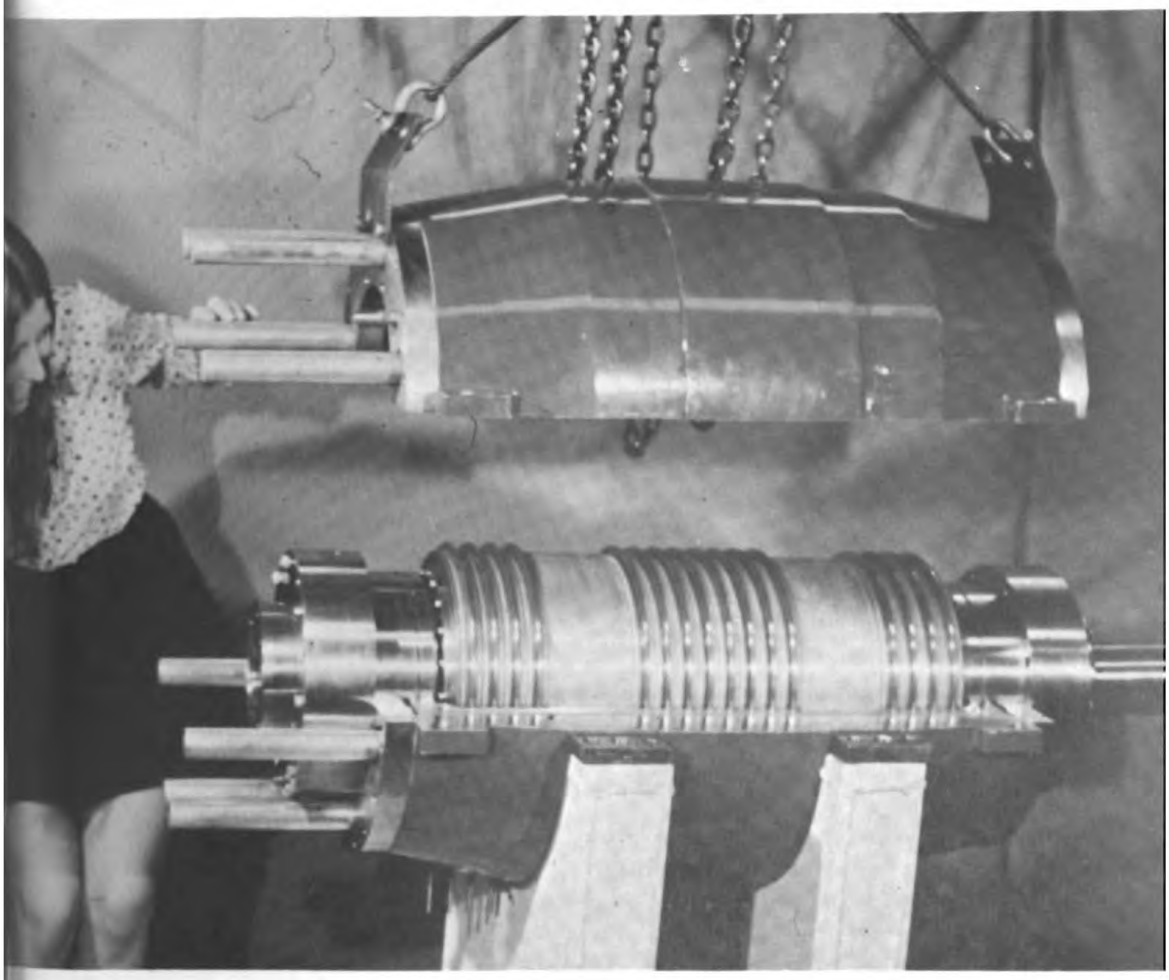
NAVAL RESEARCH

REVIEWS

MARCH 1975



PROFILES IN SCIENCE

Dr. John Bardeen

Dr. Bardeen is Professor of Electrical Engineering and of Physics at the University of Illinois. He is renown for his research in the fields of semiconductors and superconductors for which he received Nobel Prizes in 1956 and 1972. For many years Dr. Bardeen's work has been supported by the Office of Naval Research. In the 1940's Dr. Bardeen became interested in semiconductors while at the Bell Telephone Laboratories. It was there that he was instrumental in the discovery of the transistor effect.

At Illinois, Dr. Bardeen helped establish research programs on experimental and theoretical aspects of semiconductors, but his interest in recent years have been more on theoretical aspects of low temperature physics, particularly on the theory of superconductivity. Other interests have included surface properties of semiconductors and the theory of diffusion of atoms in crystals.

Superconductivity: An Emerging Technology*

It wasn't many years ago when a review such as this would begin by describing some of the details of the phenomenon of superconductivity. Such an introduction is no longer necessary. Superconducting devices now have become almost household words as familiar as lasers and transistors. Reports of actual or possible development of superconducting systems regularly appear in the press and popular journals. Part of this increased familiarity and popularity arises from the fact that in the last five years the Federal government has been spending significantly larger sums in the support of superconducting science and technology. In 1972 Federal agencies spent some 21 million dollars supporting R&D in superconductivity. Today, estimates place this annual expenditure at some 26-27 million dollars. Added to this is an estimated additional 10 million dollars being spent annually by industry, making a total of some 35 million dollars currently being spent in the US on superconductive R&D. All indications are that this sum will continue to grow. There are some 30 major industrial and government laboratories in Europe, Japan and Russia working on various applications of superconductivity. Persons who have visited Russian laboratories report that the Soviets rate superconductivity second only to lasers and ahead of semiconductor devices in terms of practical applications and economic importance.

One can divide the applications of superconductivity into two broad groupings. The first is sometimes referred to as magasuperconductivity. This includes the big muscle stuff, high power, large magnetic fields and big volumes. With this class of applications usually go big sums of money. For the most part these applications exploit the zero electrical resistance properties or the perfect diamagnetic properties of superconducting materials. Some of the large scale applications under development in the US are: superconducting magnets for fusion, MHD, energy production and energy storage; superconducting d.c. and a.c. cable for energy transmission; a.c. and d.c. superconducting motors and generators and superconducting magnetically levitated trains.

The other class is small scale applications, sometimes called microsuperconductivity or superconducting electronics. Here one is

*Material for this paper was taken from a talk by Mr. E. A. Edelsack, Office of Naval Research, at the 1974 Electronics and Aerospace Systems Conference, Washington, D.C.

usually dealing with those applications which exploit the d.c. and a.c. Josephson tunneling phenomena. Devices in this class include ultrasensitive magnetometers, infrared, millimeter and submillimeter wave detectors, voltmeters and ammeters, gravity meters, parametric amplifiers, and computer elements. This list is by no means complete; it continues to grow each day.

Applications of superconductivity cover a tremendous gamut of possibilities ranging, for example, from large superconducting magnets with stored energies approaching 10^{11} joules to the other extreme of Josephson junction devices where we are dealing with energies of the order of 10^{-22} joules. These two numbers bracket some 33 orders of magnitude in energy where one can search for useful applications. This tremendous range is one reason why the field is both interesting and challenging and why the Navy is now investing a significant amount of R&D in superconductivity. Some potential Naval applications are: ship propulsion systems; magnetic sensors for ASW; electromagnetic sensors for surveillance and communication; electronic components for communication and surveillance systems at microwave, RF and ELF frequencies; magnets for mine sweeping.

In the area of superconducting propulsion machinery, the Navy is now spending about 4 million dollars annually at Navy laboratories and with private industry. This advanced development program is funded and administered by the R&D Directorate of the Naval Sea Systems Command with the Naval Ship Research and Development Center at Annapolis as the technical lead Navy laboratory. This interest in superconducting machinery, motors and generators is stimulated by numerous potential Naval uses. The most important use for d.c. motors is for ship propulsion and for d.c. generators to supply the power for these motors. A unique feature of all superconducting machines is that they lend themselves very well to high power requirements. They may be manufactured with power ratings far greater than those which are possible by conventional means. The major advantages of superconducting machines over conventional types are in reductions in weight, size and electrical losses by as much as one third. For large size units it is estimated that there are also significant savings in cost.

Small superconducting d.c. machinery looks quite different from most conventional types. Their operation is both elegant and simple. It is based on the disc machine invented by Faraday in the 1830's (Figure 1). The basic homopolar machine consists of a simple, rotating, conducting disc with current collection at the hub and periphery. The magnetic field is produced by a superconducting magnet. Current is generated radially in the disc when it is rotated

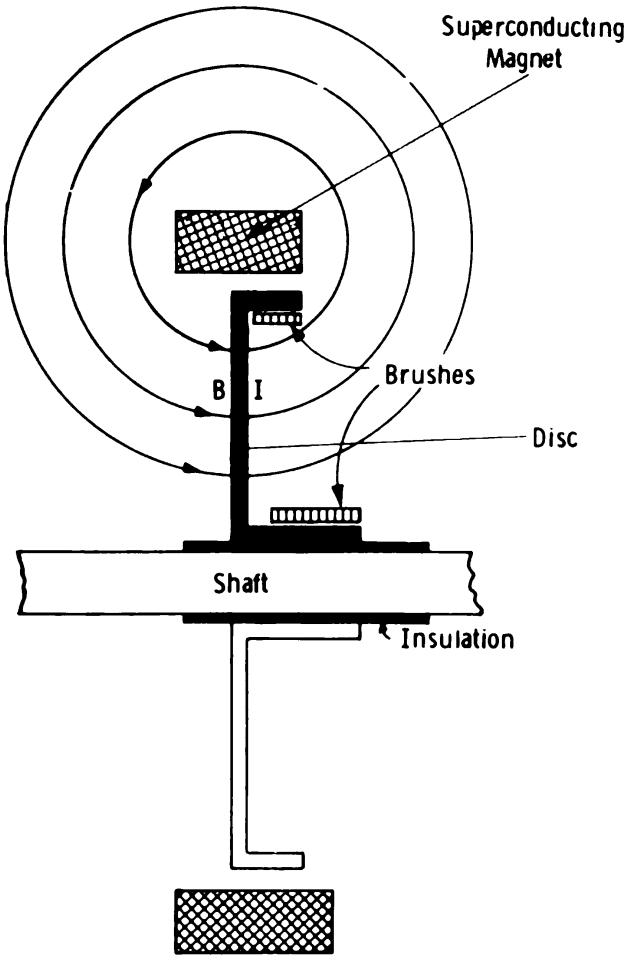


Figure 1 – Basic homopolar machine (disc type)

in a magnetic field. Conversely, if current is *applied* to the disc in a magnetic field, it will rotate and act as a motor. A design which uses a drum instead of a disc is now being developed at Naval Ship Research and Development Center, Annapolis. The use of superconducting magnets for these homopolar machines removes the limitations of conventional iron core magnets which tend to saturate around 20,000 gauss. Moderate size magnetic fields of 30 to 50,000 gauss are readily attainable with superconducting magnets.

The homopolar machine is essentially a low voltage, high current device. Several ways have been devised to raise the voltage and reduce the current. They include multiple discs, segmented discs and multiple concentric drums. Current collection techniques fall into two types; solid brushes and liquid metal contacts. The superconducting machinery efforts in England under British Navy support have concentrated on solid carbon fiber brushes while the US Navy-supported work has been largely devoted to sodium-potassium, liquid

metal, current collector systems. The design problems that still await solution before superconducting machines are widely used involve these liquid metal current collection systems and the successful design of low heat leak, liquid helium cryogenic systems which will meet the high shock and vibration requirements of shipboard use.

In addition to the savings of weight and volume which can be achieved by going the superconducting route, perhaps the most attractive feature is that these systems permit exploiting the great flexibility of all electric ship drive. The power requirements for ships vary enormously, but shaft powers have been creeping up beyond 40,000 horsepower. This power level is quite beyond the design limitations of conventional d.c. motors. The use of a.c. motors, whether superconducting or not, requires gear boxes which increase weight, size and cost as well as reducing efficiency. The use of a.c. machine systems is also restrictive on speed control unless frequency changing equipment is employed. However with the development of superconducting d.c. machines, the necessary power rating with direct drive to the propeller becomes available, which makes possible new types of naval vessels. One such example under consideration is a hydrofoil, a sketch of which is shown in Figure 2. The cover picture shows the 300 horsepower superconducting motor being built and tested at the Naval Ship Research and Development Center at Annapolis. It uses a liquid metal current collection system. This in-house Navy effort is also aimed at building a 300 kW superconducting generator.

Another large scale application of superconductivity which was initiated under Office of Naval Research support and is now jointly supported with the National Science Foundation involves the building of a superconducting microwave electron linear accelerator at

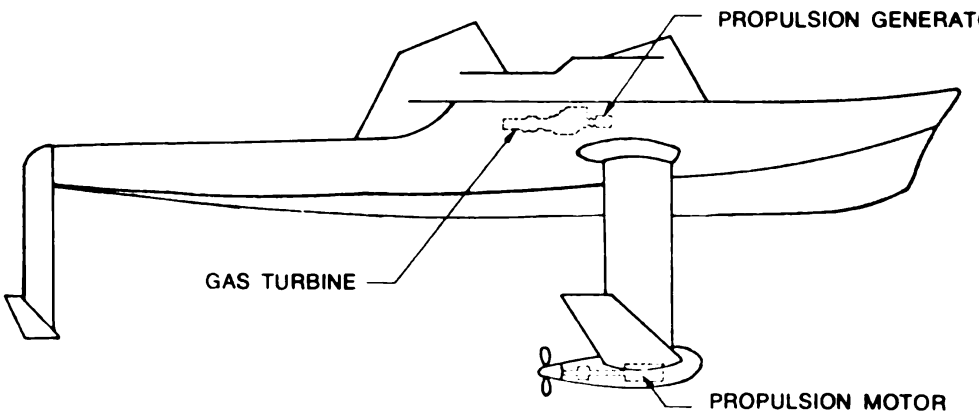


Figure 2 – Hydrofoil installation

Stanford University. The purpose of Navy support of this pioneering work has been to develop basic knowledge about high power superconducting microwave cavity systems as well as to gain insight into the operation of large scale helium refrigerators and cryogenic systems. The Stanford accelerator, when completed, will include several hundred feet of superconducting niobium microwave cavities operating at 1300 MHz. The entire accelerator system is cooled to 2 degrees above absolute zero by a giant 300 watt helium refrigerator. When completed the accelerator will be used for nuclear physics research.

The reason for going to superconducting microwave cavities is that most conventional high power radio frequency devices are limited in their performance by the large power losses on the surface of the cavities. For example, at 1 GHz the surface resistance of superconductors is almost a million times less than that of room temperature copper. Hence superconducting microwave cavities offer possibilities of achieving microwave power levels which are impossible or impractical with conventional room temperature microwave devices.

The superconducting cavity research for the Stanford accelerator has made possible microwave cavities with very high Q (the quality factor Q is the ratio of energy stored in a system to the energy dissipated). For example, Q's in the range of 10^{10} to 10^{11} have been achieved for niobium cavities at frequencies from 1 to 10 GHz. The very narrow bandwidth of these high Q superconducting cavities, as well as their great thermal and mechanical stability, make them well suited as the frequency determining element of an ultra-high stability oscillator. Under Office of Naval Research support, work is in progress studying the properties of superconducting cavity stabilized oscillators as radio frequency sources of ultra high stability. A group at Stanford University has made significant progress in reducing the magnitude of the fluctuations and the frequency drift rate of these devices. Recent results exceed the short time stability of the hydrogen maser and the rubidium and cesium clock standards.

Now let us turn to small scale or superconducting electronics applications of interest to the Navy. This R&D area is supported at the Naval Research Laboratory, at the Naval Coastal Systems Laboratory at Panama City, Florida and by the Office of Naval Research through research contracts with university and industrial laboratories. These programs study the properties of superconducting Josephson junctions and attempt to exploit them to develop new and superior electronic devices capable of detecting a wide variety of physical quantities.

To briefly illustrate how a Josephson junction works see Figures 3, 4, and 5. Figure 3 illustrates schematically that when an electric current flows in a superconductor attached to a battery, there is no voltage drop across the superconductor since it has no d.c. resistance. Figure 4 shows the case of a superconductor separated into two pieces by a thick insulator. No current flows and the voltage equals the battery voltage. In Figure 5 we replace this thick insulator with a very thin one (say 10 angstroms thick) and we observe some very unusual effects. A d.c. current flows across this structure with no voltage just as if it were a single piece of superconductor. This is a case of quantum tunneling of bound electron pairs across the thin insulator from one piece of superconductor to the other. This type of tunneling of electron pairs is called Josephson tunneling, or the d.c. Josephson effect. This sandwich type of structure is called a Josephson junction and can be built in many shapes as is shown in

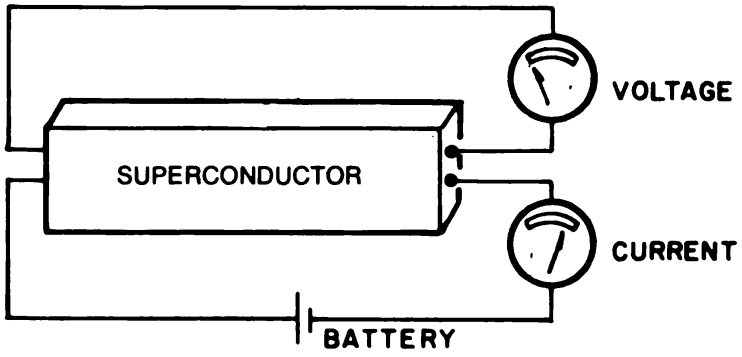


Figure 3 — When a direct current flows through a superconductor, there is no drop in voltage across it, which shows that it has no resistance.

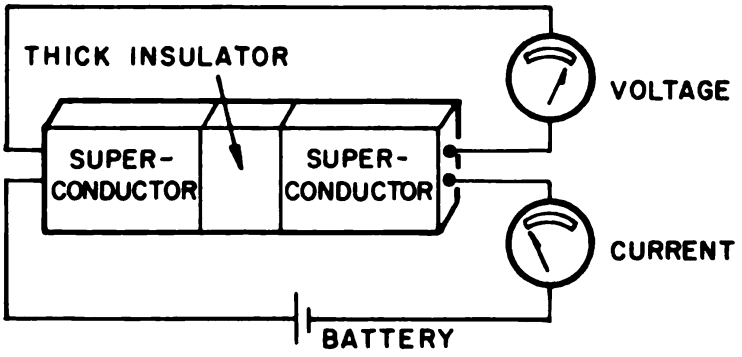


Figure 4 — A thick insulating layer between two superconductors will stop the current flow. The voltage in this case will be equal to that of the battery.

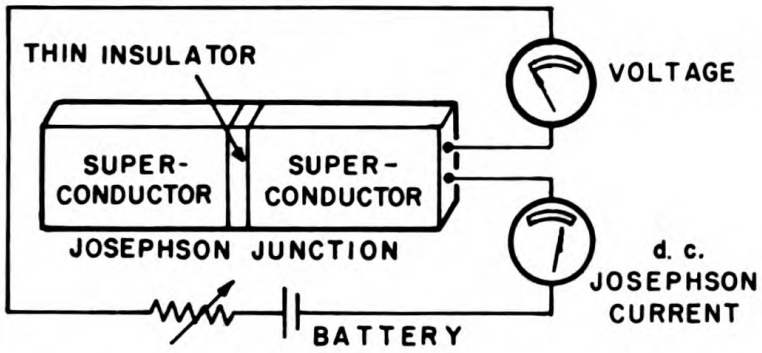


Figure 5 — At a Josephson junction, which is formed by placing a very thin insulator between two superconductors, a (d.c. Josephson) current will flow, although there is no voltage drop, because some of the superconducting electrons will tunnel through the insulator due to their quantum nature

Figure 6. If the d.c. tunneling current in a Josephson junction exceeds a critical value, an additional interesting and important phenomenon takes place. A voltage now appears across the junction and electromagnetic radiation is emitted from the junction as shown in Figure 7. This is called the a.c. Josephson effect. The frequency of the emitted radiation is linearly related to the d.c. voltage by a very simple formula. Both d.c. and a.c. Josephson effects provide many possible practical electronic applications.

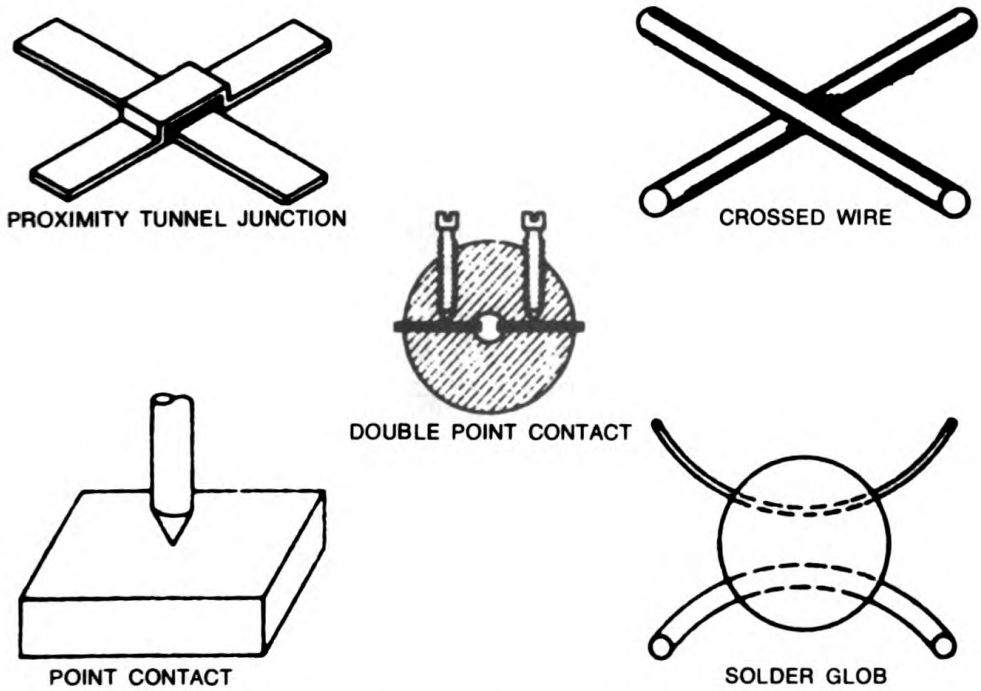


Figure 6 — Several forms of junction which exhibit the Josephson effects

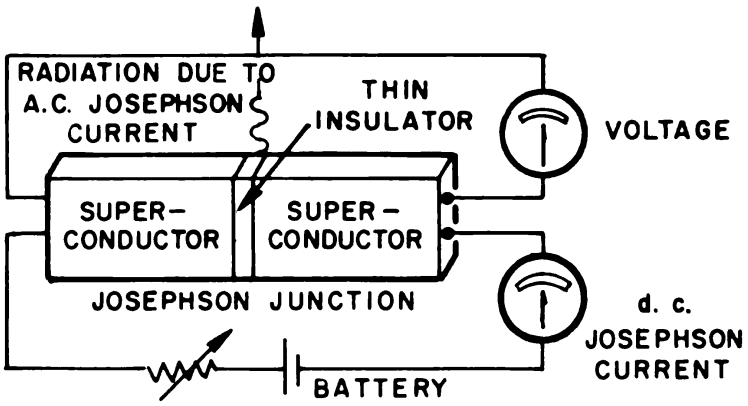


Figure 7 — Under certain conditions (if the current source forces the current to exceed the maximum d.c. Josephson current) a voltage appears across the junction; at the same time, electromagnetic radiation is emitted from the insulating gap, demonstrating the presence in the gap of an alternating (a.c. Josephson) current

One application of great interest to the Navy is the detection of minute magnetic fields by means of Josephson junctions. If a single Josephson junction is placed in a magnetic field, a plot of magnetic field versus maximum Josephson junction current looks similar to the pattern shown in Figure 8. If two junctions are connected in parallel, a plot of the maximum current flowing in the circuit versus external magnetic field will look similar to the pattern shown in Figure 9. Each oscillation corresponds to a change of 10^{-7} gauss in the magnetic field sensed by the pair of junctions. By increasing the area of the superconducting circuit loop which senses the changes in magnetic field it is possible to build magnetic sensing devices of extraordinary sensitivity. They are by far the most sensitive magnetic sensors available today. Laboratory superconducting magnetometers have been built with sensitivities of 10^{-12} gauss. Reliable ultra-sensitive portable superconducting magnetometers for field use have been built and operated with sensitivities of 10^{-10} gauss. To illustrate what such sensitivity means in practical terms, if we take a 100 tons of demagnetized steel which has only the magnetization induced by the earth's field, a sensitivity of 10^{-10} gauss corresponds to detecting the magnetic field of this steel at a distance of some 10 miles.

This extraordinary sensitivity is further illustrated by experiments at MIT in which the magnetic fields generated by the electrical activity of the human heart and brain have been detected outside the body.

Groups at various Navy and civilian laboratories are now exploring the use of superconducting magnetic sensors for search and surveillance applications. There are still some important basic research problems in superconducting magnetometry to be solved before the

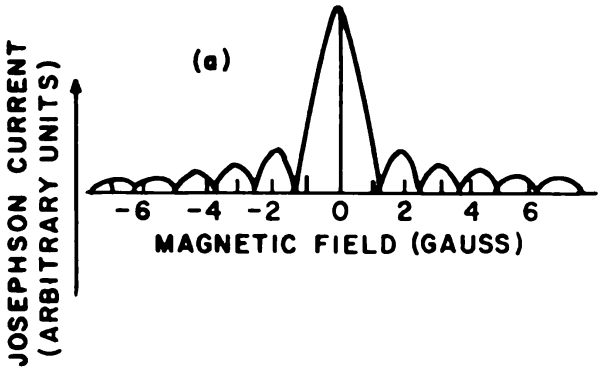


Figure 8 – Dependence of the maximum Josephson current on applied magnetic field for a single junction

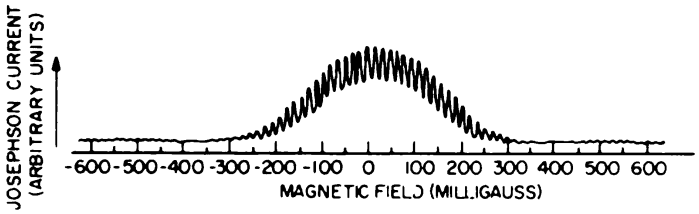


Figure 9 – Dependence on applied magnetic field of the maximum d.c. current that can be carried by two Josephson junctions in parallel

Navy can fully exploit these devices, but most of the major research hurdles already have been overcome. A significant fraction of the Navy effort in this field is moving into the realm of exploratory and advanced development.

Let us now turn to those electronic applications of superconductivity which exploit the a.c. Josephson effect. The list is long and we will mention here only a few in which ONR is now supporting research. One important application of Josephson devices is as ultrasensitive detectors of microwave and far-infrared radiation. As infrared detectors they are able to detect better than 10^{-13} watts in a one cycle bandwidth and their ultimate sensitivity and the upper frequency limit are under active study. Their use as low noise wide bandwidth detectors of millimeter and submillimeter radiation is being explored. Recent calculations indicate that very efficient devices can be built in the 30-300 GHz range.

Another potential application of Josephson junctions under study is their use as sources of continuously tunable microwave radiation. If one applies a known voltage across the junction, microwaves of a

specific frequency (483 MHz per microvolt) are emitted. Unfortunately the amount of emitted radiation which can be realized from a single junction is very small, of the order of 10^{-10} watts. This is not very useful but it appears possible to use arrays of many junctions and increase the output power to 10^{-7} watts. A continuously tunable rf source with this power level will have many practical uses.

Another area of superconducting research is that of arrays. Arrays of 50 to 100 interconnected junctions have been made, and results of preliminary work on arrays of some 500 junctions connected in series are encouraging. These arrays, if they can be successfully developed, could represent orders of magnitude improvement in several applications of interest to the Navy. They include miniaturized communication systems and the monitoring of electromagnetic emissions, particularly ELF and VLF, with reduced antenna size and increased sensitivity.

It is difficult to predict where the field of superconducting devices, be they small or large, will have their first major impact on the fleet. In 1973 a conference on Naval Applications of Superconductivity was held at the Naval Research Laboratory. The unclassified portion of the proceedings has been published (NRL Report #7822) and is recommended to those interested in knowing more about the Navy programs in superconductivity.

Memory Processes Subject of Navy Study

Under sponsorship of the Office of Naval Research (ONR), researchers at Northwestern University are conducting a study aimed at a better understanding of the different processes involved in memory and through which a person learns to remember.

Different jobs place varying degrees of emphasis on different types of memory skills. In order to utilize these skills effectively, it is necessary to determine the way they are organized and the way they function in different situations. The results of this study may lead to more efficient ways to select and train personnel whose memory skills best match the requirements of their jobs. The study is part of on-going ONR research about the functions of memory. The research is under the supervision of Dr. Benton J. Underwood, who is a recognized leader for his theories and experimental investigations of the fundamental processes of information acquisition and retention.

The main objective of the project is to obtain a clearer picture of the role that memory "attributes" play in the function of memory. A memory attribute is defined as a specific type of information which becomes part of the memory for a particular event, therefore assisting us to remember that event. For instance,

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Improved Superconducting Composite Wire

D. G. Howe*

Naval Research Laboratory

Superconductors are playing an increasing role in a number of engineering fields. These include advanced power generation systems such as large conventional generators, magneto-hydrodynamic (MHD) generators, power transmission, high-speed ground transit and controlled thermonuclear fusion reactors. The "energy crisis" has made superconductivity even more prominent as an approach to more efficient production and transmission of electrical energy. MHD generators are now in the advanced development stage, and one of the main technical difficulties remaining is the present lack of a superconductor which can supply the necessary current density for the MHD channel magnet (1).

At present, superconducting magnets which achieved fields of 100 to 150 kG use the compound Nb_3Sn. The single most important technological characteristic of a high-field superconductor is its ability to carry large currents without losses in the presence of high magnetic fields (2). Specifically, the higher the superconductor's critical current density (J_c), the shorter the length of wire required to achieve a desired magnetic field strength. Improved operating characteristics would result if a material were developed with J_c values higher than those presently available.

The intermetallic compound V_3Ga possesses a relatively high critical temperature (15°K), one of the highest critical fields, and displays good current-carrying capacity. The J_c properties of V_3Ga exceed those of Nb_3Sn in transverse magnetic fields over 130 kG (3). However, V_3Ga is extremely brittle and very difficult to fabricate and work metallurgically. Recently M. Suenaga and W. B. Sampson formed V_3Ga through a process of solid-state reaction between vanadium and a solid solution Cu-15 at. % Ga alloy (4).† In this manner the material may be processed (into wire or magnet coils) in the relatively ductile (un-reacted) state, and the V_3Ga interfacial layer is then formed as the last step of the processing.

*Mr. Howe is Research Ceramic Engineer at NRL. His fields of interest are superconductivity and metals processing.

†Atomic percent Gallium alloy.

At The Naval Research Laboratory (NRL), composite wires were fabricated by mechanical deformation of a coaxial cylinder of a V-Ga alloy surrounded by a Cu-Ga alloy sheath into the desired shape using a novel metallurgical processing technique (5). Initial studies used pure V/Cu-15.4 at. % Ga (6) and V-6.1 at. % Ga/Cu-15.4 at. % Ga (7) composite systems. The alloying of the V filament with 6.1 at. % Ga in the Cu-15.4 at. % Ga matrix resulted in a sample with a J_c double that of the pure V samples over the transverse magnetic field (H) range of 30-130 (kG). By an additional increase in the Ga content of the V-filament and the Cu matrix (V-9.0 at. % Ga/Cu-17.5 at. % Ga), substantial improvements in the growth rate of V_3Ga and in the J_c properties were achieved over those developed in NRL's earlier V-6.1 at. % Ga/Cu-15.4 at. % Ga alloy (8), (see Figure 1),

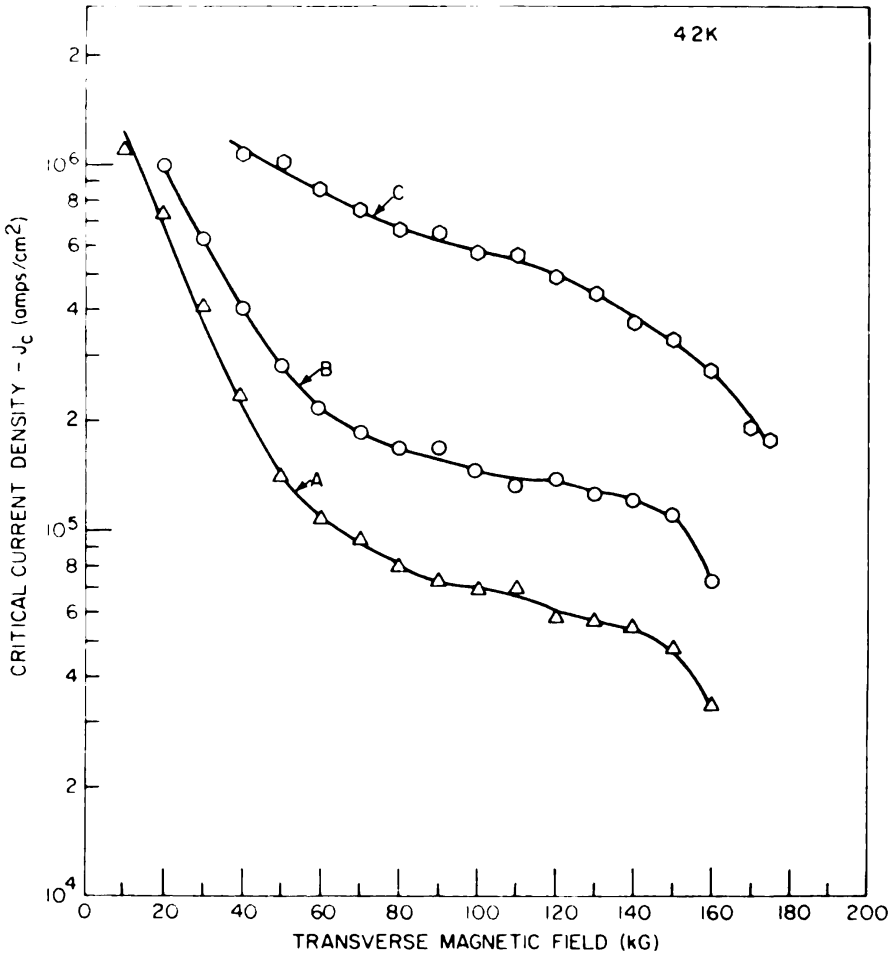

Figure 1 – Effects of alloy compositions on the J_c vs H curves for 2.3 microns of V_3Ga formed at 600°C in 0.032 in.-diam. (0.81 mm) composite wires. Curve A represents a pure V/Cu-15.4 at. % Ga wire; Curve B represents a V-6.1 at. % Ga/Cu-15.4 at. % Ga wire; Curve C represents a V-9.0 at. % Ga/Cu-17.5 at. % Ga Wire.

formed at 550°C in the V-9.0 at % Ga/Cu-17.5 at. % Ga composite system exhibited a J_c of over 1×10^6 amps/cm^2 in a transverse magnetic field of 100 kG, and remained above 4×10^5 amps/cm^2 at 170 kG. These J_c properties are at present the highest ever obtained for any superconducting material. In addition, the new NRL data (8) show that the V_3Ga composite wires have higher J_c values than above 40 kG, (see Figure 2) and that the J_c properties define the current state of the art for V_3Ga superconductors.

The superconducting composite wires developed at NRL have J_c values substantially higher than the previous state of the art as developed by Tachikawa, et al., (9) (Japan) and by Wilhelm, et al., (10) (West Germany) (see Figure 3). This accomplishment provides a nice example of DOD in-house technology adapting what had originally been developed elsewhere, modifying the techniques, and making a tremendous improvement in the superconducting properties developed elsewhere, modifying the techniques, and making a tremendous

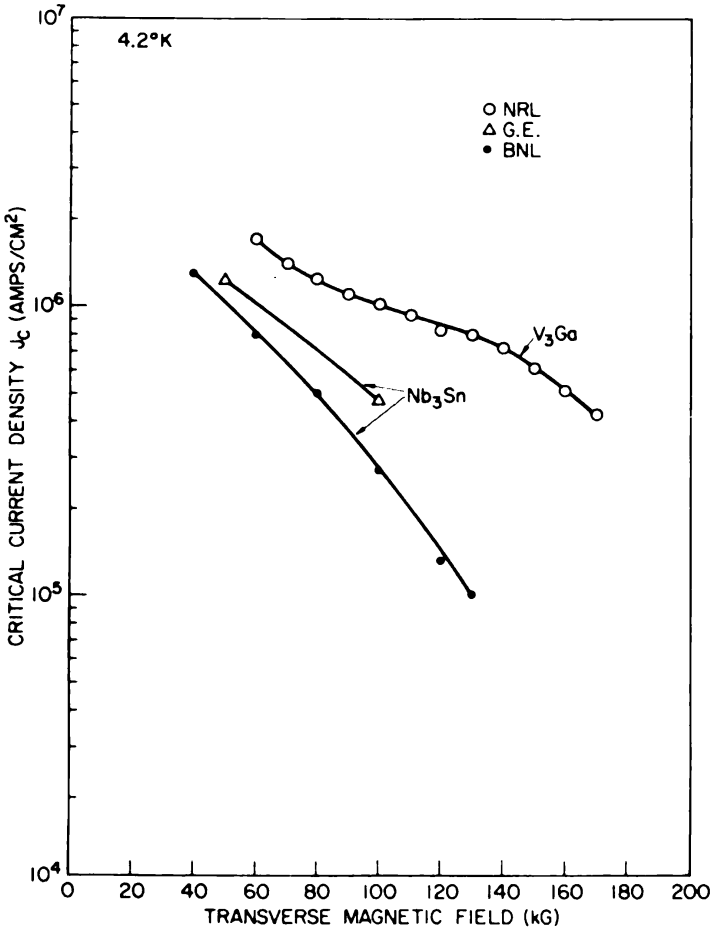

Figure 2 – Comparison of J_c vs H curves for NRL's V_3Ga and Nb_3Sn superconducting wires at 4.2°K

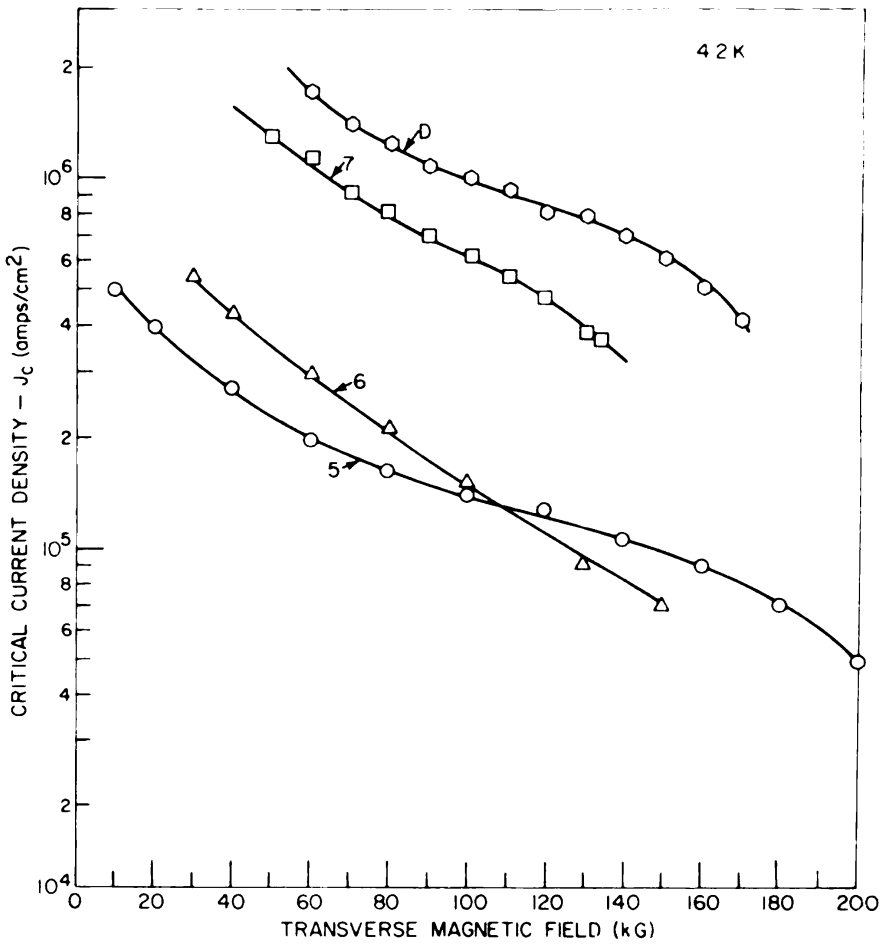

Figure 3 – State-of-the-art comparison of J_c vs H property curves for various V_3Ga composite wires. Curve D is NRL's V-9.0 at. % Ga/Cu-17.5 at. % Ga composite wire reacted at 550°C; Curve 5 is A.E.C. data (Suenaga, et al., reference 4); Curve 6 is the Japanese data (Tachikawa, et al., reference 9); and Curve 7 is the West German data (Wilhelm, et al., reference 10).

improvement in the superconducting properties developed in V_3Ga composite wires. The improved properties developed in V_3Ga could very well open the way for wide commercial use of this technology in the civilian sector as well as in the military. Moreover, this accomplishment also provides evidence to counter to a recent article (11) that was both critical of the widespread slippage of U. S. technology relative to foreign competition (particularly Japan and West Germany in the field of electronics) and to the meager "spin-offs" of technological findings by DOD and NASA to the civilian sector.

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remembering names because of their sounds shows that the "acoustic" attribute had become a part of our memory for those names; a "temporal" attribute, on the other hand, is necessary to remember the particular times certain events occurred.

One of the goals is to determine whether these different attributes function independently of each other in the overall processes of memory, or they form a few groups, or clusters, of closely interrelated attributes. This may also clarify the phenomenon of loss of memory performance we know as "forgetting." It is generally assumed that forgetfulness is caused by different memory attributes that interfere with each other.

Depending on the outcome of the research, it may one day become possible to construct a "memory-aptitude" test to determine the relationship between attributes and performance at different jobs. If it can be shown that particular attributes are necessary to certain kinds of memory functioning, a standardized memory-aptitude test could be utilized to match a particular individual to a particular job requiring basically the attributes he is well endowed with. Finally, research will explore the possibility that certain desirable memory attributes or skills may be developed or reinforced by the appropriate memory training.

The research at Northwestern will be performed in laboratory experiments with students as subjects. In order to obtain valid results, the researchers plan to develop memory experiments that reflect "working memory" – real life situations in which the demands of a job require the establishment of memories of short duration. This can be simulated by the memories formed and utilized by a person driving a car. He is continually exposed to a variety of stimuli: other cars, trucks, warning signs, pedestrians, etc. The memories established by these stimuli are vital in order to perform the job of driving safely, but are no longer important after the driving has been done. Analogous Navy situations can be found in jobs requiring short-lived memories such as that of a sonar operator, or an air traffic controller.

Hydrogen "Sponge" Storage

Saul Wolf*

Naval Underwater Systems Center

Serious attention is being given to hydrogen as fuel for the day when the cost of fossil fuels will exceed that of hydrogen. Unfortunately the quantity of hydrogen as the gas to meet this country's energy demands just does not exist. Hydrogen compounds will have to be torn apart to liberate the gas. Ideally this would require the same amount of energy as was liberated when these compounds were formed. At first glance it would appear pointless to use energy to liberate hydrogen from a compound and then react the hydrogen to obtain energy for some other use. If the Second Law of Thermodynamics still holds, there must be an overall energy degradation. And so there is.

What we're talking about, however, is money, not an energy balance. If we look upon hydrogen as a medium for storing and transmitting energy, then its competitive edge over electricity appears. Energy from an electric generating plant can be stored in hydrogen more effectively than it can in batteries, and transmitting energy as hydrogen through pipelines is more efficient than transmitting it as electricity over wire, according to the Institute of Gas Technology.

How does one go about manufacturing hydrogen gas? One usually thinks of the decomposition of water by electrolysis according to the formula

$$H_2O \rightarrow H_2 + 1/2O_2.$$

Hydrogen also can be obtained chemically as, for example, through the conversion of calcium bromide and steam to calcium hydroxide acid,

$$CaBr_2 + 2H_2O \xrightarrow{\Delta} Ca(OH)_2 + 2HBr,$$

and then using mercury to extract the hydrogen from the acid by the reaction,

$$Hg + 2HBr \longrightarrow HgBr_2 + H_2.$$

*Mr. Wolf is on the staff of the Weapons Department, Naval Underwater Systems Center. His fields of interest are propellants and energy conversion.

One means of recovering the starting materials, calcium bromide and mercury, can be illustrated by

$$Ca(OH)_2 + HgBr_2 \longrightarrow CaBr_2 + HgO + H_2O$$

$$HgO \xrightarrow{\Delta} Hg + 1/2O_2.$$

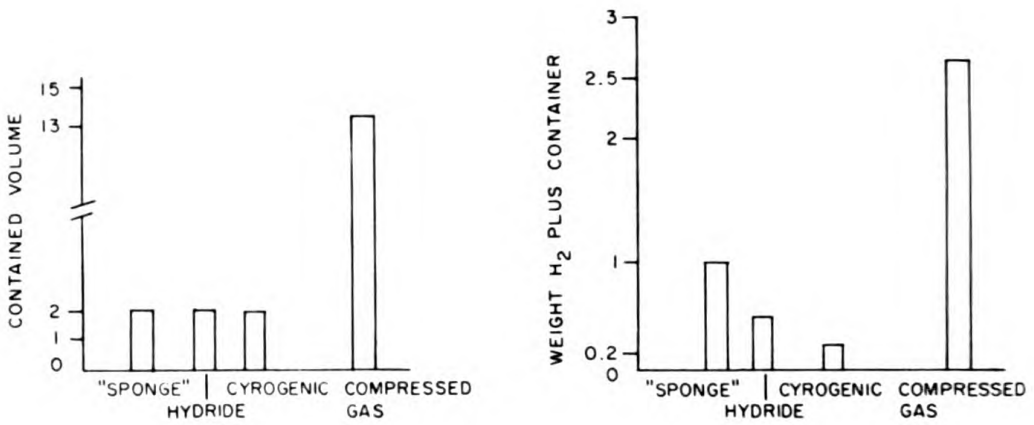
For stationary applications, hydrogen delivered by pipeline can be used on demand – burned for heating or cooling or converted to electricity in a fuel cell. For mobile applications it will have to be stored. Hydrogen can be stored as a compressed gas, as a liquid, as a hydride or absorbed on intermetallic compounds. For a given application, the method selected would depend on a balance of economic, simplicity, safety, weight and volume considerations.

Recent work by Phillips in the Netherlands with rare-earth intermetallic compounds indicated that their use as hydrogen "sponges" should be given most serious consideration since it appeared that very large amounts of hydrogen could be absorbed on these intermetallics, stored thereon at very moderate pressures and desorbed reversibly merely by allowing pressure to bleed down.

The rare-earth intermetallic compound $LaNi_5$ (Lanthanum Pentanickel) was selected for initial study at the Naval Underwater Systems Center (NUSC) as the storage medium for hydrogen for fuel cell or other energy conversion device application. Selection was based on a preliminary study, the results of which are shown in Figure 1. In-service use of cryogenic hydrogen would present severe safety and logistic problems. The compressed gas presents weight, volume and safety problems. Both the sponge and the hydride would present the fewest safety problems. While both have comparable volume requirements, the hydride is superior in terms of weight, the sponge superior in terms of system simplicity. Since underwater systems are normally volume-limited, rather than weight-limited, and simplicity is always a desired objective, the selection of $LaNi_5$ for study appeared reasonable.

$LaNi_5$ is a hard, brittle alloy with shiny, metallic plane surfaces. Its calculated density is 8.43 g/cc. When activated with hydrogen the material disintegrates into a fine grey-brown powder (Figure 2) with an apparent density of 3.85 g/cc. The distribution of $LaNi_5$ particle sizes obtained after disintegration upon activation with hydrogen is shown in Figure 3.

With no hydrogen absorbed, the difference results from the voids between the comminuted particles. Saturation with hydrogen increases the volume of each particle by 25%. In principle, then, the



STORAGE SYSTEM	"SPONGE" HYDRIDE	CYROGENIC	COMPRESSED GAS
STORAGE TEMPERATURE	AMBIENT	AMBIENT	-423° F	AMBIENT
STORAGE PRESSURE	30-45 PSI	AMBIENT	AMBIENT	2000 PSI
OPERATING TEMP	AMBIENT	530°F	-423°F	AMBIENT

"SPONGE" SYSTEM = H_2 ABSORBED IN $LaNi_5$ RARE EARTH COMPLEX
HYDRIDE SYSTEM = MAGNESIUM HYDRIDE

Figure 1 — Comparison of various hydrogen storage systems (for unit mass of hydrogen).

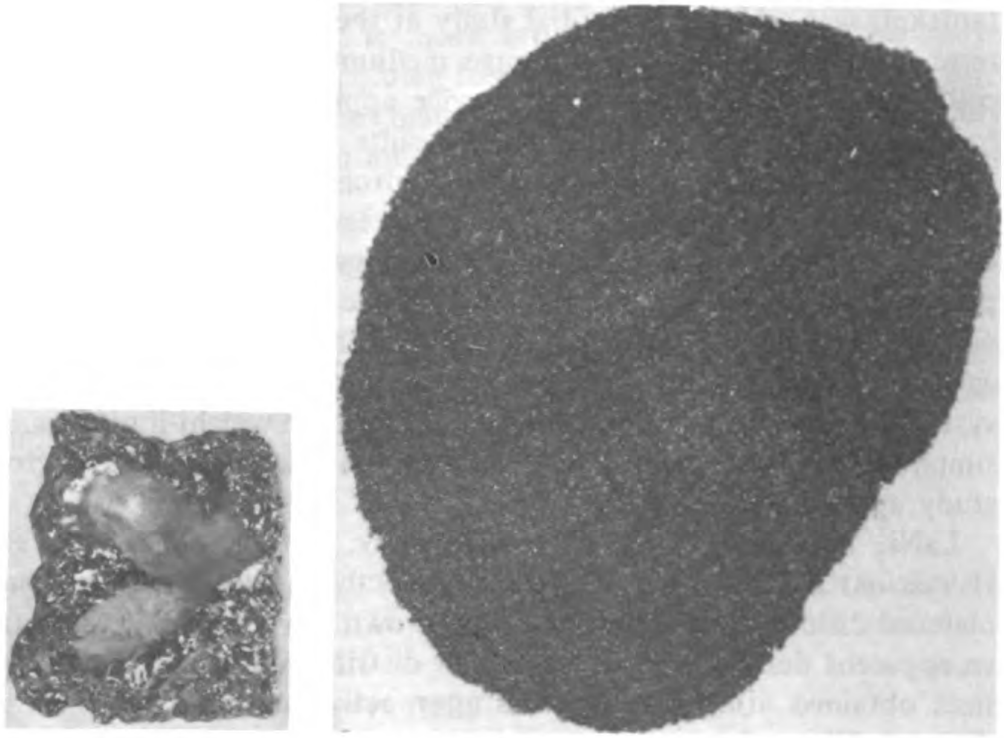


Figure 2 — Lanthanum Pentanickel: left, unactivated $LaNi_5$; right, activated $LaNi_5$.

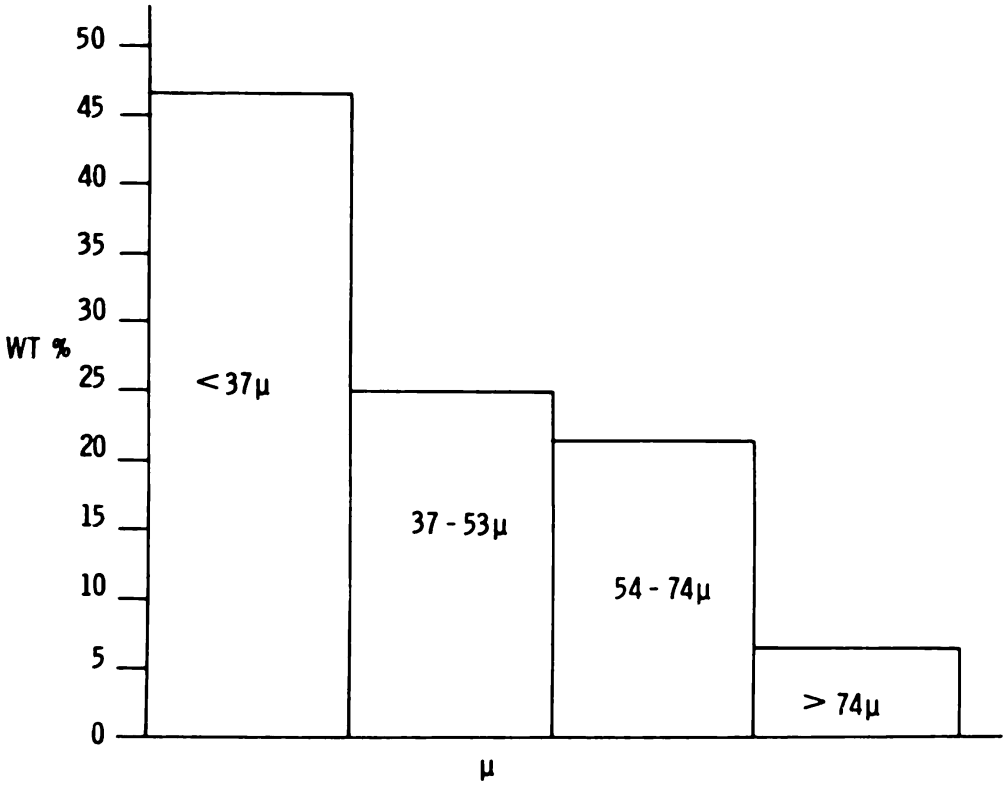


Figure 3 — Particle size distribution activated $LaNi_5$.

activated powder could be pressed to a free volume of 25% before charging with hydrogen. This would give an apparent density of 6.74 and almost halve the volume of sponge shown on Figure 1, thus making it that much more promising.

The density of hydrogen in $LaNi_5$ under 2.5 atmospheres at room temperature is theoretically 6.7 atoms per each $LaNi_5$ as shown below.

$$LaNi_5 + 3.35H_2 - LaNi_5H_{6.7}.$$

The apparatus shown schematically in Figure 4 was used at NUSC to obtain data presented below. High pressure hydrogen gas was regulated down to 5 atmospheres and allowed to flow into the pressure bomb until the "sponge" was saturated. The inlet to the pressure bomb was closed and temperature equilibrium established. The bomb outlet was then opened and the hydrogen bled out through a wet-gas meter. Constant bath temperature was maintained via a heater and thermostat. Test chamber pressure and hydrogen volume release were monitored versus time. The desorption isotherms obtained are shown in Figure 5. The total volume desorbed is independent of the

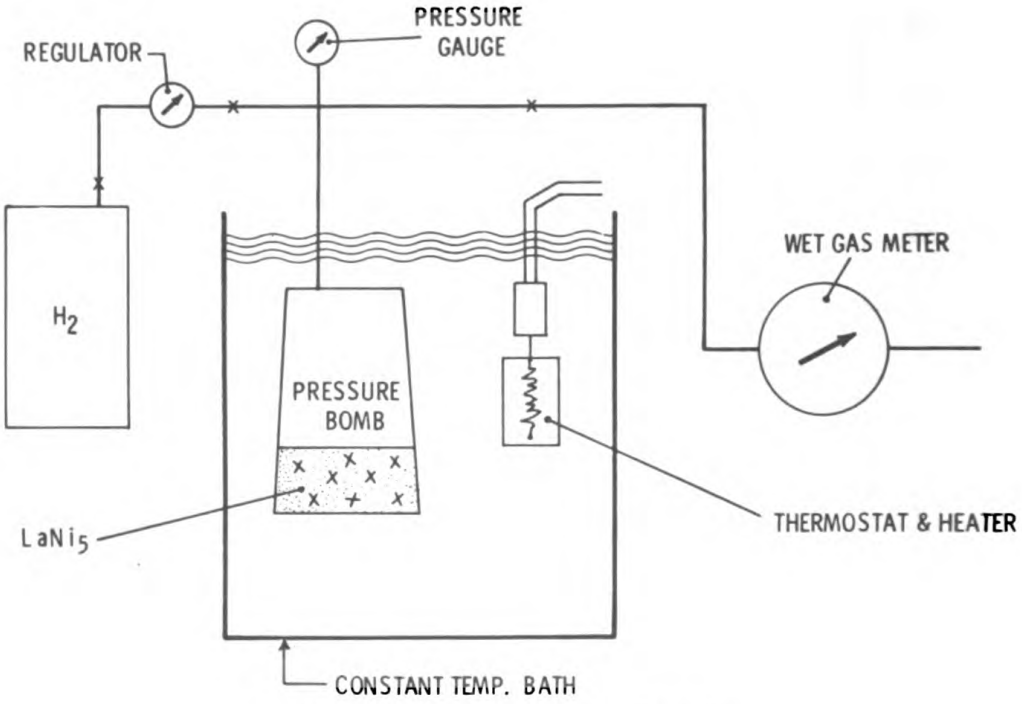


Figure 4 — Test apparatus schematic

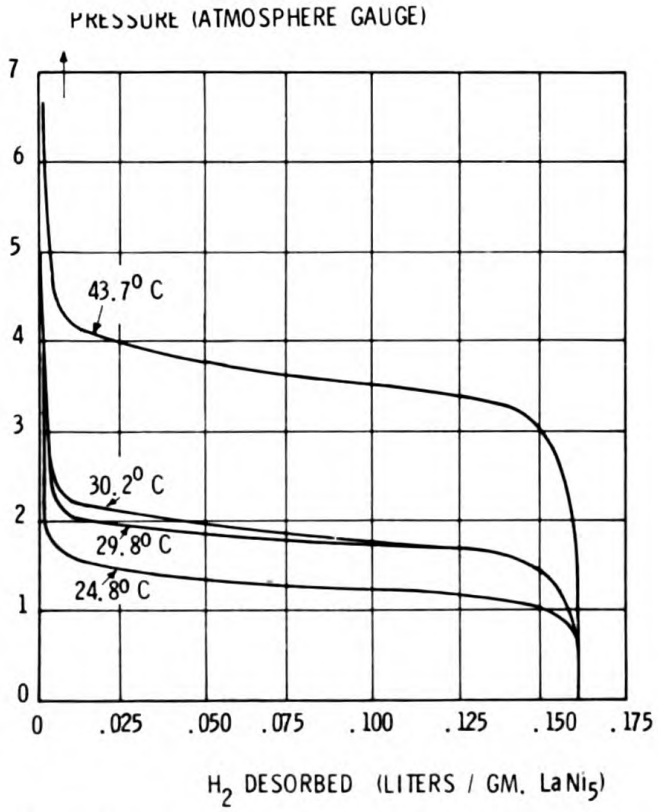


Figure 5 — System $LaNi_5$ — H_2: desorption isotherms

desorption temperature. The results obtained demonstrate the reversibility of the absorption-desorption process.

In regard to desorption rate versus temperature (Figure 6), all of the hydrogen is desorbed in minutes even at room temperature. Desorption rates are compatible with probable application (fuel cell or other long operating-time energy conversion system). A comparison of dissociation pressure versus temperature data taken at NUSC with those from Phillips shows good agreement (Figure 7).

$LaNi_5$ appears to absorb hydrogen selectively and may well be useful as a hydrogen purifier. In fuel cells, catalyst life is improved considerably by removal of impurities found in commercial grade hydrogen.

Results of the NUSC study indicate strongly the practical utility of $LaNi_5$ for storage of hydrogen for fuel cell or other energy conversion device application. Safety, weight and volume considerations favor by far sponge storage over compressed gas storage. For volume-limited applications, the sponge appears superior to the other storage means considered. For weight-limited applications, trade-off studies for the particular application would have to be made to decide between hydride and sponge. Continued research at NUSC will provide

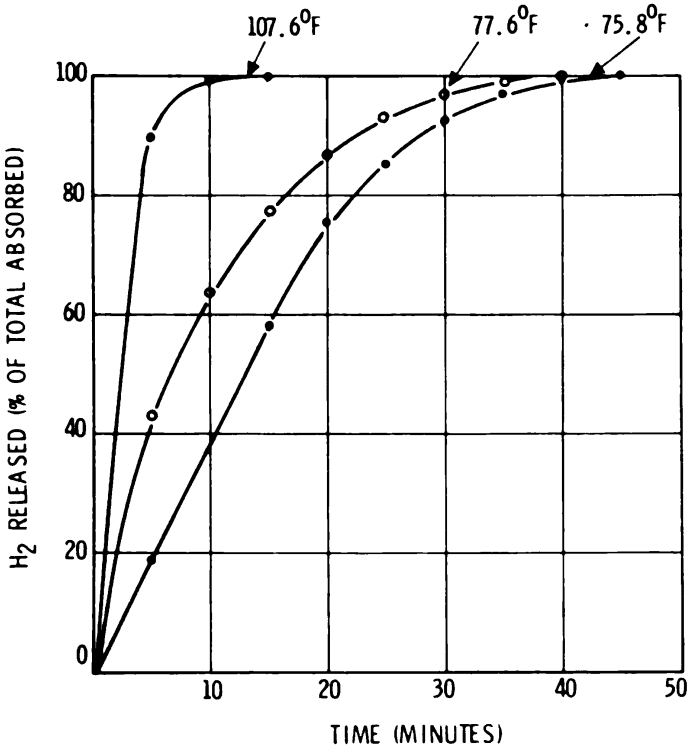


Figure 6 – System $LaNi_5$ – H_2: desorption rate vs. temperature (back pressure = 1 atm absolute)

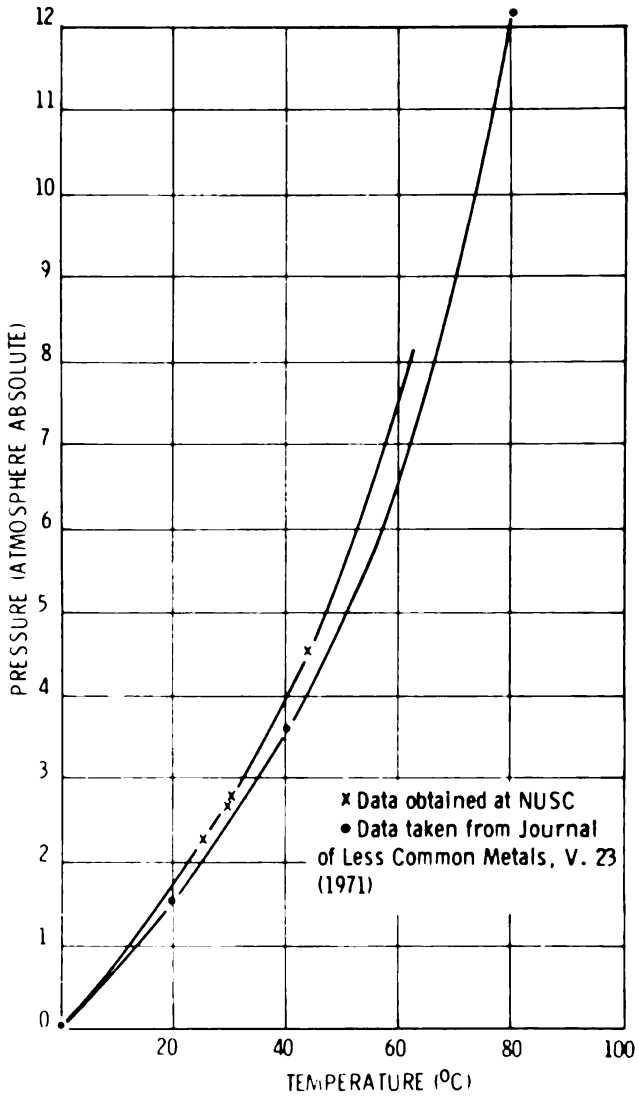


Figure 7 — Dissociation pressure vs. temperature

the data necessary for such trade-off studies and will include means for increasing the apparent density of activated $LaNi_5$ and further studies of the efficacy of the "sponge" as a hydrogen purifier.

Wideband TV for Deep Sea Probes

Naval Research Laboratory (NRL) scientists and technicians, have developed a cable television system for use with deep ocean search equipment that promises to give scientists a better real time look at the ocean's bottom.

Tests at sea have proven the TV system capable of producing vivid reception at the TV monitors aboard NRL's research vessel, the USNS MIZAR.

(Continued on Page 24)

On the Naval Research Reserve

Program to Improve Training for Reservists

The Naval Reserve recently initiated a program to improve surface ship training for Reservists drilling at inland facilities. Ship Operational Trainers (SOTs) are being installed at most of the larger Naval Reserve Centers, SOTs are mock ups of Bridge, Command Information Center, Communications, Engineering, and Damage Control Rooms. Each function is housed in its individual compartment and is interconnected through a problem-generating room. Training situations can be simulated for a large variety of situations, from navigating a narrow channel to battle problems.

The Fleet Analysis and Support Division of ONR is studying ways to best use SOTs. Under study is the plan of conducting coordinated task group exercises, similar to regular Naval exercises, in the SOTs. Control of the exercises will be from a central computer facility which will be connected to the SOTs through long distance telephone circuits. It is believed that existing Navy training simulators can be adapted for this purpose.

SOTs permit the active forces to closely work with the Reserves. For instance, an active ship at sea or at a pier could work with a remote Reserve Unit. This could help implement the new program where the Reserve Unit actively supports a particular ship or station or activity. The old concept of the Reserves was being a manpower pool to be called on when needed by the active forces.

Research Reserve Unit ONR HQ 208 of Chattanooga, Tennessee is now working with the Fleet Analysis and Support Division of the Office of Naval Research on this project.

Proposed Shipboard Sewage Treatment System

To conform to the Environmental Protection Agency's regulations on overboard descharge, a study of the possible sewage systems is underway at the Office of Naval Research. This study is being managed by the Microbiology Section and deals with the effects of the emission of treated sewage into marine waters as well as a study of several proposed treatment systems.

Last year the Naval Reserve assisted the program by reviewing the CHT system which is presently being installed in a great

many Naval vessels. This system does not discharge any sewage overboard, but it is fraught with problems relating to operational considerations and is extremely expensive. The project also includes evaluating newer systems which will overcome these problems, yet meet EPA's requirements.

Research Reserve Unit ONR HQ 208 of Chattanooga, Tennessee is now working with the Microbiology Section of ONR on the project.

R and D Symposium at Naval Reserve Association National Convention

Recently, Selected Reserve Headquarters Research Laboratory Unit 306 conducted a three hour research and development symposium at the National Naval Reserve Association Convention held at the Mayflower Hotel in Washington. The program included the following topics presented by members of the unit: Naval Research and Development, the Research Reserve, Project Dialogue, a film on the Naval Research Laboratory and a review of NRL's R and D programs. The session was followed by a general discussion. Presentations were made by the Secretary of the Navy, the Chief of Naval Operations, and other dignitaries.

(Continued from Page 22)

Prior to cable TV, investigators had to wait for films to be developed from 35 mm and 70 mm still cameras used on underwater towed vehicles. The film cameras will still be used for backup and to provide high-resolution records.

The video equipment differs from other long-cable (6,000 meters) systems previously used in deep ocean research in that the television signals are heterodyned into the 0.5-4.25 megahertz band in order to eliminate interference encountered with existing search system telemetry without incurring the very large cable losses present at higher frequencies.

The heterodyne method is unusual because the 3.75 MHz bandwidth is of the same order of magnitude as the 4.25 carrier frequency.

While the video telemetry equipment has been designed for deep water transmissions, it can also be used with other types of equipment which require wide signal bandwidth.

Ten years ago scientists developed a unique, towed, deep sea research vehicle (on which the new TV system will be mounted) for NRL's research vessel, MIZAR. The vehicle, which was dubbed the "Fish," can be lowered through a centerwell on the MIZAR to depths of over 20,000 feet for ocean bottom studies.

Research Notes

Study on Improved Method of Treating Burns Supported by Navy

Research on a means of treating serious burns that appears to speed recovery, relieve pain, and greatly diminish or eliminate scarring and need for skin grafts is being supported by the Navy. The work is underway at Moraga Medical Laboratories, San Diego, under the direction of Dr. Michael J. Saliba, Jr.

The technique under study uses heparin, well known as a powerful anticoagulant, to augment conventional burn treatment. Reference to the dramatic success achieved by Dr. Saliba was made by Rear Admiral M. D. Van Orden, Chief of Naval Research, during an address delivered in January of this year at a Navy medical conference in San Diego.

Prior to receiving support from the Office of Naval Research, Dr. Saliba in preliminary tests showed that large doses of heparin can produce cures of second- and third-degree burns in humans even when as much as 60 percent of the body has been covered by the burn. Although the anticoagulant or free-flowing blood effect of heparin poses the threat of hemorrhage, this has not occurred in more than 250 cases treated by Dr. Saliba. Dr. Saliba believes that the remarkable results achieved by heparin stem from the increased blood flow caused by the anticoagulant and other properties of heparin.

The effectiveness of heparin in burn therapy was first noted by researchers as early as 1949 in animal studies. However, it was not found to work on humans. Dr. Saliba theorized that this was because only small doses were used, and this led him to begin his own experiments with massive doses of heparin to treat burns.

The results of this work were published in the *Journal of the American Medical Association* for July 16, 1973. Heparin, given intravenously, consistently relieved general burn pain. Heparin injected topically into burn blisters relieved local blister pain. When applied topically to denuded burn areas, it largely or completely relieved local burn-surface pain. There was also no local burn-tissue swelling and no general body swelling. No respiratory problems were encountered.

None of the patients treated with heparin, including those with third-degree burns, required skin grafts, which are normally needed to repair burn-damaged areas of the body. In one case, skin was grafted on a portion of a third-degree burn to shorten the healing time, but similar third-degree burns on the same patient healed without grafts. In none of the cases were there any contractures nor was there any limitation or impairment of the movement of hands, fingers, knees, ankles or feet. Scarring was also absent from all patients receiving heparin, and the new skin growth was uniformly of high quality, full thickness, smooth, pliable and comfortable.

In conventional treatment of burns, physicians wait at least 24 hours to determine the burn extent and depth because the damaged area increases in size

after the injury. Heparin therapy, however, was started immediately, and the initial burn area proved to be the maximum size. Burns progressively became smaller and healed; and there was no noticeable extension in depth.

Heparin applied to burn surfaces was found to be safe and effective when used throughout the entire healing period. Injection of heparin into the vein, however, was limited to the first three days to avoid a possible hemorrhage resulting from the use of the anticoagulant. As a precaution, the clotting factor was checked regularly so treatment could be immediately terminated if a danger point was approached. Heparin cannot be used in burns accompanied by bleeding due to trauma, in patients known to have bleeding problems, and in active ulcer patients.

Further experiments on the efficacy of heparin in treating burns are being conducted by the Moraga Medical Laboratories under a contract with the Office of Naval Research. Work on the biochemical properties of heparin as related to burn therapy is being sponsored by ONR elsewhere.

Multipurpose, Real-Time Holographic Polariscope

Naval Research Laboratory scientists have modified a real-time holographic interferometer, which permits the observation of a complete set of interference patterns from a single reference hologram.

The apparatus consists of a conventional off-axis transmission holographic setup, with the addition of several polarization optical elements to alter the polarization of the light at various stages of a procedure to study an object.

These elements are adjusted to produce circularly polarized light for recording the reference hologram. After producing the hologram, these elements are readjusted to any desired state of polarization; and the corresponding interference pattern is observed in real-time and may be changed at any time to view a different type of interference pattern.

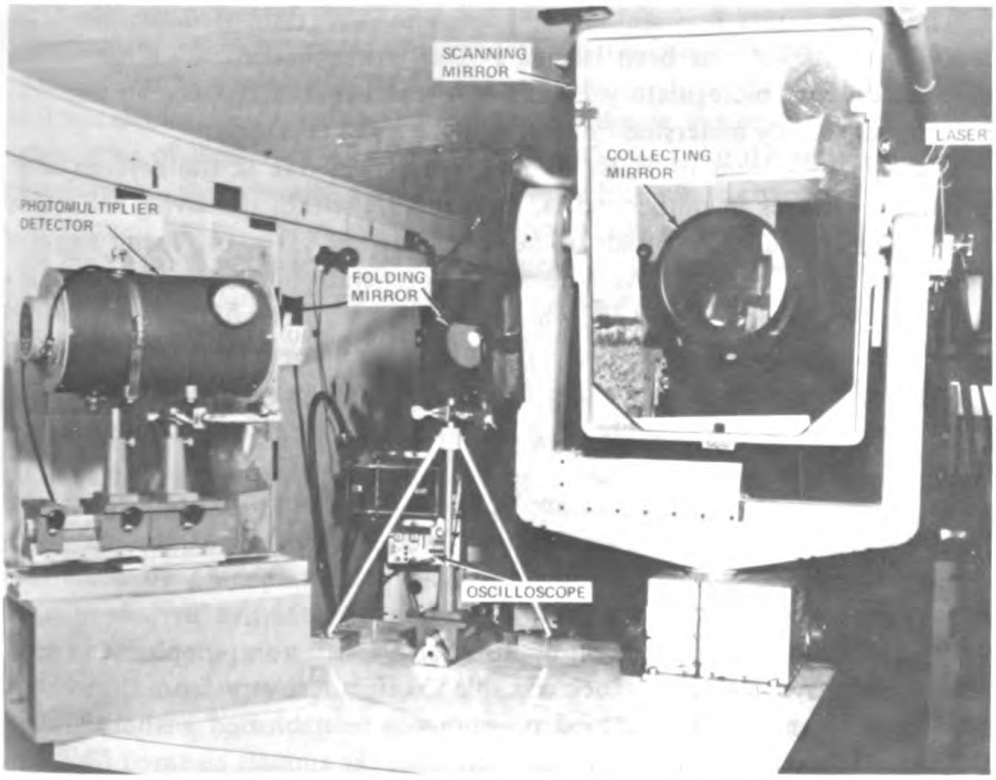
Laser System Promises New Applications

A team of optical scientists from the Naval Research Laboratory (NRL) recently completed some sea surface measurements with a laser/receiver system that have had a significant impact on a number of Navy programs and that may have more widespread marine applications as well.

Possible marine applications for the new measurement technique, could include the detection and location of surface wave changes caused by oil spills, the remote sensing of sea state conditions, direction-finding and ranging on navigational aids and obstacles, and oceanographic studies of air/sea interaction.

The measurements, made by G. L. Stamm and L. A. Harris of NRL's Optical Sciences Division, were of the sea's scattering characteristics to a beam of 1.06-micrometer-wavelength laser radiation incident on the water at grazing angles.

Results showed the strength of scattered sea echoes and their variations with sea surface roughness conditions. This work differed from previous measurements of others insofar as they were made at grazing angles.



A laser transceiver scanning array used in measuring sea echoes. Receiver views the same area of water surface illuminated by the laser.

The equipment used was a Q-switched Neodymium:YAG laser (with an energy of 0.1 Joule/pulse, a 20-nanosecond pulse duration, and a 3-milliradian beamwidth) and a receiver consisting of several mirrors, optical filters, a photomultiplier detector, and associated processing and display electronics. The system was made mobile by installation in a trailer.

With the increased use of electro-optical and laser systems in the Navy in recent years, there has arisen a need for more information on the optical characteristics of the marine environment in which the systems could be used.

New Drug Developed With Potential of Protecting Against Heart, Brain Damage

A powerful new drug that has the potential of enhancing the survival of mammals suffering lethal heart and brain damage has been developed by a Navy scientist, Dr. B. D. Polis, a biochemist at the Naval Air Development Center, Warminster, Pennsylvania. Tests have been conducted on monkeys in which the drug restored their heart action and blood pressure after prolonged and repeated episodes of fibrillation following myocardial infarction. The Office of Naval Research plans further studies intended to determine the suitability, effectiveness and safety of the drug for human use.

The drug, which is essentially a polymeric, free radical derivative of the prostaglandin PGBl, has been labeled PGBx. Postaglandins are a recently discovered class of bioregulatory compounds that apparently play an important but not completely understood role in extreme stress or shock.

One of the actions of PGBx discovered by Dr. Polis is the reversal of degenerative changes in mitochondria, the structure within the living cell responsible for the production of adenosine triphosphate (ATP), the major source of useful biological energy. As a result of degenerate mitochondria, there is a reduction in the supply of ATP, which is necessary for such essential life functions as muscle contraction, protein synthesis, and nerve activity. By reactivating the degenerate mitochondria so that they resume their normal function, PGBx restores the vital supply of ATP. PGBx has no effect on normal intact mitochondria.

In a preliminary attempt to apply PGBx, Dr. Polis, in conjunction with Dr. E. T. Angelakos, Hahneman Medical College, Philadelphia, and colleagues, conducted experiments with primates, which were subjected to acute heart attacks produced by coronary ligation, leading to successive periods of ventricular fibrillation. Administration of PGBx along with norepinephrine (a strong heart stimulant) and electric shock was able to effect recovery from the extended fibrillation in that effective blood pressure was reestablished without artificial support. This recovery was achieved even after the animals endured fibrillation for as long as 24 minutes, long after norepinephrine and electric shock had no effect on the control animals. This result suggests a possible use for PGBx in heart surgery as well as treatment of myocardial infarctions.

Failure of circulation as a result of fibrillation can cause brain damage through lack of oxygen. Even with the resumption of normal heart action, fatal damage is likely to occur in the brain if fibrillation persists for a sufficient length of time. In the experiments, however, after as much as eight minutes of fibrillation the electroencephalograph (EEG) record showed that electrical activity in the brain was restored to a substantially greater degree in animals treated with PGBx than in the controls.

Accordingly there is hope that PGBx might be useful in treating battle casualties suffering shock as well as victims of surgical shock. Experience has shown that even when a patient who has had a heavy loss of blood is given massive blood transfusions in a short time, thereby presumably resupplying the necessary oxygen to the brain, the individual frequently goes into irreversible shock and dies. Such shock conditions may respond to PGBx.

There is additional speculation that PGBx has the potential of protecting pilots against acceleration stress. Such an eventuality would permit a significant gain in conscious performance in high performance aircraft. Another possible application is enhancing the survival of personnel in an oxygen-deprived environment, such as a disabled submarine.

The new research program planned to be supported by the Office of Naval Research will be a combination of synthetic organic chemistry, physical biochemistry, physiology and pharmacology that will have the goal of making PGBx available for clinical testing as soon as possible.

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Computer Program to Calculate Laser Propagation

Optical scientists at the Naval Research Laboratory report progress in the development of a computer program to self-consistently calculate the steady-state thermal blooming of a focused laser beam.

The calculation is accomplished in a coordinate system which follows the trajectories of light rays of a beam which is Gaussian at the entrance aperture. Furthermore, the complex amplitude is altered by a phase change which removes the vacuum beam radian phase oscillation. Thus, what are actually calculated are the phase changes due to the nonlinear heating of the absorbing medium.

Thermal blooming occurs when an intense laser beam propagates through a gas or liquid; the absorption of energy leads to a density decrease and, hence, an index of refraction decrease in the region occupied by the beam. This in turn leads to spreading of the beam with time, as the light rays seek regions of higher index. When such action occurs the beam is said to be "thermally bloomed." If there is a convective mechanism (e.g., wind) to remove the heated fluid, a steady state evolves in which the beam attains a characteristic crescent-shaped irradiance distribution.

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Cover Caption

The 300 horsepower superconducting motor being built and tested at the Naval Ship Research and Development Center at Annapolis.

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