with different types of magnetic compensation showed a change of one mgal for 1000 mgals change in gravity. Through the use of a Helmholtz coil, the U.S. Coast and Geodetic Survey also report that they are now getting results similar to those obtained with the Cambridge pendulums.

While this is an improvement, there still remains a discrepancy of two mgals for 1000 mgals change in gravity with latitude that is not accounted for. There is still no set of pendulums that is generally accepted as giving a true measure of the change in gravity with an accuracy of greater than ten mgals between the equator and the poles.

Because the results obtained with the Gulf quartz pendulums might have been abnormal or peculiar to the set of pendulums used, two other sets of Gulf quartz pendulums were borrowed from the Gulf Co. Observations made over the same course as before, between Fairbanks, Alaska, and Mexico City have now just been completed. Both sets of pendulums were swung at each observation site so that two independent sets of measurements were obtained over the entire range. Although it was planned to fly the equipment south from Mexico City as far as Quito, Ecuador, making additional measurements en route at Guatemala, Nicaragua, Panama, and Colombia, this had to be abandoned because of failure to secure adequate clearances for work in Guatemala. To obtain an equivalent gravitational effect, observations were extended up to Paso de Cortez in Mexico at about 12,000 ft elevation. The range in gravity covered by the measurements is about 4800. The number of observation sites was approximately forty.

Since the Cambridge University pendulums were swung this past summer by the Dominion Observatory of Canada over the Mexico City--Fairbanks, Alaska portion of this line, covering approximately 4200 mgals, direct comparisons will be available between these two types of pendulums over a sufficient range in gravity to permit a thorough study of the differences obtained. It is then planned to determine the cause of these differences. These special comparative studies will be completed before the 1954 meeting of the International Association of Geodesy and Geophysics in Rome and action can then be taken toward adoption of an international gravity standard.

Just as there is no standard for comparing gravity measurements, there is also no standard method for calibrating gravimeters. Most observers use the calibration furnished by the manufacturer or make their own calibrations by making multiple ties over small intervals of gravity as determined by pendulum observations. As far as the writer is aware, no manufacturer is claiming a calibration better than one part in 2000. Furthermore, this calibration applies only to that part of the instrument's range that can be readily checked. Calibration over one portion of the scale may be quite different from that for another portion. The only positive solution appears to be a calibration range extending over a sufficiently large change in gravity to permit comparison with standard values of gravity.

It was with this objective in mind that the original series of pendulum measurements with the Gulf quartz pendulums was undertaken

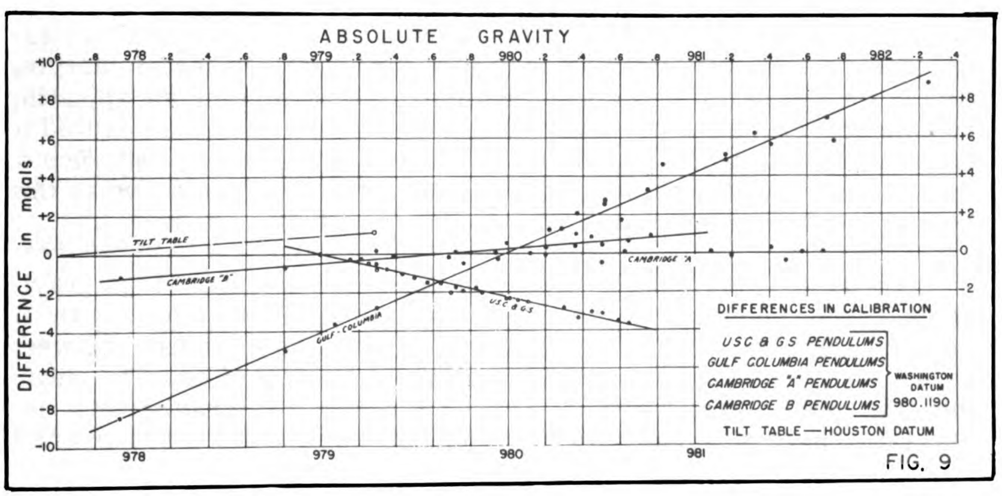


FIG. 9

between Mexico City and Fairbanks, Alaska. With the extension of this line of measurements in Mexico, and the resolution of the present differences between pendulums it is believed a standardization range will be available for calibration purposes which can be occupied in its entirety in ten days with a gravimeter using regularly scheduled air transportation to make a round trip from Washington, D.C., with stops at Chicago, Illinois; Madison, Wisconsin; Minneapolis, Minnesota; Huron, South Dakota; Denver, Colorado; Cheyenne, Casper and Sheridan, Wyoming; Billings, Lewiston, Great Falls and Cutback, Montana; Lethbridge, Edmonton and Grand Prairie, Alberta, Canada; Ft. St. John and Ft. Nelson, British Columbia; Watson Lake and Whitehorse, Yukon; and Fairbanks, Alaska. As all plane stops are for ten minutes or more, there is ample time for gravimeter observations to be made at each stopover.

In addition to the problem of calibration there is at present no uniformity in either the method of determining instrumental "drift" with gravimeters or the method used in applying closures incorporating both drift and "tares" (jumps) in readings introduced by sudden shocks or knocks. Some groups tend to follow the procedures adopted in geophysical prospecting and be as precise as is practical. That is, sufficient closures are taken to permit the short-term drift rate to be determined and with this procedure "tares" due to shock can be easily located and corrected.

Other groups are apparently determining drift on the basis of the over-all closure for the period of an entire survey which may involve two or three months or more. This procedure assumes a uniform drift rate with no tares in the readings. While such a procedure simplifies computations and speeds up field progress it is not conducive to the best results.

In addition, some groups are handling tares in readings as lump-sum corrections while others appear to be distributing such corrections throughout a whole network of stations. This latter procedure in the writer's opinion is to be condoned only as a last resort when the place of occurrence of a known tare cannot be adequately determined. Because of individual differences in drift rate and susceptibility to tares of different gravimeters as well as differences in accuracy required for different surveys, no set standard procedure can be established for carrying out the field work as regards determining the closures or for adjusting the data for closures. However, there should be a record submitted to a central agency indicating field procedure used, the characteristics of the instrument and the method of closure adjustment employed so that the data can be evaluated on a relative basis with other data.

Tares are also found in pendulum measurements as well as gravimeter measurements and the only safeguard against such effects is frequent closures. In the present line of pendulum stations between Alaska and Ecuador, closures were obtained at eight sites. The entire line was double run and most of it triple run with gravimeters and therefore, there will be no difficulty in determining the place at which a tare occurs or its magnitude. In this way a proper correction can be applied and none of the values will be biased as would be the case if final closure value representing perhaps the net effect of two or more tares were distributed over all of the stations occupied.

Finally, until measurements and studies designed to arrive at a satisfactory gravity standard are completed, it does not appear wise to adopt a standard, or to attempt to adjust the various international gravity networks into an integrated whole.

NBS Announces Three New Publications

Report of the Thirty-Eighth National Conference on Weights and Measures, Misc Pub 209, 116 pages, 40 cents.

This publication contains the addresses and reports on weights and measures given by representatives who attended the conference sponsored by NBS May 19-22, 1953, and a list of all delegates including the conference's officers and committees. The report covers such topics as prepackaged foods, flour weights, automatic packaging machinery, livestock weighing supervision, electronic scales, technicalities in weights and measures court cases, the proposed international conference on legal metrology, and the performance of inspectors and gasoline pumps. The report also includes actions of the conference with regard to recommended methods of sale of anhydrous ammonia and other liquid chemical fertilizers with pressure characteristics; preheated fuel oils; peat moss in package form; rope; seeds (agricultural, horticultural, and floricultural); and pickles and pickle products in package form.

Magnetic Fields of Cylindrical and Annular Coils, Applied Math Series 38, 29 pages, 25 cents.

This publication gives the axial and radial components of the magnetic field at any point in space of a cylindrical or an annular coil carrying an electric current. The results are expressed in terms of complete elliptic integrals or of Legendre functions which involve ratios of the significant dimensions of the coils.

In the past many formulas have been published which give the resultant effect of the magnetic field as either the inductance of such a coil or the force between two such coils when a known current exists in them. In contrast with this, the present publication gives a basis for computing in full detail the magnetic field itself, point by point. No formulas for this purpose have been readily available hitherto.

In experimental work it is frequently necessary to produce an accurately known magnetic field, and the use of one or more solenoidal coils of measurable dimensions is usually the most convenient way of accomplishing this. Possible applications range from the laying-out of large current-limiting reactors in electric power stations to the design of coils for studying paramagnetic resonance in atomic nuclei.

Tables of Circular and Hyperbolic Sines and Cosines for Radian Arguments, Applied Math Series 36, 407 pages, $3.00.

To meet the continuing demand from scientists and engineers, these tables of circular and hyperbolic sines and cosines are being reissued. These functions are of fundamental importance in pure and applied mathematics.

The interval of the argument and the use of radian measure should prove of particular convenience to the user. Specifically these tables contain sin x, cos x, sinh x and cosh x, x + 0(.0001)1.9999, 9D; sinh x and cosh x, x = 0(.1)10, 9D; a conversion table of degrees, minutes, seconds $\longleftrightarrow$ radians and a table of multiples of $\pi/2$.

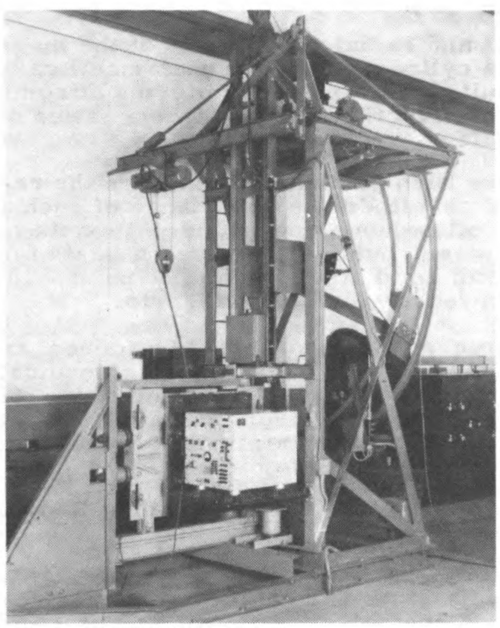
(These publications may be ordered from the Government Printing Office, Washington 25, D.C. Foreign remittances must be in U.S. exchange and should include an additional one-third of the publication price to cover mailing costs.)

Designing For Vibration Resistance

Approximately 90 percent of the damages to equipments resulting from shock and vibration can be eliminated in future designs using currently available components, provided those components are chosen, modified (if necessary, in view of past test experiences), and mounted on structures that have good damage resistance.

That is the major conclusion reached by engineers at the Naval Research Laboratory after an eight-year shock and vibration study of shipboard units, both electronic and non-electronic. An analysis was made of 270 individual items, tested by NRL's Shock and Vibration Branch in accordance with prevailing Navy and military specifications. The equipments tested ranged in weight from 3025 pounds to less than one ounce and in size from a radar antenna measuring 17 feet across the tips of the reflector to small 30-ampere ferrule-type fuse clips. Shipboard units were selected for study, since the extremely severe operating conditions on Naval vessels demand higher degrees of reliability and ruggedness than other military applications.

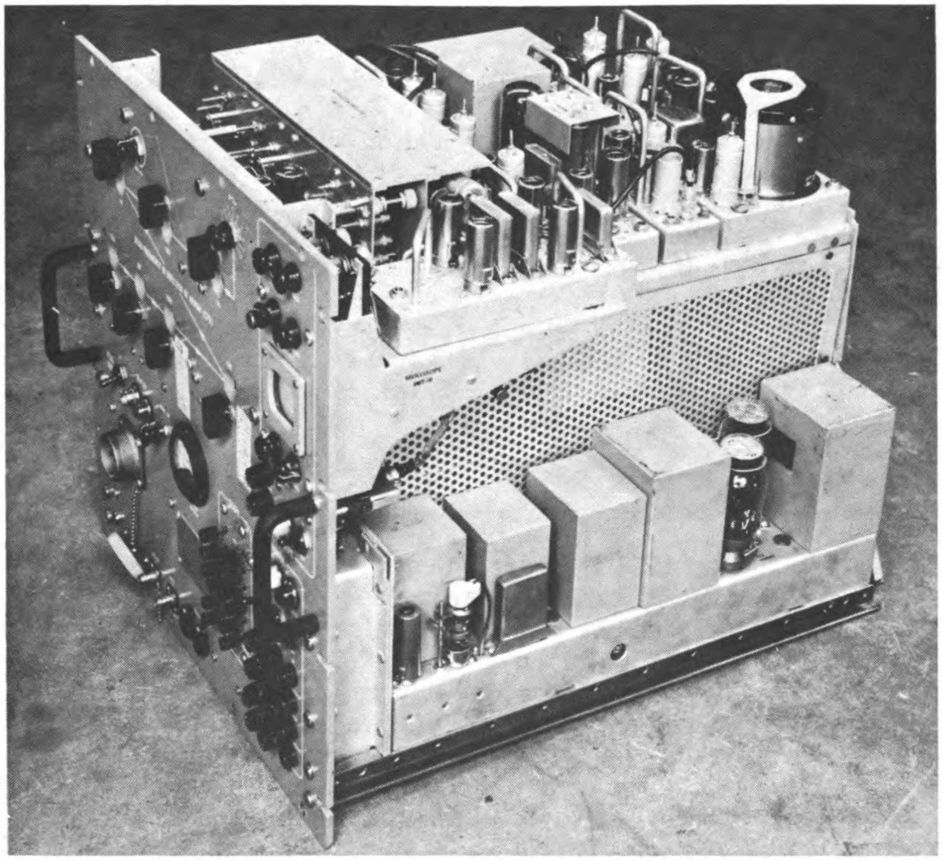
Contrary to previous belief, it was found that vibration was as damaging to the equipments tested as was shock, even though the inertial forces acting on the units during vibration were low compared with shock—normally between 2 to 5 gravity units (or g's) as compared to 300. The reason was the repetitive nature of the vibration forces as compared with the short-duration shock blows. An equipment well-designed for vibration was usually resistant to shock, but an equipment that passed shock tests might or might not have passed vibration tests. (In the Laboratory's investigations, vibration tests were performed first, except in the case of lighting units.)



Electronic unit without shock mounts is damage resistant, thanks to good structural design and careful placement of components. Unit being tested weighs 200 pounds, contains 2-inch cathode ray tube, a meter, 66 miniature electron tubes, 3 normal size tubes, a crystal, and numerous transformers.

Chassis, cabinets, and frame structures were found to be the principal areas of design which require more consideration by the equipment designer. Most of the difficulties resulted from a lack of sufficient structural stiffness. Poor structural design not only caused damage to itself but was reflected in component performance under both vibration and shock and was perhaps the chief reason why components failed.

The tests showed that critical components should—and can—be arranged to benefit from the maximum deflections of the structure occurring during shock with very little increase in the damaging effect of vibration. Fortunately, the only components currently used which can be listed as critical are electron tubes and relays. Completely enclosed rotary-type relays and ruggedized electron tubes are possible—and promising—solutions to this problem.



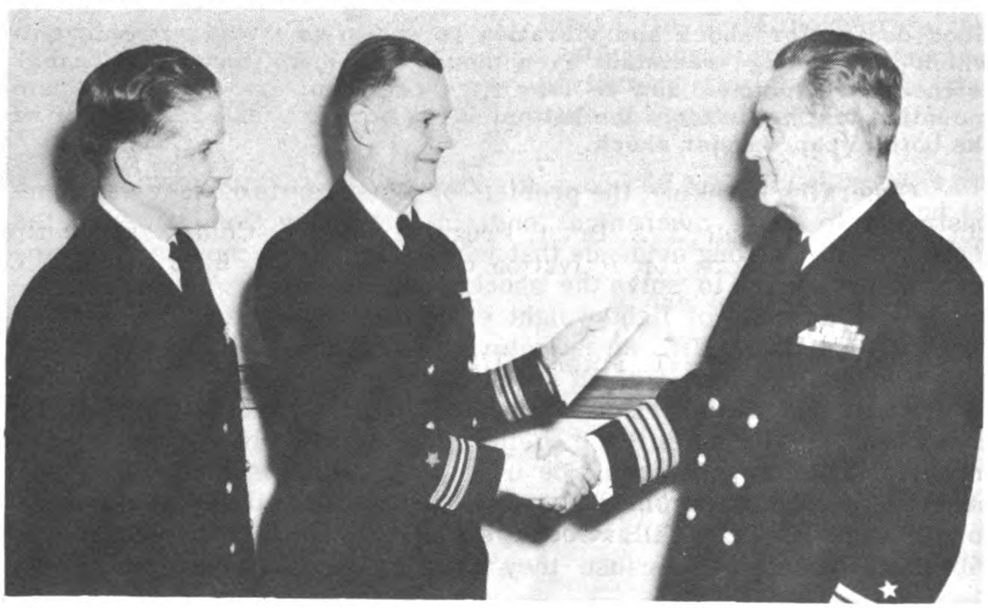
Good design for shock and vibration is shown in this electronic unit which was damage-resistant even though not shock-mounted. Transformers are mounted low to lower the center of gravity. Aluminum mounting feet set in from the bottom edges permit greater deflection of the bottom panel under shock.

Generally speaking, the problem of resistance to damage was demonstrated to be a mechanical one. In this connection, however, the tests provided strong evidence that just putting shock mounts on equipment is not enough to solve the shock and vibration problem. For example, in the case of light-weight equipments (electronic as well as non-electronic), the NRL investigators found that many equipments could pass the required tests <u>without</u> shock mounts. Apparently this was due to the fact that designers paid more attention to structural detail and component installation in these equipments. Admittedly, there are cases in which shock mounts should be used; an example is medium-weight, packaged electronic equipments, which usually require shock mounts for the entire system. In any case, shock mounts are not desirable for vibration resistance because they function as vibration amplifiers.

On the Naval Research Reserve

Michigan Unit Receives Commendation

On 14 January 1954 Research Reserve Company 9-16, Lansing, Michigan, was presented a commendation from Admiral Holloway, Chief of Naval Personnel, for being designated outstanding Research Reserve Company in the Ninth Naval District during Fiscal 1953. Officers of this unit are pictured above. The presentation was made by Captain Dundas P. Tucker, Commanding Officer, Office of Naval Research Branch Office, Chicago, to Lieutenant Commander Ira B. Baccus, who has been Commanding Officer of the company since January 1951. Lieutenant Commander Elbert S. Churchill represented the Washington Research Reserve Office at the ceremony.



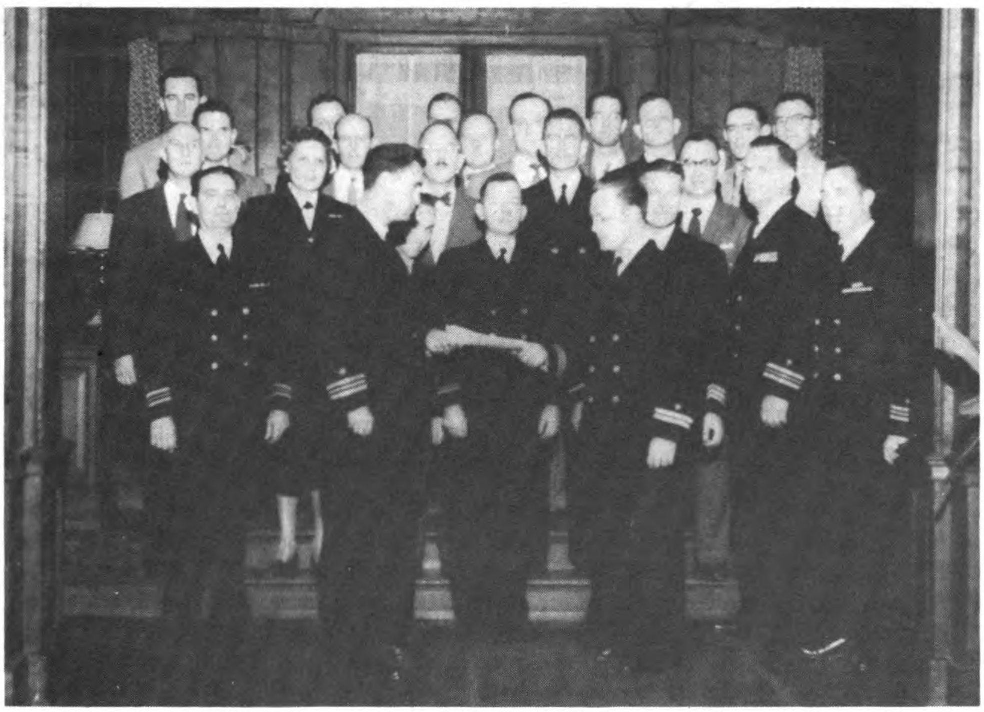
Company 6-13,

Aiken, South Carolina Is Activated

Pictured below are the officers of Research Reserve Company 6-13.

Formal activation of this unit took place recently at a dinner meeting at the Willcox Hotel, Aiken, S.C. Strom Thurmond, Governor of South Carolina, was guest speaker at the meeting. The reservists were also addressed by LCDR C. A. Buist of the 6th Naval District of Charleston and Dr. L. W. Butz, Head of the Chemistry Division of ONR. Orders for the officers of Company 6-13 were handed to LT R. O. Hutchinson, Commanding Officer, by LCDR Buist.

LCDR White, inspector-instructor from the Augusta Naval Training Center, was also present.



<u>In Front</u>: LCDR C. A. Buist, Program Officer, Com 6, presenting orders for activation of Research Co. 6-13 to LT R. O. Hutchison.

<u>First Row</u>: CDR L. T. Palmer, LT T. L. Bourbannais, LTJG Dennie Ray, CDR T. S. Brown, LCDR Robert White, LCDR S. P. Day.

<u>Second Row</u>: Gov. Strom Thurmond, LT Kathrine Nuzum, Dr. L. W. Butz, LCDR Robert McKeller, LCDR John Pollack.

Third Row: CDR N. J. Howard, LCDR M. B. Andrews, LCDR Sidney Katz, LT A. B. Anderson, LTJG Edward Toops, LCDR J. Howard Jones.

Fourth Row: LT W. D. Crawford, LCDR Winston Davis, ENS Walter Laird, LCDR William Gray, CDR David Hake.

Annapolis Unit Organized

Members of the newly organized Annapolis Naval Research Reserve Unit W-7 and representatives of the Office of Naval Research, which has control of NRR Units. Seated (from left): CAPT C. A. Peterson, Assistant Director for Laboratories at the Naval Engineering Experiment Station where the Unit will hold its meetings, LCDR E. M. Herrmann, Commanding Officer, Annapolis Unit, CAPT F. C. Wiesner, ONR Battalion Commander, and CAPT C. G. Grimes, Deputy and Assistant Chief, ONR. Standing: LCDR F. R. Gessner, Jr., LCDR J. M. Vallillo, LTJG W. V. Smith, LTJG R. C. Francis, LCDR W. C. Phillips, LTJG J. S. Post, LT R. L. Phebus, LCDR H. V. Nutt, LCDR H. C. Schmidt, and LT H. W. Schab.

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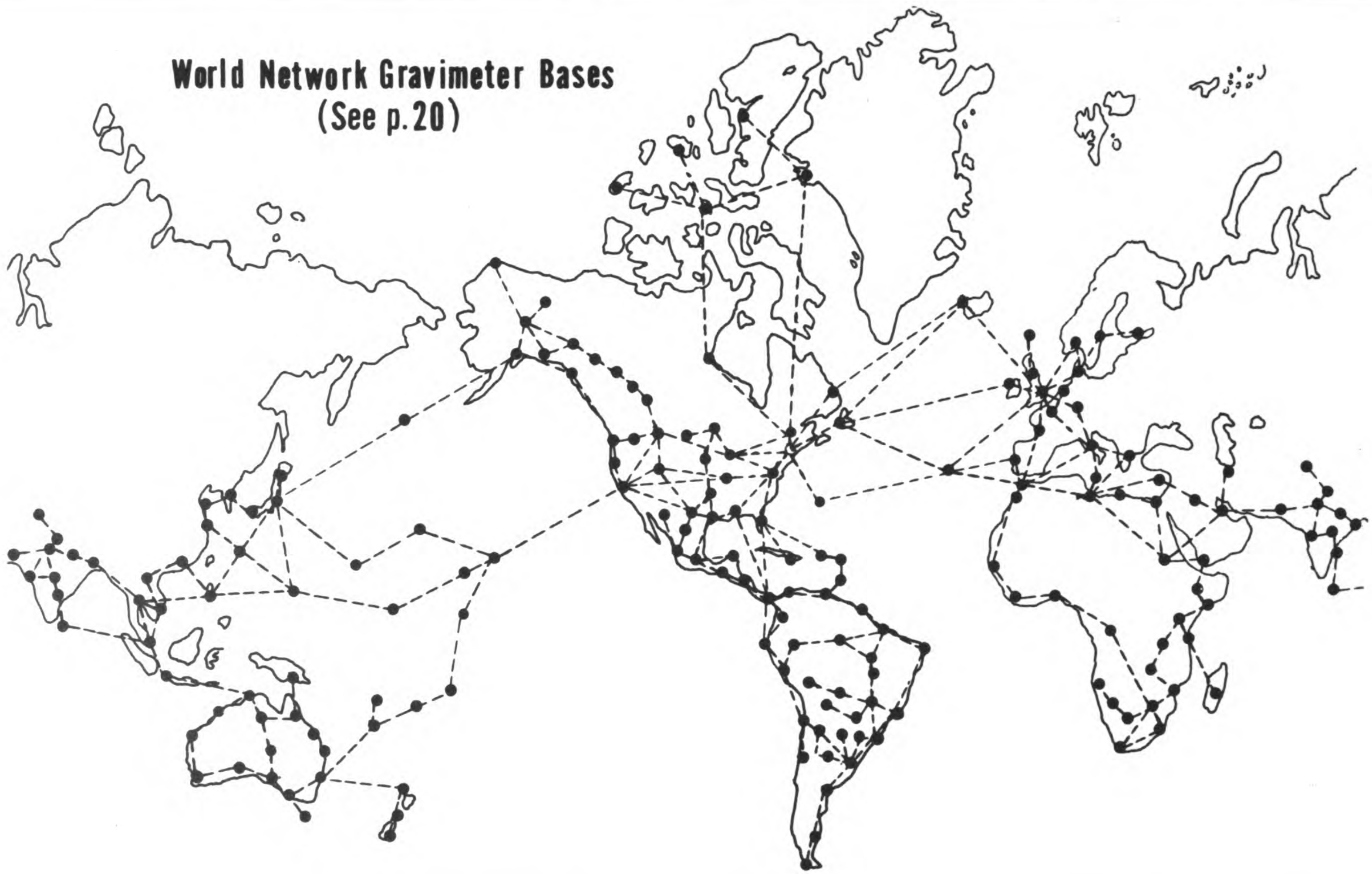
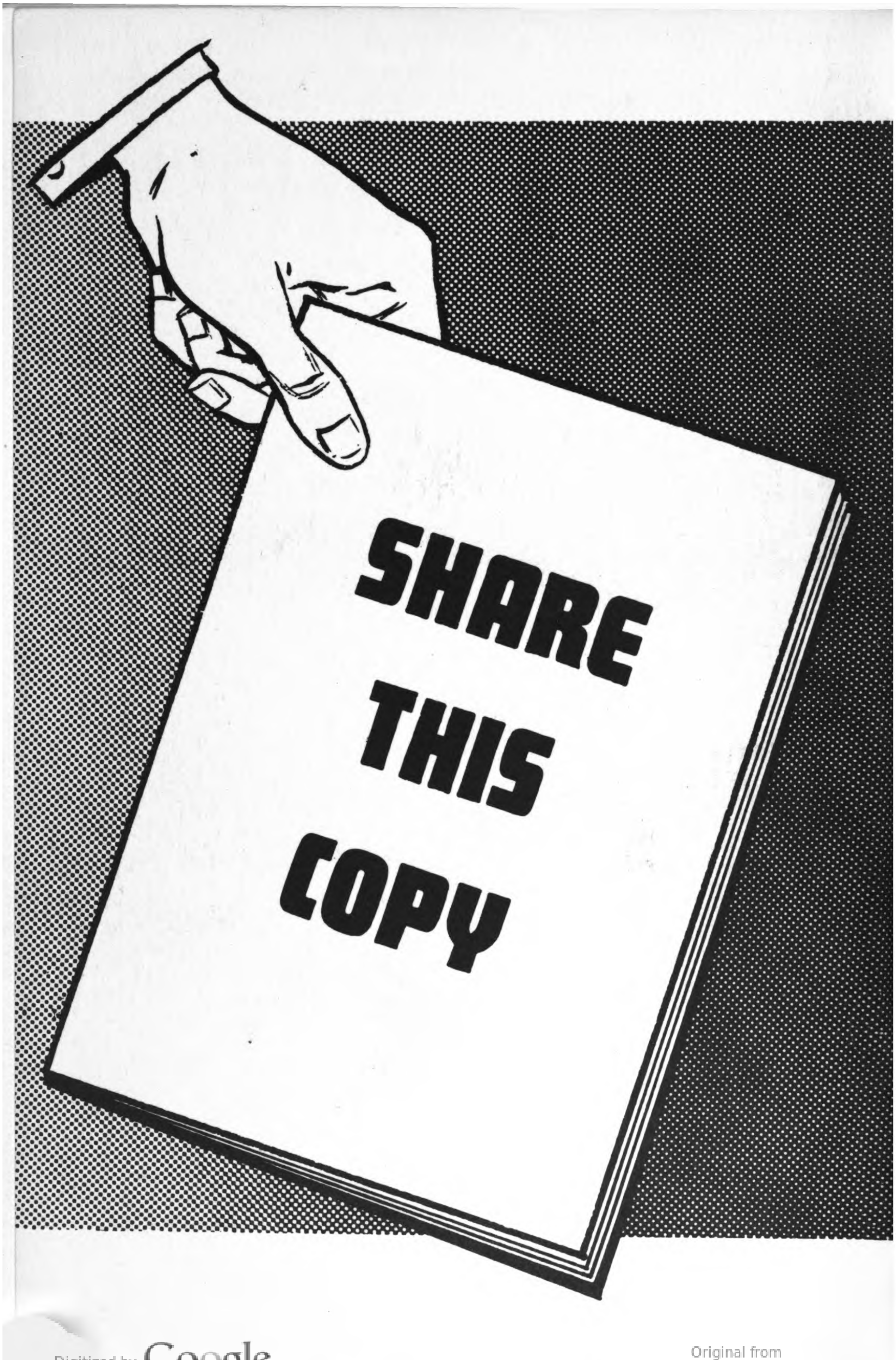
World Network Gravimeter Bases
(See p. 20)

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