• SEPTEMBER 1949

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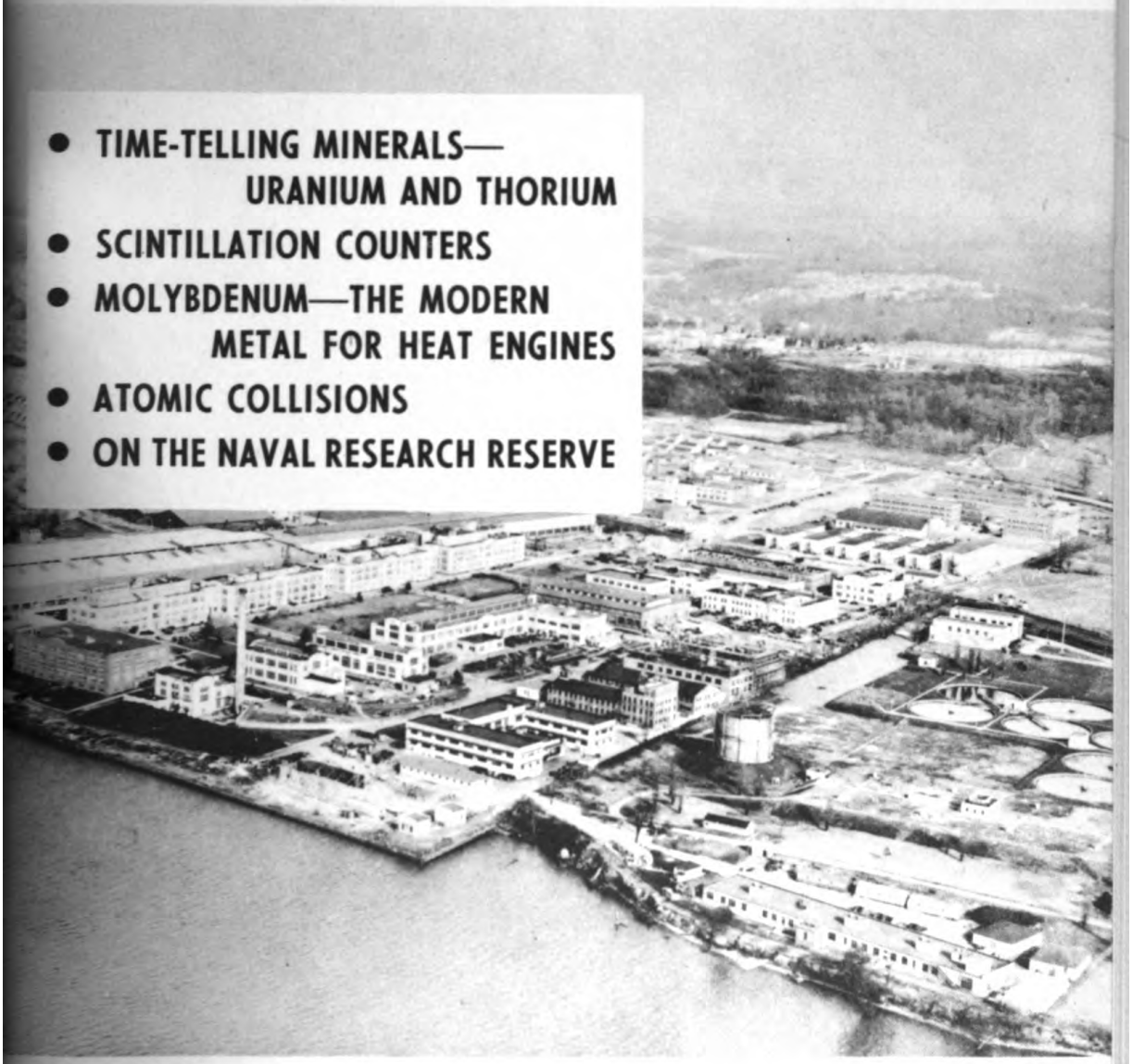


OFFICE OF NAVAL RESEARCH
DEPARTMENT OF THE NAVY
WASHINGTON, D. C.

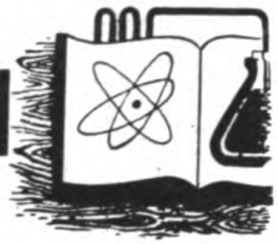
NAVEXOS P-510

COVER PHOTO: The Naval Research Laboratory of today where extensive basic and applied research programs are conducted in chemistry, electricity, mechanics, metallurgy, nucleonics, optics, physics, radio, and sound.

Approved by Bureau of Budget, 13 April 1948.

RESEARCH REVIEWS

● Informs the Fleet of ONR-sponsored Research



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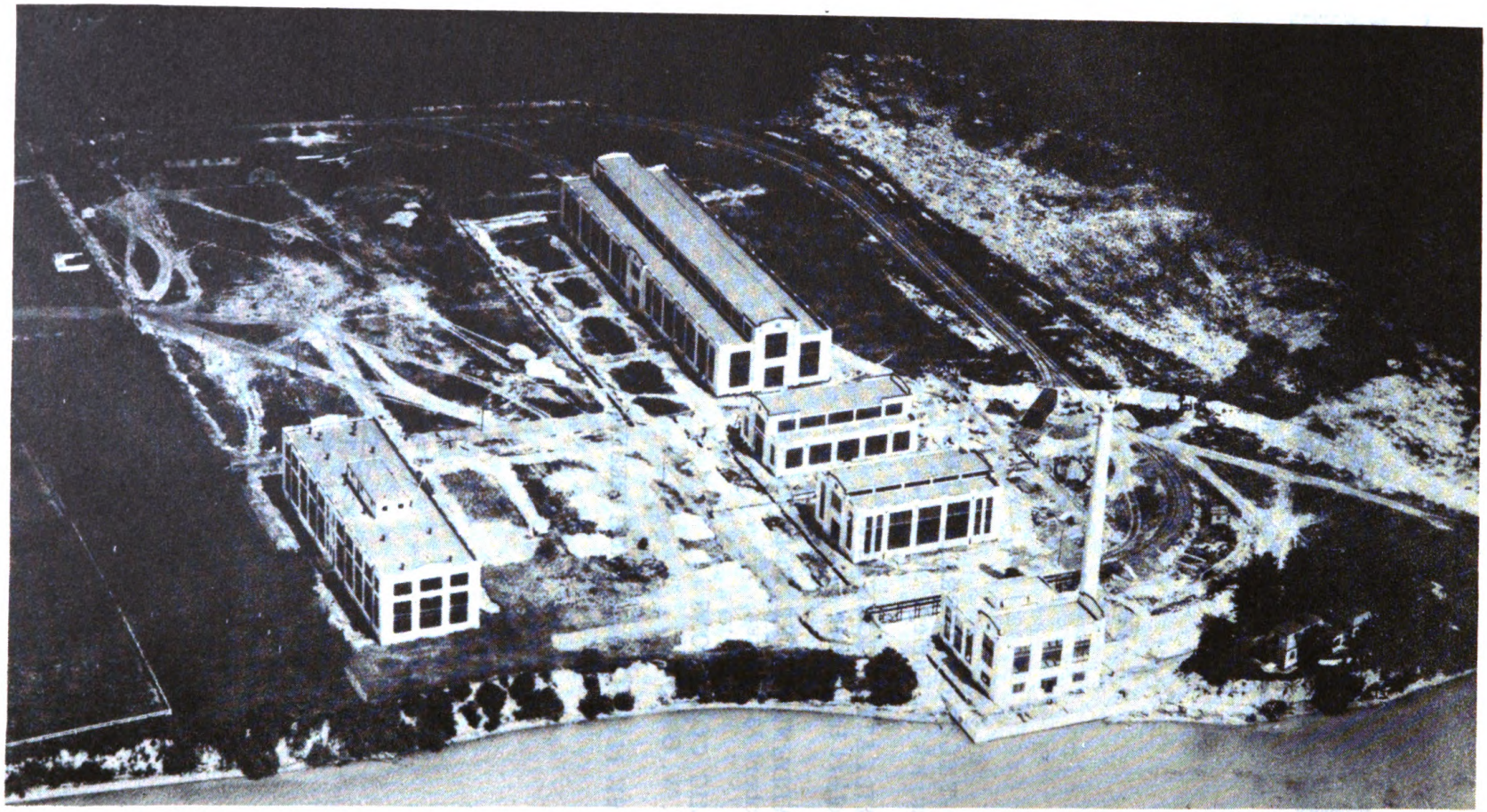

The Naval Research Laboratory of yesterday where investigations in radio and sound made up the principal scientific programs.

Editorial Notes

Research Reviews recently moved from the administrative offices in downtown Washington, D. C., to the Naval Research Laboratory, located eight miles from the heart of the city. The Laboratory, built on the banks of the Potomac River, is today one of the largest and best equipped research institutions in the country. Its facilities, some of which are not duplicated in any other laboratory, are housed in 67 modern buildings situated on a tract of approximately 55 acres.

The staff of Research Reviews, now in the immediate environment of science in the making, is much impressed and somewhat awed with the big Naval laboratory--not only with what it is today but with its history and past achievements.

The Naval Research Laboratory, and the pioneer scientists who were first associated with it, were largely responsible for selling research to the Navy in the days when most people were not research-minded. Established in 1923 to keep the Navy apace and in advance of technical and scientific discoveries and developments, the Laboratory had its beginnings in five small buildings. Its mission was then, as it still is today, "to increase the safety, reliability, and efficiency of the Fleet by the application of scientific and laboratory experimentation to naval problems."

Possessing vision and initiative, the NRL pioneers not only made positive and rich contributions to the libraries of science, but also did much to create the appreciation and the spirit of research which built the large and important establishment of today. Born of the need for scientific and technical knowledge and know-how as emphasized by experience in World War I, the Laboratory in World War II proved the wisdom of a far-sighted research program. Superiority in communications, detection and ranging, guided missiles, and hundreds of other fighting needs, paid off in big dividends.

Research in the Navy has now progressed to the stage of contract research, with the Office of Naval Research sponsoring a huge basic research program in university and industrial laboratories throughout the country. A large share of the credit for this increased recognition of the importance of science and the scientist to a strong and vital Navy and to national security goes to the Naval Research Laboratory.

Time-Telling-Minerals— Uranium and Thorium

Patrick M. Hurley
Massachusetts Institute of Technology

In almost all of the applications of geological science, there is still the basic need for correlations of geological events in terms of time. The rocks at present exposed at the surface vary both in composition and in time of origin. To bring order to the complex distribution of elements in the earth's crust, a knowledge is required not only of the present surface distribution but also of the history of events that caused the distribution. Only by piecing together the geological history of an area can there be, in general, any long-range predictions regarding the subsurface distributions.

For the last 15 percent of the time since the earth was formed, age correlations are usually worked out from fossilized remains of plants and animals which changed continuously as they evolved, with the result that specific types can be correlated with certain times in the past. However, the first 85 percent of time in earth history is unmarked by usable fossils, and the geologist needs another type of continuous change in order to correlate the age of rocks. Such a continuous process is the breakdown of the naturally occurring radioactive elements.

Minerals are formed in environments that contain at least traces of all the elements. Thus any mineral contains not only its essential chemical components, but also traces of the elements not essential to its structure but which occur in the environment and which are trapped in the crystal structure in various ways. Thus a few minerals are chemically composed of uranium and thorium; but all minerals contain at least slight amounts of these elements. These radioactive atoms may act as a natural clock, and under certain circumstances may be used to tell the time that has passed since the crystal was formed. The age of that particular rock or geological body in turn dates an event in the earth's history. Since the radioactive element breaks down to stable end-products at a known rate, the measurement of the amount of end-product produced and the amount of radioactive element still left in the crystal affords a knowledge of the time it took to accumulate the end-product.

Many difficulties are encountered in the application of this idea. The radioactive elements breaking down and the decay products building up must remain within the mineral throughout the time involved. If

Patrick M. Hurley, assistant professor of geology, Massachusetts institute of Technology, received his Ph.D. in 1940 after several years of mineral exploration in the northwest. During the war he was a research associate with the National Defense Research Committee, working on tactics and ordnance in anti-submarine warfare, and model experimentation in underwater ballistics.

Dr. Hurley's present research under ONR contract deals with geological distributions of uranium and thorium and the possible applications to age measurement.

there is any loss or gain of either constituent other than by radioactive change, the ratio will give an erroneous age. Furthermore, it is necessary to know how much of the decay product, if any, was present in the mineral at the start. Some of the ways of evaluating these errors can best be described by an example.

Let us suppose that a crystal of a mineral containing both uranium and thorium as essential constituents was formed in a body of hot rock one billion years ago, and several thousand feet below the surface. Since that time erosion has removed the overlying rock, and the crystal, picked up at the surface, is analyzed for uranium and thorium, and also for the decay product, lead. Under ideal conditions, the amount of lead divided by its average rate of production by the uranium and thorium would give the age of the mineral. It has been found, however, that this simple determination is seldom correct, usually because of loss of the radioactive elements by solution in ground waters, or because of the presence of lead in the mineral at the start. The next step, therefore, is to determine the ratio of the isotopes in the lead by means of a mass spectrometer. Since uranium 238, uranium 235, and thorium 232 break down to lead 206, 207, and 208 respectively, it is now possible to check the separate age ratios against each other to see if they agree. Before doing this, however, the amount of lead in the crystal at the start is shown by the lead 204 abundance, and this amount is subtracted. Finally, as a third check, the ratio of lead 207 to lead 206 gives a partially independent age measurement because of different decay rates of uranium 238 and uranium 235. From these data it is generally possible to correct for losses and arrive at the true age of the mineral.

The method described above has the disadvantage of being laborious, as well as being limited at the present time to minerals containing relatively large amounts of uranium and thorium. An attempt is being made under ONR-sponsored research to develop another method based on the helium accumulated as a by-product of the breakdown of uranium

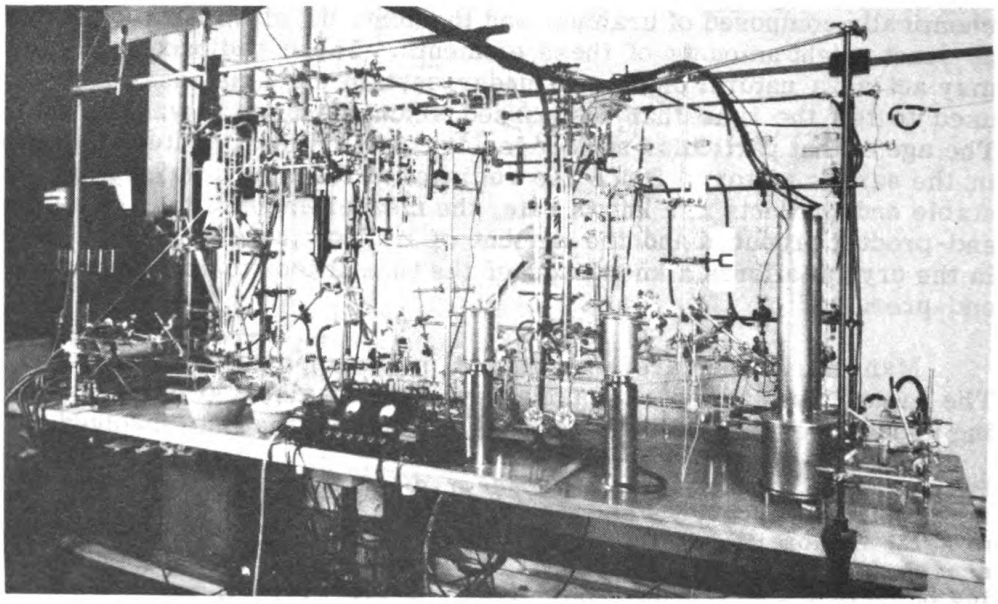

Fig. 1. Apparatus for measurement of radiogenic helium contained in common rock minerals. On the right are ionization chambers for determination of thorium and uranium in minerals by separate measurement of thoron and radon.

and thorium. In this case the uranium and thorium present as minor impurities in almost all minerals is sufficient to yield a measurable quantity of helium; thus, this method should be applicable to common rocks and minerals provided the helium does not escape. Measurements in this case are relatively simple. The powdered sample of rock or mineral is spread thickly on a large source plate and the alpha particle emission is counted in an ionization chamber. This count is proportional to the rate at which helium has been building up in the material. The amount of helium in the sample is then determined by fusing a part of the sample in a vacuum system, removing other gases, and measuring the helium volumetrically. The amount of helium per gram of sample, divided by the rate of its production per gram as alpha particles, then gives the age of the material, assuming ideal conditions. The alpha chambers used have a source area of 160 cm^2 and a background of 20 alphas per hour, so that in 8 long counts material running as low as 2×10^{-14} gm/gm Ra or 6×10^{-8} gm/gm U can be measured. This includes almost all rocks and minerals. Corrections are made for source absorption, decay of parent elements, and thorium/uranium ratio.

Present research is being devoted to an investigation of suitable minerals and rocks, and the reasons for failure of others. At the present time, age measurements are being made successfully on the mineral magnetite, which occurs in many rocks in amounts that can be separated and used. Ordinary rocks taken as a whole show low ages that may be the result of helium leakage from the minerals; however, there are other possible causes of the low results that are being investigated and which eventually may be overcome.

The oldest part of the earth yet found is the root of an ancient mountain system extending east-west through Ontario and western Quebec, and into eastern Manitoba. This belt contains a large proportion of Canada's mineral wealth. Helium measurements on magnetite from the mineral deposits in the belt show ages exceeding 2 billion years, and the rocks that were folded into the mountains were found to be still older. Other ancient mountain systems of the continent show progressively younger ages. As belts of this type are the sources of most of our supplies of base and precious metals, their extent and correlation in geologic history is of interest.

A valuable by-product of the research is an increasing knowledge of the mode of occurrence of uranium and thorium in various rock types. As a result of several unforeseen facts which came to light in the course of the research, new phases of investigation have been initiated in the geochemistry of these elements.

Scintillation Counters

Robert Hofstadter
Princeton University

It has been known for many years that individual alpha particles produce fluorescent light flashes when they strike certain crystals, notably those of zinc sulfide. The individual light flashes are called "scintillations" because of their resemblance to sparkles or twinklings. Although beta particles and gamma rays likewise produce light in crystals, until recently individual flashes due to single beta particles or gamma quanta could not be detected. In 1947 the detection of a single beta particle or single gamma quantum became possible. In these cases the individual scintillations could not be observed by eye but were detected by a type of photocell known as a photomultiplier tube. H. Kallmann was the first to demonstrate that single crystals of naphthalene (moth-ball material) produced beta particle scintillations large enough to be detected above the noise pulses of the photomultiplier. Many other investigators have added significantly to the literature in this rapidly growing field.[1]

The alpha particle scintillation in activated zinc sulfide crystals is readily observed by the human eye. Self-luminous watch dials, if examined with a hand lens in the dark, will show small random flashes in the painted figures of the dial. These scintillations are produced by alpha particles emitted by radium salts mixed with the zinc sulfide crystals. Such large scintillations as these are easily detected by the photomultiplier tube, which is sensitive enough to detect flashes of intensity fifty times smaller.

The photomultiplier tube has a photo-surface similar to the type found in ordinary photocells. However, this tube has, in addition, a series of electron-emitting surfaces which multiply successively the original number of electrons liberated at the photo-surface by the light flash. The number of electrons in the output pulse may be made a million fold larger than the number at the photo-surface. It is with this tube that the beta and gamma flashes may be detected. The combination of the luminescent crystal and the photomultiplier has been appropriately called a "scintillation counter."

Robert Hofstadter, assistant professor of physics at Princeton University, received his B. S. degree (1935) from the College of the City of New York and his M. A. and Ph. D. degrees (1938) from Princeton University. During the war, Dr. Hofstadter worked at the National Bureau of Standards on proximity fuses and at the Norden Laboratories Corporation on bomb director problems. He is currently studying the interaction of high energy gamma rays with electrons.

Dr. Hofstadter is the author of published articles on photoconductivity of crystals, infrared spectroscopy, and electronics as well as on crystal conduction and scintillation counter studies.

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[1] For a bibliography of the early work see: R. Hofstadter, Phys. Rev. 75, 796 (1949).

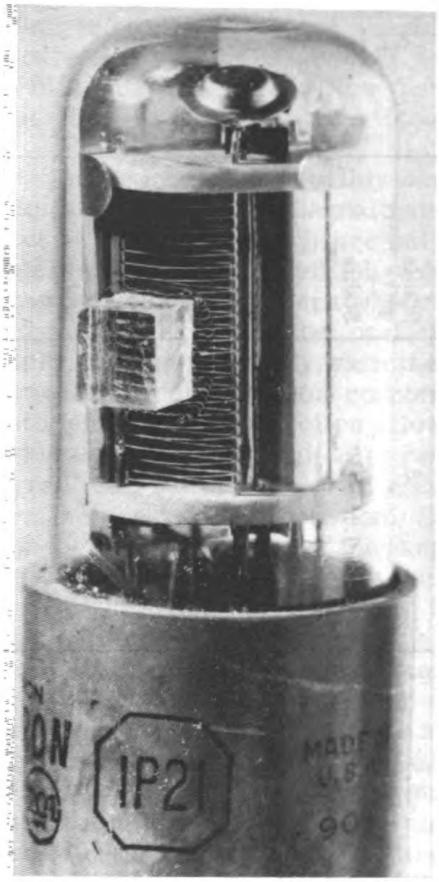

Fig. 1. Scintillation counter using sodium iodide crystal cube and 1P21 photomultiplier tube. The excellent geometry of the counter is evident--the sensitive volume is simply that of the small crystal cube. A light-tight cover, connections to amplifier and power supply complete the detecting unit.

Other crystalline materials were soon found and some proved even more useful than the naphthalene "moth-ball" counter. A scintillation counter with a transparent cube of sodium iodide (thallium activator) cemented to the photo-multiplier tube is shown in Figure 1. Clear single crystals of this material have been made with sides as large as four centimeters.

At the present time there are two principal types of crystals which are efficient scintillation materials--organic and inorganic luminescent crystals. Not all luminescent materials are useful in this type of application--only those in which the light is emitted with little time lag are suitable. Some of the useful organic crystals are naphthalene (probably with activating impurities), phenanthrene, anthracene, stilbene, and diphenyl. Inorganic scintillation materials are zinc sulfide (silver activator); sodium iodide, cesium iodide, potassium iodide, lithium iodide (all requiring thallium activators); calcium tungstate, calcium fluoride, cadmium sulfide, and probably many others. Both types of materials have distinguishing features. The organic materials produce small light pulses which disappear quickly. The inorganic materials produce large light flashes which last longer than the flashes from most organic substances. In both cases the light pulses last an amazingly short time (less than a millionth of a second), so that both types of materials make "fast counters." In comparison with these responses the Geiger counter is "slow" (discharge is complete in 100 microseconds, i.e., 100 millionths of a second).

Table I shows some data now known for the materials and counters in current use. Accurate measurements on pure or chemically analyzed samples are, for the most part, not available. Our data must therefore be considered only as approximate and in some cases quite crude. It appears, from the table, that many of the useful materials must be "activated" by artificial impurities in much the same way as phosphors for luminescent lamps. Whether or not this is the general case cannot be said at the present time.

Spectacular advances in our knowledge of elementary particles and processes and of atomic nuclei have been made with tools which we now take for granted. For example, the Wilson cloud chamber, the

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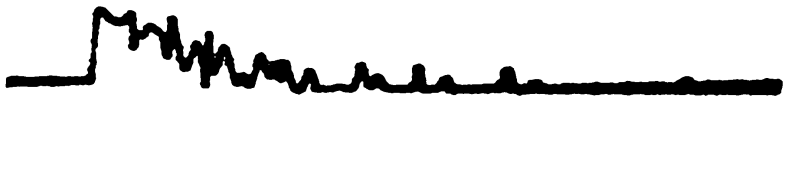
TABLE I. DATA ON MATERIALS AND COUNTERS NOW IN USE

Device	Resolving time in micro-seconds. Time for pulse to decay to zero in case of scintillation counter	Relative magnitude of light pulse due to a standard beta particle. Color or light pulse	Percent efficiency for stopping and counting 1 Mev gamma rays. Crystal is one centimeter thick.	General properties	Counter may detect with reasonable efficiency
Geiger-Meuller counter	100	-	0.1 - 1.0	Fairly rugged	α. β, γ
Photomultiplier, alone	0.001 - 0.0001	Sensitive mainly to blue violet and ultra-violet light	Very small	Rugged	-
Scintillation counter using sodium iodide (thallium)	0.75	1.0 Blue	23	Hygroscopic, must be coated or enclosed	α. β, γ
Scintillation counter using potas-sium iodide (thallium)	~10	1.0 Blue	19	Slightly hygroscopic	α. β, γ
Scintillation counter using cesium iodide (thallium)	~10	1.0 White	28	Stable	α. β, γ
Scintillation counter using lithium iodide (thallium)	~10	~0.5 Blue-green	25	Very hygro-scopic, must be enclosed	α. β, γ Slow neutrons
Scintillation counter using calcium tungstate	~3 - 20	~0.5 Blue	38	Stable quite inert	α. β, γ
Scintillation counter using powdered zinc sulfide (silver)	30 - 60	Very large for α par-ticles, small for β particles because of powdered form	0.1 - 1.0	Stable	α
Scintillation counter using naphth-alene (commercial)	0.1 - 0.3 Depends on sample	0.2 Ultraviolet	7.1	Sublimes slowly	β, γ
Scintillation counter using naph-thalene plus 1% anthracene	~0.21	0.3 Blue	7.1	Sublimes slowly	β, γ
Scintillation counter using anthracene	~0.08	0.3 Blue	7.8	Stable	β, γ
Scintillation counter using stilbene	~ .04	0.15 Blue	7.2	Stable	β, γ
Scintillation counter using diphenyl plus 1% anthracene	~ .04	0.10 Blue	7.4	Sublimes slowly	β, γ

Geiger counter, the photographic emulsion and the different forms of ionization chambers have all added fundamentally to our knoweldge of subatomic phenomena. Now the scintillation counter can be added to the list of such venerable aids to our senses.

The introduction of this new instrument may well lead to some new discoveries of a fundamental nature for the scintillation counter reaches out in directions which are only partially explored. As an example, in elementary particle (billion volt energy) physics there are at least two new scales of phenomena which the scintillation counter will permit us to examine. First, the particles are highly penetrating and can be studied most favorably when their whole life or space path can be followed. The scintillation counter, offering a solid medium (crystal) for stopping the particle, often allows the entire course of the particle to be studied. The length of solid required may be large, perhaps inches or even feet, but the length of a conventional gas-filled counter would be entirely out of the question. Second, the time scale of many nuclear phenomena is well below the range of conventional counters which, under good circumstances, may be used to resolve two ionizing events occurring within the same counter in an interval of 10 microseconds. The scintillation counter opens a field in which time differences of the order of 0.01 microsecond, or perhaps less, may be observed. Figures 2 and 3 show typical photomultiplier current pulses photographed on oscilloscope screens. Each pulse is a response of the crystal to an individual gamma ray in sodium iodide (thallium activator) and stilbene respectively. In the latter case, the shape and duration of the pulse are largely limited by the response of the amplifier. Although many nuclear processes take place in a shorter time interval, we may now enter with our new probe into the realm of the lifetimes of positrons and π-mesons (0.01 microsecond).

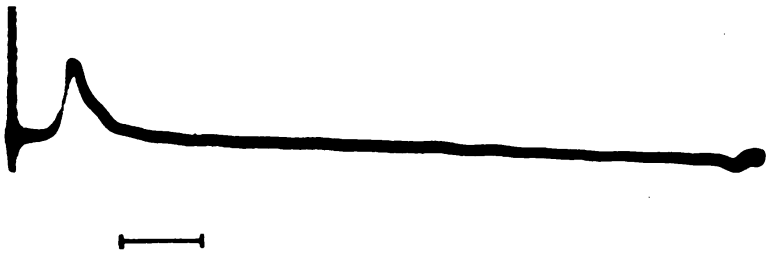
The significance of the speed-up in response time, compared with conventional counters, may be further appreciated when the large-pulsed particle accelerators become operative. Many of these machines will emit one million particles in an interval of 10 microseconds. The counting of all separtae events must be performed in this incredibly short time! Only very fast counters will be able to accomplish this task and also detect coincidences that occur in the short operating times.



0.1 MICROSECOND

Fig. 2. The light pulse shown as a photomultiplier current (vertically) against time (horizontally). The scintillation material in this case is sodium iodide (thallium activator).

Fig. 3. Same as Figure 2, but with stilbene as the scintillation material. It should be noted that there is a difference between the time scales of the two figures.



Another striking feature of the scintillation counter is shared by certain of the older detectors, such as the Wilson chamber. The scintillation counter can measure the intensity of the light flash and can thereby indicate the ionizing power of the particle studied. From the ionizing power, the energy of the particle can be determined if its mass is known. If the mass of the particle is not known, significant clues to its value may be found from a study of the ionization or light pulse.

Many other interesting applications of the new counter will suggest themselves to the reader. The rugged nature of the photomultiplier tube (it does not have a heater or filament) and the inert properties of a fluorescent crystal strongly favor the scintillation counter for field service. The high sensitivity of such a counter to gamma rays is an attractive feature that no other counter possesses. Applications of the scintillation counter to military and industrial uses, medicine, biology, and other fields are not to be touched on here. Broadly speaking, the new counter will find great uses in those fields where gamma rays and X-rays are employed.

It is impossible to say where the advances in counter technique may lead, either scientifically or practically speaking. Hundreds of investigators are working on the applications of the scintillation counter technique to nuclear, elementary particle, and X-ray physics, to cancer research and diagnosis, and to military and industrial survey instruments. Many other investigators find great interest in crystal luminessence studies and seek information from such sources for a better understanding of the structure of solid matter. Chemists study the influence of impurities and molecular groupings on the phenomena of fluorescence.

At Princeton University, a small group works on the application of the scintillation counter technique to a study of the Compton effect at low and high energies. This group also attempts to understand the physics of the crystal for its own sake and for the possible hints which may lead to the discovery of a material or technique giving better behavior than is now known.

This work has been partially supported by Princeton University and by the joint program of the Office of Naval Research and the Atomic Energy Commission. Messrs. F. B. Harrison, J. A. McIntyre, J. C. D. Milton and S. L. Ridgway have aided in this work.

Molybdenum—the Modern Metal for Heat Engines

Robert M. Parke
Battelle Memorial Institute

The attainment of more compact and efficient power plants depends, in part, on the perfection of heat-resisting materials superior to those available today. One approach to this problem is through the development of the refractory metal molybdenum.

A research investigation on molybdenum was initiated in May, 1949 with the primary objective of raising the metal's usefulness as a heat-resistant engineering material, to a level consistent with its abundance. Certain technical problems, to be described below, must be solved to realize this objective.

Present requirements for heat-resistant metals are being met largely by alloys in which iron, nickel, or cobalt are the major constituents. To make any substantial increase in the operating temperature of the metal parts of heat engines, a metal must be selected which has a melting point greater than that of iron (2800°F), nickel (2700°F), or cobalt (2650°F). All metals with melting points above 2800°F are either difficult to fabricate or scarce, or both. Molybdenum is one of the high-melting metals (its melting point is 4750°F) which is fairly abundant, and although not easy to fabricate seems to be susceptible to improvement in this respect.

Molybdenum is now used chiefly as a minor constituent of alloys to increase strength or corrosion resistance. A small portion of the total molybdenum produced[1] is used as a pure metal, largely as wire and sheet in the lamp and electronics industries. These uses have grown steadily over the past twenty years, yet the technology of molybdenum has not advanced to the stage of fabricating the relatively large pieces which would be required in heat engines.

Improvements in design, in fuels, and in heat-resistant materials, are the three most important means by which the efficiency and the effectiveness of heat engines may be increased. Improved heat-resistant materials will increase efficiency directly by permitting higher operating temperatures for the stressed members in the engine.

Robert Mabie Parke, technical advisor in research on high-temperature-resistant materials at Battelle Institute, received his B.S. in chemical engineering in 1926 from the University of Michigan. After metallurgical studies at the same university, he received his Master's in 1933.

A specialist in the development of refractory metals and methods for producing them, Mr. Parke supervised work in metallurgy at the Applied Physics Laboratory operated jointly by the Kellex Corp., Silver Spring, Md. and John Hopkins University, before joining Battelle. He has also been director of research for the Climax Molybdenum Co., Detroit, Mich. At Climax he was associated with the development of gas turbine heat-resistant materials and the development of erosion-resistant metals used in high-velocity guns.

[1]The present annual production (20 to 25 million pounds) could be increased substantially if the need arose.

The high melting point of molybdenum and its availability in this country[2] make it a promising metal for raising the maximum operating temperature of load-carrying members in propulsive devices. It is endowed with certain other properties which can be expected to contribute to its successful use as a heat-resistant metal. Its thermal conductivity is approximately double that of pure iron and its coefficient of thermal expansion is among the lowest of pure metals. The magnitude of these properties will aid in preventing distortion due to high rates of heat transfer.

At the same time there are a number of disadvantageous properties which must be overcome before molybdenum can be widely used as a structural material at elevated temperatures. Inherent inability to resist rapid oxidation above 1400° F in air is probably the metal's chief disadvantage. This defect is due to the fact that above 1400° F, molybdenum trioxide (the oxide which commonly forms on molybdenum under atmospheric conditions) evaporates as rapidly as it forms, giving no protection to the parent metal.

By the application of well known hot-forming and heat-treating techniques, molybdenum can be rendered ductile but subsequent operations such as welding, rolling, or even exposure to a temperature above 2500° F, may permanently embrittle it.

Another bar to progress is the lack of knowledge of the metal's behavior under stress at elevated temperatures while exposed to combustion gases.

These are all matters that must be thoroughly studied and the present investigation attempts to take proper account of them.

Molybdenum, like other high-melting metals, is produced in simple shapes such as wire, rod, and sheet by powder metallurgy. Recently a method of preparing molybdenum by melting and casting has been developed. This new method will receive attention in the present investigation since it now seems very probable that molybdenum will ultimately be produced commercially by melting as well as by powder metallurgy.

The Battelle project will be concerned with: (a) securing certain fundamental knowledge of molybdenum needed in the development of fabrication processes, (b) determining the elementary mechanical properties needed to design structures of molybdenum operating at high temperatures, (c) improving the mechanical properties of molybdenum, and (d) developing molybdenum-rich alloys having greater strength than the pure metal.

One of the specific problems being considered is to determine the solid solubility of carbon and oxygen in molybdenum in the temperature interval 1500° F to 4000° F. Carbon and oxygen are known to influence the mechanical properties of molybdenum. There are theoretical reasons and experimental evidence to indicate that a marked change in ductility will occur near the limits of solubility of these elements in

[2]For the past 25 years about 90 percent of the world's need for molybdenum has been met from sources within the continental U. S. This proportion is not expected to change significantly in the next decade.

molybdenum. Almost no data on these solubilities exist. Solution of this problem will be somewhat more difficult than the usual equilibrium diagram work because of the high temperatures and low solubilities which are involved.

Another specific problem being investigated is to improve ductility of the weldment in molybdenum-to-molybdenum welds. Molybdenum can be joined to itself by ordinary welding methods but the joint is brittle (at least at room temperature) and is subject to premature failure under mechanical shock.

Work has also been initiated on improving the room-temperature ductility of cast molybdenum. The initial step will be to study the various possible causes for the brittleness of cast molybdenum. Since it is usual to melt a portion of the metal near the joint during welding, information concerning the problems on cast molybdenum and on welding will be mutually helpful.

A fourth problem is to measure mechanical properties of molybdenum and molybdenum-base alloys. The elastic and plastic properties between 1500°F and 4000°F needed for design purposes are to be determined. The necessity for providing protection from the atmosphere while measuring these properties, and the employment of testing temperatures beyond those commonly used in metallurgical research, mean in general that special equipment and procedures must be employed.

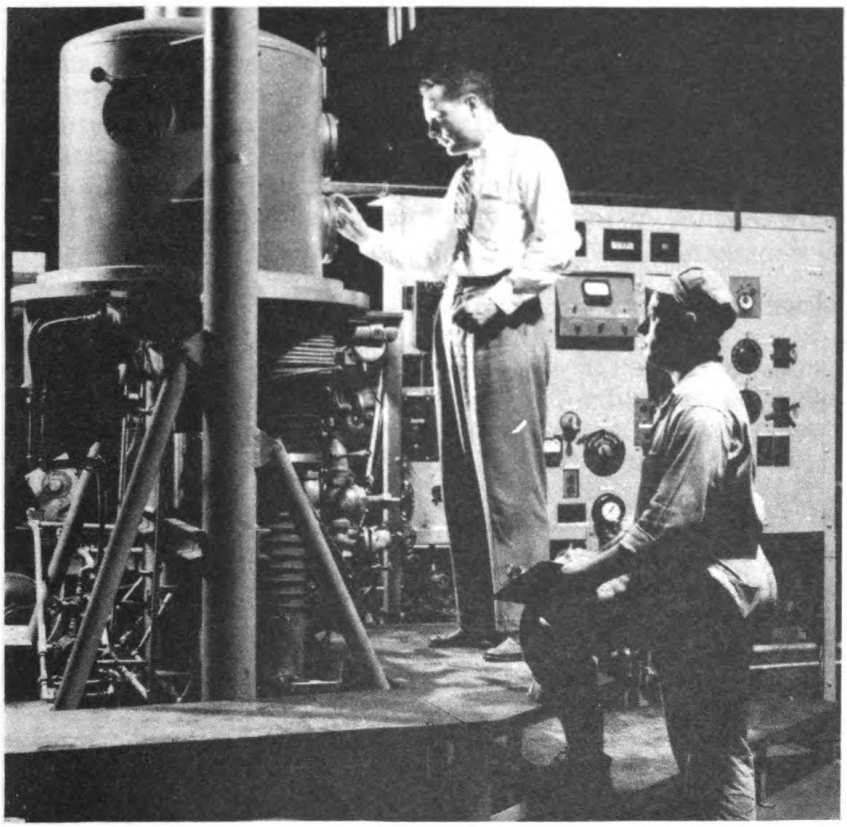


Fig. 1. An arc-melting unit, used in the study of alloys of molybdenum, recently installed at Battelle Memorial Institute. The unit was designed and constructed by the Bureau of Ordnance and assembled at Battelle.

Development of molybdenum-base alloys represents a fifth problem. Binary alloys of molybdenum with boron, beryllium, cobalt, chromium, columbium, iron, nickel, platinum, tantalum, titanium, tungsten, vanadium, and zirconium will be prepared and examined in a search for high strength and resistance to atmospheric corrosion at elevated temperature. Certain of the alloys will be prepared by melting in vacuum or in inert atmospheres. The melting device designed especially for this work, and now installed at Battelle, is shown in Figure 1.

It will be noted that the very important problem of preventing oxidation of molybdenum at high temperature receives attention in this Battelle investigation only through the search for oxidation-resistant alloys. Other methods of attacking this problem are not being followed because it is believed that they are receiving adequate research effort under other sponsorship. Those connected with this investigation will keep in close touch with all phases of the research on preventing high-temperature oxidation.

An advisory committee of 10 to 15 individuals selected from the interested industrial laboratories and government agencies will aid in assigning work to other laboratories, in integrating the program with allied research, in distributing technical information on molybdenum, and in identifying significant and related technical problems.

Atomic Collisions

H. W. Berry
Syracuse University

A very simply conception of an atom and one that gives a surprisingly good picture of its behavior is to think of the atom as a submicroscopic billiard ball. The atoms of the air traveling with speeds of a thousand miles an hour collide and bounce off one another in a way much like myriads of balls heading in all directions might do. For air under normal pressure these collisions are very frequent, about ten billion per second, and so, in spite of their high velocity, they travel on the average only about 1 inch for 400,000 collisions. As the pressure is reduced, the distance between collisions becomes greater, and at pressures of one-millionth of an atmosphere it is about 2.5 in. for each collision.

Since we cannot follow the molecules of the air in their random motion, we cannot observe these collisions, and consequently we cannot tell whether our simple picture of billiard ball molecules is really a true one. Perhaps a more accurate analogy would be a billiard ball with a hard center but with a sponge rubber overlayer which gets softer away from the center. If this is the construction of atoms then a glancing collision would not change the direction of an impinging atom as much as if the construction were like that of a hard billiard ball.

Actually we get nearer the truth if we just picture two particles which exert a force on each other but do not necessarily touch. Two electrically charged balls (say both balls have a negative charge) would do this, and we know that the force exerted by one on the other would decrease as the distance is squared between them. This is called a coulomb force and would be a "soft" force much like our sponge rubber ball.

Now for the atoms where we have many electrons distributed about the center nucleus and where this distribution will change as the atoms overlap, we would not expect the force of one atom on the other to be dependent on the distance as simply as it is for just two point charges. Furthermore, we suspect that there might be present here forces that we have not observed in our studies of laboratory sized objects.

If we could, however, study the collisions of atoms in an ordered way we might be able to deduce the force that exists when two atoms are close together. This can be done if we use a stream of atoms which have all the same velocity, and shoot this stream into another group of atoms which are moving around relatively slowly, that is, into a gas at rest. Some of these projectile atoms will have collisions--in some cases almost head-on, in others merely glancing--with the gas atoms, and as

H. W. Berry graduated from Syracuse University and received his Ph.D. from Washington University, St. Louis, Mo. He was associated with Case Institute of Technology from 1942 to 1943 and did war research at Radiation Laboratory, University of California, from 1943 to 1946. Dr. Berry has been at Syracuse University since that time. His research fields include ionization of gases by atom bombardment, secondary electron emission by bombardment of metal surfaces by ions and atoms, and scattering of neutral atom beams.

a result of these collisions the projectile atoms are deviated. These deviated atoms are said to be scattered (Figure 1 (a)). Suppose we assume several kinds of forces and see what kind of a scattering distribution we would get. By this distribution, we mean how many are scattered

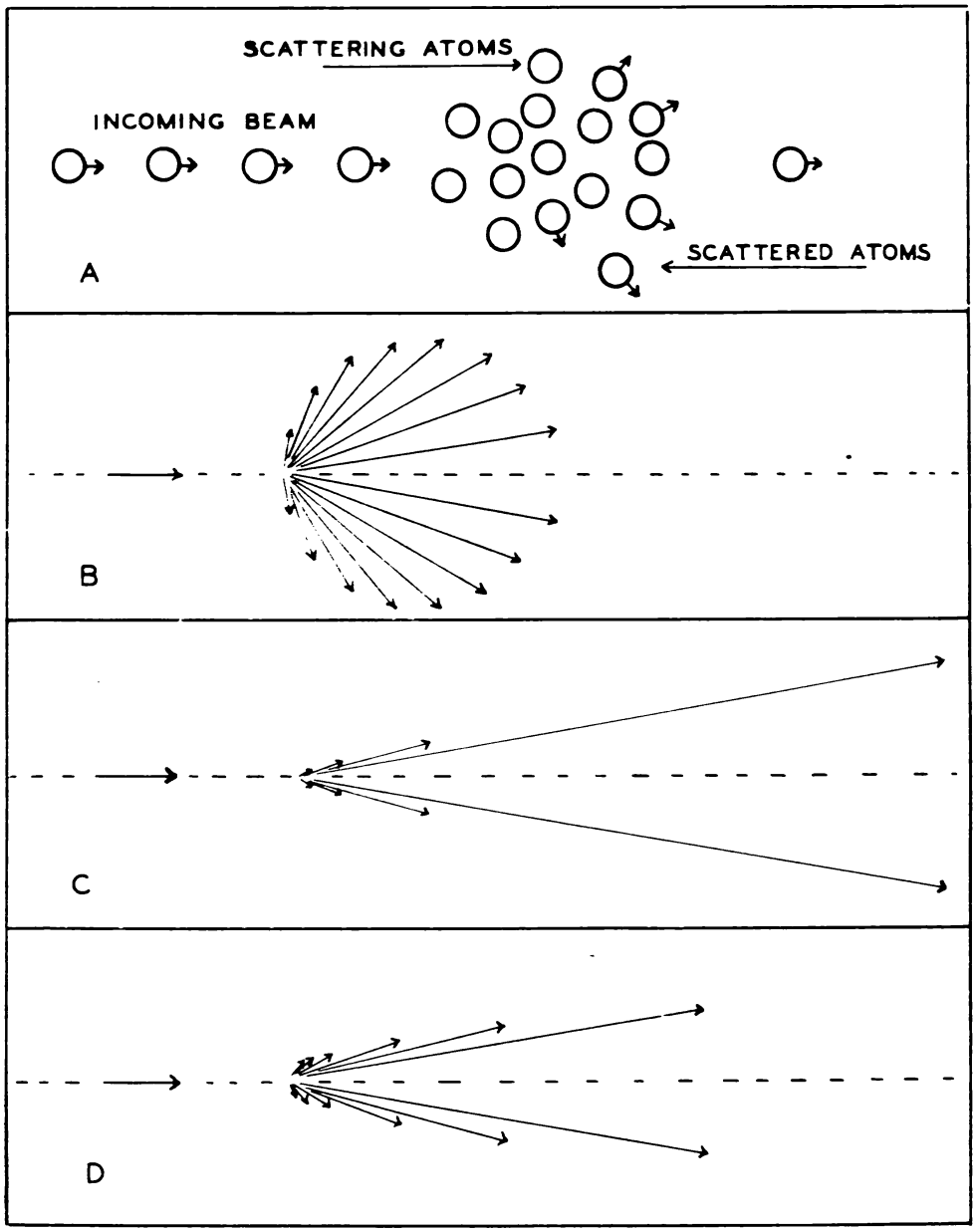


Fig. 1. (a) Schematic picture of incoming fast beam of atoms being scattered by collisions with other gas atoms. (b) Diagram of the relative number of 1000 electron volt argon atoms scattered from the beam in the direction of the arrow assuming the atoms are like hard billiard balls. The length of the arrow is proportional to the number of atoms scattered in that direction. To get the three dimensional picture rotate the diagram about the dotted line which is the original beam direction. (c) Same as (b) but assuming the force between the atoms to be a coulomb or "soft" force. (d) The observed distribution for 1000 volt argon atoms scattered by other argon atoms initially at rest.

with only a small deviation, and how many with larger angular or other deviations. To illustrate this, a number of arrows are drawn in the different directions in which the scattered atoms from the fast stream may be deviated. The length of the arrow is shown proportional to the relative number of atoms going off in that direction.

First let us consider the example of the hard billiard ball. There is no force until two touch and as soon as they do the force becomes very great. This is called a "hard" force and would result in a scattering distribution such as that shown in Figure 1(b). As the other extreme let us consider particles in action where the force would be a coulomb force, or one which decreases as distance is squared between the particles. This we have called a "soft" force and would cause a scattering distribution like that pictured in Figure 1(c).

Now let us consider this as applied to atoms. If we can shoot a stream of fast atoms through another group of like atoms at rest; and if we can measure in our experiment how many are scattered at the different angles, we can work backward and find what kind of a force exists between the atoms. We should expect a force somewhere between a very "hard" force with the hard billiard balls and a "soft" coulomb force.

To make our stream of fast atoms in the laboratory we proceed as follows: We put argon gas in our "gun" (see Figure 2), bombard the gas atoms with electrons and, as a result of this bombardment, knock off one and more infrequently two, of the outer electrons of the atom. Now we have argon ions (atoms which are short an electron) with a positive charge, and by applying a voltage between the plate and grid we can speed up these ions to any desired velocity; for example, if we use 1000 volts between the grid and plate, then the argon ions will be given a velocity of 156,000 mi/hr. These shoot through the intervening space, which is made almost devoid of atoms by pumping, and enter the region N (neutralization of ions). Here there are more argon gas atoms. And peculiarly some of these fast ions will snatch an electron from one of the argon atoms present and so become again an uncharged argon atom but now one with a high velocity. By eliminating any ions left in the stream after passing through N, we have now a high-speed atom stream which we scatter in region S (scattering region) which contains more argon gas atoms at rest. Here those that are scattered are caught by our collector which can be set to collect those scattered at any angle from 0° to 90°. By counting the relative numbers in each direction, we can make an arrow diagram and deduce what kind of a force there is between these atoms while they collide.

The arrow diagram showing the distribution of scattered argon atoms for a 1000 volt beam is shown in Figure 1(d). This we see represents a force somewhere between the hard billiard ball and the "soft" coulomb forces. Further analysis actually shows that the force and distance are related logarithmically. This means that as the atoms approach, the force is at first quite small. But as they get nearer, this force rapidly increases as it would for our sponge rubber balls in which the rubber gets harder nearer the center.

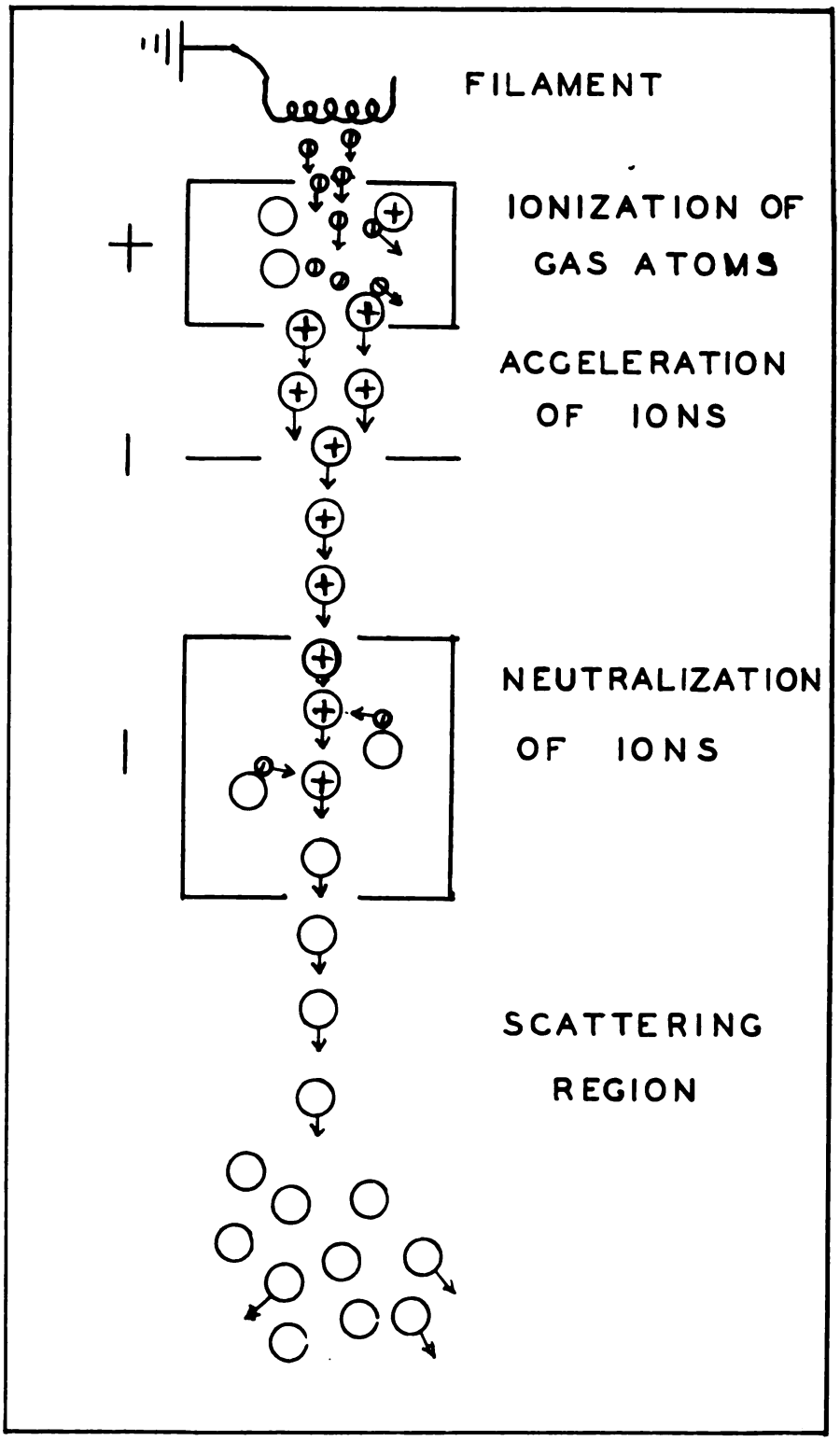


Fig. 2. A schematic picture of an ion beam first produced, then neutralized to become an atom beam and finally scattered.

It is hoped that such knowledge of interatomic forces as is found here will be of help in explaining and predicting, among other things, the properties of solids. As these high-velocity beams represent gas atoms at extremely high temperatures, perhaps these or similar experiments will also lend information about the interaction of high temperature gases and metal surfaces.

On the Naval Research Reserve

Volunteer Reserve Unit 6·6

Formal ceremonies for the activation of Volunteer Naval Research Reserve Unit 6-6 were held in the Naval Armory at the University of North Carolina on June 30, with visiting dignitaries from the Sixth Naval District and the Office of Naval Research in Washington present.

Pictured here are the officials who took part in the activation ceremonies. Left to right: Chancellor R. B. House; CDR William I. Corbett, Charleston, who represented the Commandant Sixth Naval District; LCDR Raymond F. Stainback, Chapel Hill, Commanding Officer of the new Unit; and CDR Fred Wiesner, ONR-Washington, who addressed the officers at the initial meeting.

Special Devices Center Meeting

The Special Devices Association, composed of more than 600 naval and civilian personnel who have been or are connected with the Special Devices Center, held its fifth annual reunion meeting on 19, 20, and 21 August at the Center, Port Washington, L. I., N. Y.

The Association was formed shortly after V-J Day while the special Devices Division was located in Washington, D. C., for the purpose of advancing the development of rapid training techniques as a measure of national preparedness. The current president of the Association is LCDR Viktor Schreckengost, USNR, commanding officer of Volunteer Research Reserve Unit 9-11, Cleveland, Ohio.

RADM T. A. Solberg, USN, Chief of Naval Research, addressed the group on "SDA Participation in the Over-all ONR Mobilization Plan." The mission of Special Devices in the National Military Establishment was discussed by CAPT J. R. Ruhsenberger, USN.

Two Naval Air Reserve TV shows and a network salute to the Association, as well as a tour of the Center, were included in the program. A formal business session was held and officers and two new councilmen were elected.

Benefit to Reservists

Reservists performing active or inactive training duty who suffer disability or death in line of duty are entitled to receive the same compensations as officers of the regular Navy or Marine Corps. As provided by Public Law 108 of the 81st Congress, such reservists or their beneficiaries are "entitled to receive the same pensions, compensation, death gratuity, retirement pay, hospital benefits, and pay and allowances, as are now or may hereafter be provided by law or regulation for officers of the regular Navy or Marine Corps."

Training Duty

A two-week course for Reserve Officers in radiological safety, chemical warfare, and associated subjects is available at the Naval Unit, Chemical Warfare, Edgewood Arsenal, Md., with a quota of three officers. Convening dates are 19 September, 17 October, and 28 November. Officers of any classification are eligible. There is no course for enlisted men either regular or reserve. For officers having special qualifications, such as an advanced degree in organic chemistry, biophysics, biochemistry, and physiology, training duty may be arranged outside of the above listed courses by request to the Commandant.

A two-week course in Photographic Interpretation is available at the U. S. Naval Photographic Interpretation Center, Washington, D. C., with a quota of three officers. The first course began in July, 1949, and succeeding courses convene the second Monday of each month. Previous photographic interpretation training is desirable for officers ordered to this training duty.

Summer Leave

Reserves who are absent from drills because of vacation or business trips should notify the CO of the unit or the VNRR Program Officer in advance. The officer will not be counted as an absentee and the percentage of attendance of his unit will not drop. Leave up to 100 days can be granted.

Officially Activated Volunteer Research Reserve Units

Designation	Place and Time of Meeting	Commanding Officer and Mail Address
1-1	Navy Headquarters Auditorium, Bldg. 60 Boston, Mass. 2000, 1st & 3rd Mon.	CAPT J. W. Harrond, USNR ONR Branch Office 495 Summer St. Boston, Mass.
1-2	Brown University NROTC Bldg. Providence, R. I. 1930, 2nd & 4th Tues.	LCDR C. J. Fisk, USNR Oceanographic Institute Woods Hole, Mass.
1-3	University of Massachusetts Amherst, Mass. 1900, 1st & 3rd Tues.	LCDR E. D. Emerson, USNR Mechanical Eng. Department University of Massachusetts Amherst, Mass.
3-1	Cornell University Medical College New York 21, N. Y. 1930, 1st & 3rd Tues.	CDR J. D. Hardy, USNR 1300 York Ave. New York 21, N. Y.
3-2	Special Devices Center Engineering Building Sands Point, Port Washington Long Island, N.Y. 1930, Alternate Mon., beginning July 1	CDR L. E. Yoder, USNR Sands Point, Port Washington Long Island, N.Y.
3-3	Naval Militia Boathouse USNR & USMCR TraCen 3 Porter Ave. 2000, 1st & 3rd Mon.	LCDR Ralph Bloom, Jr., USNR 184 Connecticut St. Buffalo, N. Y.
3-4	University of Rochester Harkness Hall (NROTC) Rochester, N. Y. 1930, 1st & 3rd Tues.	CDR Henry C. Sheve, USNR USNR & USMCR TraCen 900 East Main St. Rochester, N. Y.
3-5	Yale University NavResTraCen New Haven, Conn. 1930, 2nd & 4th Thurs.	CDR D. S. Bowell, USNR NavResTraCen Ft. Nathan Hale Park New Haven 13, Conn.
3-6	NavResTraCen Syracuse (Liverpool), N. Y. 1930, 2nd & 4th Mon.	LT A. O. Quinn, USNR NavResTraCen Syracuse (Liverpool), N. Y.
3-7	NavResTraCen Scotia, N. Y. 2000, Every 2nd Thurs.	LCDR G. H. Baldwin, Jr., USNR NavResTraCen Scotia, N. Y.
4-1	Nassau Tavern Princeton University Princeton, N. J. 2000, 1st Wed.	LCDR Paul Busse, USNR Aeronautical Eng. Bldg. Princeton University Princeton, N. J.

Designation	Place and Time of Meeting	Commanding Officer and Mail Address
4-2	Franklin Institute 20th St. & Parkway Philadelphia, Pa. 1930, Alternate Thurs.	LCDR W. G. Amey, USNR Electronics Section Franklin Institute Philadelphia, Pa.
4-3	Carnegie Institute of Technology 104 Industries Hall Pittsburgh, Pa. 2000, 2nd & 4th Thurs.	CDR N. D. Cole, USNR Office of Naval Research University of Pittsburgh 303 Thaw Hall Pittsburgh, Pa.
4-4	Pennsylvania State College College Station, Pa. 2nd & 4th Tues.	CDR E. R. Queer, USNR % Engineer Experiment Station Pennsylvania State College College Station, Pa.
4-5	University of Delaware Wilmington, Del.	LCDR Donald MacCreary, USNR NavResTraCen Foot of Madison St. Wilmington, Del.
W-1	Navy Dept. T-3. Bldg. Rm. 1515 Washington, D. C. 2000, 1st & 3rd Thurs.	CDR W. M. Richardson, USNR ONR T-3, Bldg. Rm. 2602 Washington, D. C.
W-2	Naval Research Laboratory Bldg. 8. Auditorium, 1900, 1st Thurs. Interior Dept. 2000, 3rd Thurs. (Joint Meeting with W-1)	LCDR H. A. Tanner, USNR Bldg. 8, Rm. 152 Naval Research Laboratory Washington, 20, D. C.
W-3	Navy Dept. T-3, Bldg. Rm. 1803 Washington, D. C. 2000, 1st & 3rd Thurs.	
W-4	Navy Dept. T-3 Bldg. Rm. 1515 Washington, D. C. 2000, 2nd & 4th Wed.	LCDR Lawrence Gardiner, USNR Atomic Energy Commission Public Health Bldg. Rm. 102 Washington, D. C.
5-1	University of Virginia Rouss Physics Laboratory Charlottesville, Va. 1930 Alternate Wed.	LTJG P. B. Buck, USNR 4 Copeley Hill Charlottesville, Va.
5-2	Virginia Polytechnic Institute Bldg. 364 Blacksburg, Va. 1915, 1st & 3rd Fri.	LCDR E. D. Harrison, USNR P. O. Box 575 Blacksburg, Va.
5-3	Camp Detrick Frederick, Md.	CAPT. LeRoy D. Fothergill, USNR Camp Detrick Frederick, Md.
6-1	Georgia Institute of Technology Physics Bldg., Rm. 103 Atlanta, Georgia 2000, Alternate Thurs.	CDR J. E. Boyd, USNR Physics Bldg. Georgia Institute of Technology Atlanta, Ga.
6-2	Alabama Polytechnic Institute 318 Ross Laboratory Auburn, Ala. 1930, 1st & 3rd Tues.	LT J. E. Land, USNR Chemistry Dept. Alabama Polytechnic Institute Auburn, Ala.
6-3	Oak Ridge National Lab. A.E.C. Townsite Oak Ridge, Tenn. 2nd & 4th Tues.	LCDR D. J. Mallon, USNR P. O. Box P Oak Ridge, Tenn.
6-4	University of Florida Engineering Bldg. Gainesville, Fla. 1930, 1st & 3rd Tues.	LCDR E. G. Rietz, USNR Chemistry Dept. University of Florida Gainesville, Fla.

Designation	Place and Time of Meeting	Commanding Officer and Mail Address
6-5	NavResTraCen Gulfport, Miss.	LT V. O. Smallwood, USNR 2412 East Ave. Gulfport, Miss.
6-6	University of North Carolina Chapel Hill, N.C.	LCDR R. F. Stainback, USNR 317 W. Univ. Dr. Chapel Hill, N.C.
6-7	Duke University Biology Bldg. Durham, N.C. 2000, 1st & 3rd Thurs.	LCDR John H. Roberts, USNR 2813 Legion Ave. Durham, N.C.
8-1	Tulane Univ. Chemistry Bldg. Rm. 27 New Orleans, La. 1930, 1st & 3rd Tues.	LCDR J. M. Scott, USNR Chemistry Dept. Tulane University New Orleans, La.
8-2	Louisiana State University Baton Rouge, La. 1930, 2nd & 4th Wed.	LCDR W. N. Edwards Jr., USNR Chemistry Dept. Louisiana State University Baton Rouge, La.
8-3	Texas A. & M. College P & MA Bldg. College Station, Tex. 1930, 2nd & 4th Mon. and 2nd Thurs.	LCDR Norman F. Rode, USNR Electrical Eng. Dept. Texas A. & M. College College Station, Tex.
8-4	Rice Institute NROTC Bldg. Houston, Tex. 1930, Alternate Wed.	LTJG John J. Banewicz, USNR 4811 Mt. Vernon St. Houston, Tex.
8-5	University of Texas Physics Bldg. Rm. 201 or Chemistry Bldg. Rm. 15 Austin, Tex. 2000, Alternate Tues. and Wed.	LCDR G. H. Ayers, USNR Chemistry Dept. University of Texas Austin, Texas
8-6	USNRTC Galveston, Tex. (Irregular)	LTJG C. N. Sechrist, USNR 1235 3rd Ave. North Texas City, Tex.
9-1	Navy Pier Campus Chicago, Ill. 1900, 2nd & 4th Tues.	CAPT George C. Lamb, USNR Technological Institute Northwestern University Evanston, Ill.
9-2	University of Illinois 319 Gregory Hall Urbana, Ill. 1930, 1st Wed.	LCDR A. C. Williams Jr., USNR Psychology Dept. University of Illinois Urbana, Ill.
9-3	University of Michigan Angell Hall, Rm. 18 Ann Arbor, Mich. 1930, (Irregular)	CDR C. M. Davis, USNR Geography Dept. University of Michigan Ann Arbor, Mich.
9-4	Ohio State University Old Armory, OSU, Rm. 107 Columbus, Ohio 1930, 2nd & 4th Tues.	LCDR Karl E. Krill, USNR Engineering Experiment Station Ohio State University Columbus, Ohio
9-5	Iowa State College NROTC Bldg. Ames, Iowa. 1930, 1st & 3rd Wed.	LCDR O. C. Kreider, USNR Mathematics Dept. Iowa State College Ames, Ia.
9-6	University of Minnesota Murphy Hall Auditorium Minneapolis, Minn. 1930, 1st Mon. & 3rd Tues.	LCDR J. A. Wise, USNR 220 Experimental Eng. Bldg. University of Minnesota Minneapolis, Minn.

Designation	Place and Time of Meeting	Commanding Officer and Mail Address
9-7	Purdue University Stanley Coulter Hall Rm. 111 Lafayette, Ind. 1930, 2nd & 4th Thurs.	LT L. M. Baker, USNR Psychology Dept. Purdue University Lafayette, Ind.
9-8	Washington University Crew Hall Rm. 101 St. Louis, Mo. 2000, 1st Wed.	CDR R. M. Varney, USNR Physics Dept. Washington University St. Louis, Mo.
9-9	Missouri School of Mines & Metallurgy Mechanics Hall Rm. 204 Rolla, Mo. 1930, 1st & 3rd Thurs.	CDR R. A. Cooley, USNR Missouri School of Mines & Metallurgy Rolla, Mo.
9-10	USNRTC Peoria, Ill. 1930, 1st & 3rd Wed.	LCDR F. C. Albers, USNR 108 Devon Lane Peoria, Ill.
9-11	NavResTraCen 7700 Clinton Road Cleveland, O. 2000, 1st & 3rd Mon.	LCDR Viktor Schreckengost, USNR 2366 Noble Road Cleveland 21, O.
9-12	Colorado A. & M. College Botany Bldg. Annex Ft. Collins, Colo. Time and date not established	LTJG W. D. Thomas, USNR Colorado A. & M. College Botany & Plant Pathology Dept. Ft. Collins, Colo.
9-13	USNRTC Des Moines, Ia. Time and date not established	LCDR J. R. Maloney, USNR 2920 48th St. Des Moines 10, Ia.
9-14	University of Wisconsin USN Armory Madison, Wis.	CDR W. B. Sarles, USNR University of Wisconsin Madison, Wis.
9-15	Community Center Midland, Mich.	LTJG D. D. McCollister, USNR 1220 Michigan St. Midland, Mich.
11-1	1030 E. Green St. Pasadena, Calif. 2000, 1st & 3rd Tues.	LCDR H. J. Pedersen, USNR 1030 E. Green St. Pasadena, Calif.
11-2	NROTC Armory Pasadena, Calif. 2000 Alternate Thurs.	LCDR J. H. Biggar, USNR 680 E. Colorado Dr. Pasadena, Calif.
11-3	University of California Los Angles, California 2000, 1st & 3rd Mon.	CDR L. P. Delsasso, USNR Physics Dept. University of California Los Angles, Calif.
12-1	801 Donahue St. San Francisco, Calif. 2000, 2nd & 4th Mon.	CDR J. E. Laurance, USNR ONR Branch Office 801 Donahue St. San Francisco, Calif.
12-2	University of California Donner Laboratory Rm. 201 Berkeley, Calif. 1945, 2nd & 4th Mon.	LCDR Nello Pace, USNR Life Science Bldg., Rm. 2519 University of California Berkeley, Calif.
12-3	Stanford University Engineering Corner Rm. 208 Stanford, Calif. 2000, 2nd & 4th Wed.	CDR L. S. Jacobsen, USNR Mechanical Eng. Dept. Stanford University Stanford, Calif.

Designation	Place and Time of Meeting	Commanding Officer and Mail Address
12-4	Fresno State College McClain Hall Rm. M-103 2000, 2nd & 4th Thurs. 2000, 8 Sept. 1949 (First Fall Meeting)	CDR Ralph A. Jack, USNR Physics Dept. Fresno State College Fresno 2, Calif.
12-5	University of California LeConte Hall Room 208 Berkeley, Calif. 1930, 2nd & 4th Wed.	CDR C. F. Garland, USNR Engineering Design Div. University of California Berkeley, Calif.
12-6	College of Agriculture University of California Animal Science Bldg. Rm. 213 Davis, Calif. 1st Mon. (During Summer)	LT Arthur H. Smith, USNR Animal Husbandry Dept. College of Agriculture University of California Davis, Calif.
13-1	University of Washington Anatomy Bldg. Rm. 108 Seattle, Wash. 1930, 2nd & 4th Mon.	CDR H. S. Bennett, USNR Anatomy Dept. School of Medicine University of Washington Seattle, Wash.
13-2	American Legion Hall Richland, Wash. 1900, 2nd & 4th Tues.	LT W. W. Gonder, USNR General Electric Co. Richland, Wash.
13-3	Y.M.C.A. Pullman, Wash. 1930, 2nd & 4th Mon.	LCDR W. G. Gnaediger, USNR Community College Service State College of Washington Pullman, Wash.
13-4	Swan Island Portland, Ore. 1930, 1st & 3rd Mon.	LCDR Richard F. Stevens, USNR 811 N.E. Oregon St. Portland, Ore.
13-5	Oregon State College Corvallis, Ore.	LCDR Albert V. Logan, USNR Chemistry Dept. Oregon State College Corvallis, Ore.

Note: In order to keep this list up-to-date, Commanding Officers of subject units are requested to notify Office of Naval Research, Code-104, T-3 Bldg., Rm. 1059, Washington, D. C., of any additions or corrections.

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