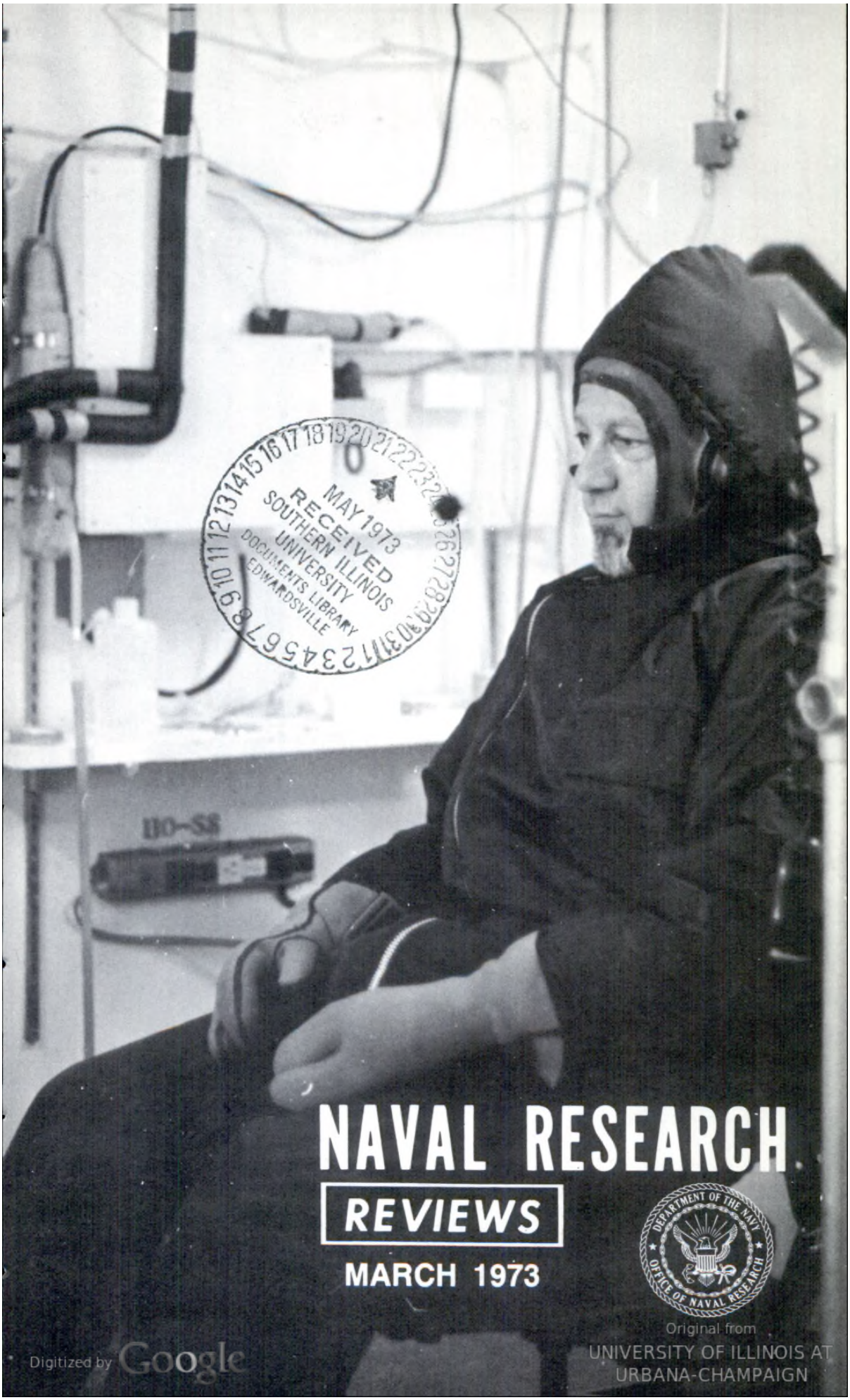
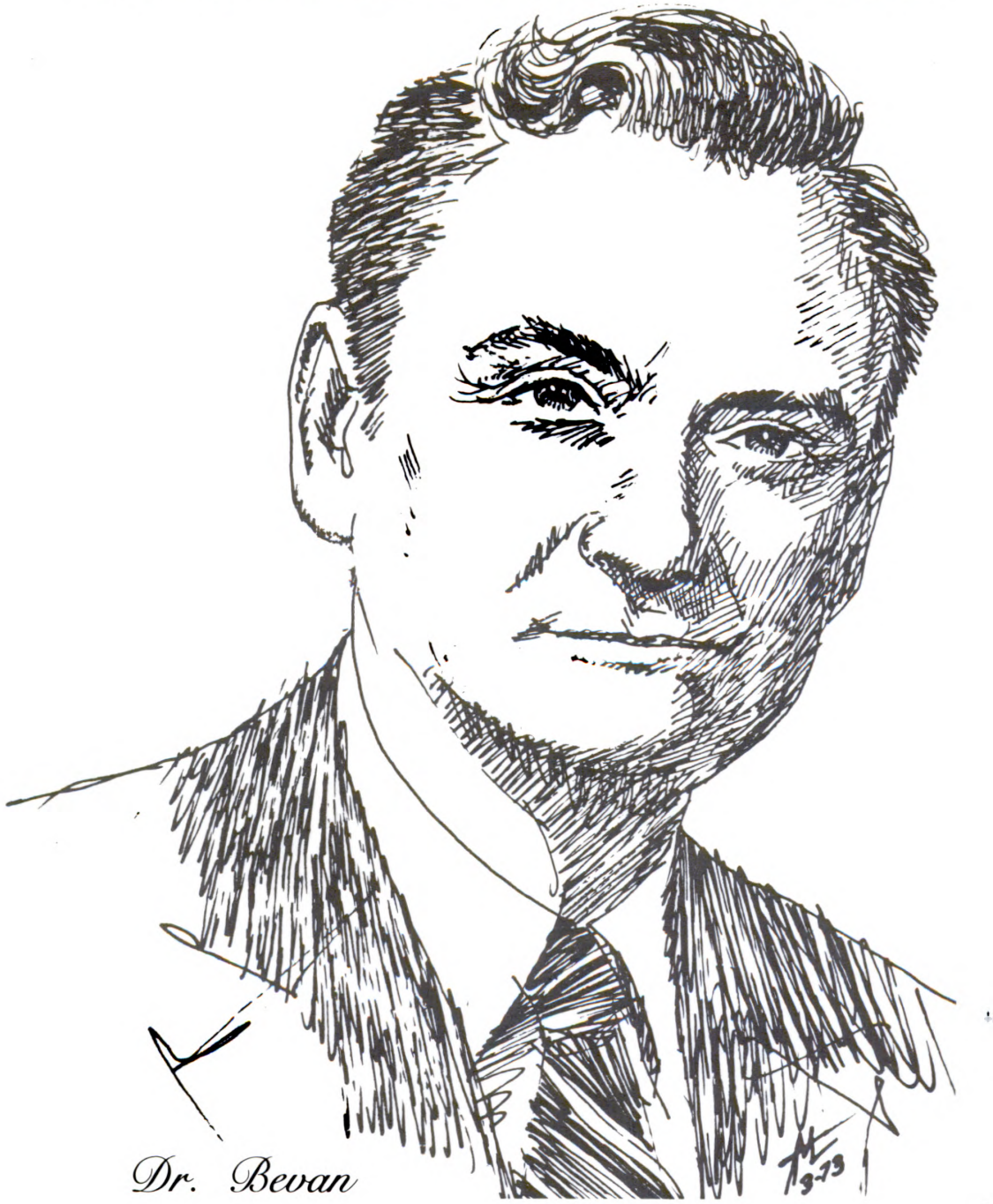


PROFILES IN SCIENCE



Dr. Bevan

Dr. Bevan's contributions to psychology are widely recognized. His emphasis on the cognitive aspects of perception have greatly influenced those experimenting in the areas of visual search, vigilance behavior, and human engineering. Remarkably, Dr. Bevan has continued his research production while assuming increasingly heavy administrative responsibilities. Having served as department head, dean, vice president for academic affairs, and then provost at major universities, he currently divides his time between his laboratory at the Johns Hopkins University and the executive office of the American Association for the Advancement of Science.

The Thermal Drain of Comfortable Hyperbaric Environments

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There is growing evidence that men living in hyperbaric conditions, whether in laboratory chambers or in saturation dives at sea, are under thermal stress like that of cold exposure, even though the temperature is in the "normal" range. An analysis I made two years ago pointed speculatively in that direction, but since then several studies have supported the idea that living in hyperbaric environments presents a considerable thermal drain. One of these was a 5-day saturation dive in a habitat at 516 ft (16.6 Ata) in warm Hawaiian waters, which turned out to be distressingly cold for the divers. Another was a 1200-foot (37 Ata) saturation dive in the hyperbaric chamber at the Institute of Environmental Medicine, University of Pennsylvania, where I helped in studying the thermal aspects of the environment. At the Fifth Symposium on Underwater Physiology at Freeport, Bahamas, in August 1972, Terry Moore and coworkers described a chamber dive in Hawaii where the habitat pressure was 16.1 Ata, but the gas temperature was kept up to the recommended level for comfort; and at about the same time the proceedings of the 1970 conference on hyperbaric and underwater physiology in Marseilles appeared, which contained a report on experiences in the German habitat Helgoland operated in the cold North Sea. Both of these exposures added to the evidence of thermal or metabolic stress. The Office of Naval Research has been supporting the author's work for several years.

The ocean saturation dive at 16.6 Ata at the Makai Undersea Test Range, Hawaii, was characterized by Jon Pegg, the medical officer, as producing divers who were almost continually cold and whose behavior was that of individuals under stress. The habitat temperatures were between 22 and 25 C, and the water temperature outside between 19 and 21 C. The 22 KW of heat available could not raise the habitat temperature higher. Contributing to the cold and discomfort was the failure of the hot water shower used for rewarming following a dive. At night sleeping was interrupted by shivering despite heavy covers. The divers estimated that they could have spent three times as much time outside

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if they had been able to rewarm adequately. Forty-five excursion dives were made, with an average length of about half an hour. Because it was impossible to rewarm, the divers could not comfortably make a second dive in the same day. As one expression of the cold stress, despite eating foods as desired, the divers lost an average of 2.9 kg (over 6 lbs) in weight, which Pegg felt should be attributed to increased metabolism due to excessive heat loss. This account of a saturation dive in the relatively warm waters off Hawaii emphasized two major points about living in hyperbaric environments. The first was that thermal comfort requires a higher-than-normal gas temperature, and the second was that men can apparently adjust to a steady thermal drain by increasing metabolic level, which causes weight loss.

Actually, cold is not felt in most saturation dives because the divers have gas temperatures of their choice, and they avoid feeling either cool or warm for the long days and nights of confinement. Chamber experiments have shown that hyperbaric gas must be kept quite warm.

Let us examine the comfort question more closely. When lightly clothed men are confined in a hyperbaric chamber of undersea habitat and allowed to choose the temperature in which they feel comfortable for days of exposure, the higher the pressure is the higher the comfort temperature must be, and the narrower the temperature band. Figure 1 shows this effect graphically. The scale of "convective character" is a device to arrange hyperbaric gas mixtures and other immersion fluids in a consistent manner. The density (in grams per liter) times the specific heat (in cal/gm-°C), times the thermal conductivity (in cal/min-Cm-°C) is divided by viscosity (in centipoises). Then this number is related to the number for air at 1 Ata, which is 0.61. In this scale of convective character, air becomes 1 and water becomes 167. In the 1200-foot saturation dive at the University of Pennsylvania, the four subjects who spent six days at this pressure chose a temperature between 32.5 and 33.5 C, and the convective character of that environment was 144. This new point would fall within the temperature range shown on the figure. Moore and his collaborators would agree, since their comfort temperature was 29 C for heliox at 16.1 Ata, and Pierre Varene and his coworkers in France have similar data for several pressures. Table 1 summarizes these observations.

Convective transfer increases remarkably with pressure, and the skin temperature is much closer to gas temperature than one observes for men in air. In the 1200-foot dive at the University of Pennsylvania, for example, the gradient between skin temperature and gas temperature was only about 2°C. Nevertheless, in these environments heat transfer from the skin to the environment is predominantly convective. In my previous analysis, it looked as though a fluid with a convective character of about 120 would cause a heat loss of 100 kcal/hr, approximately the normal

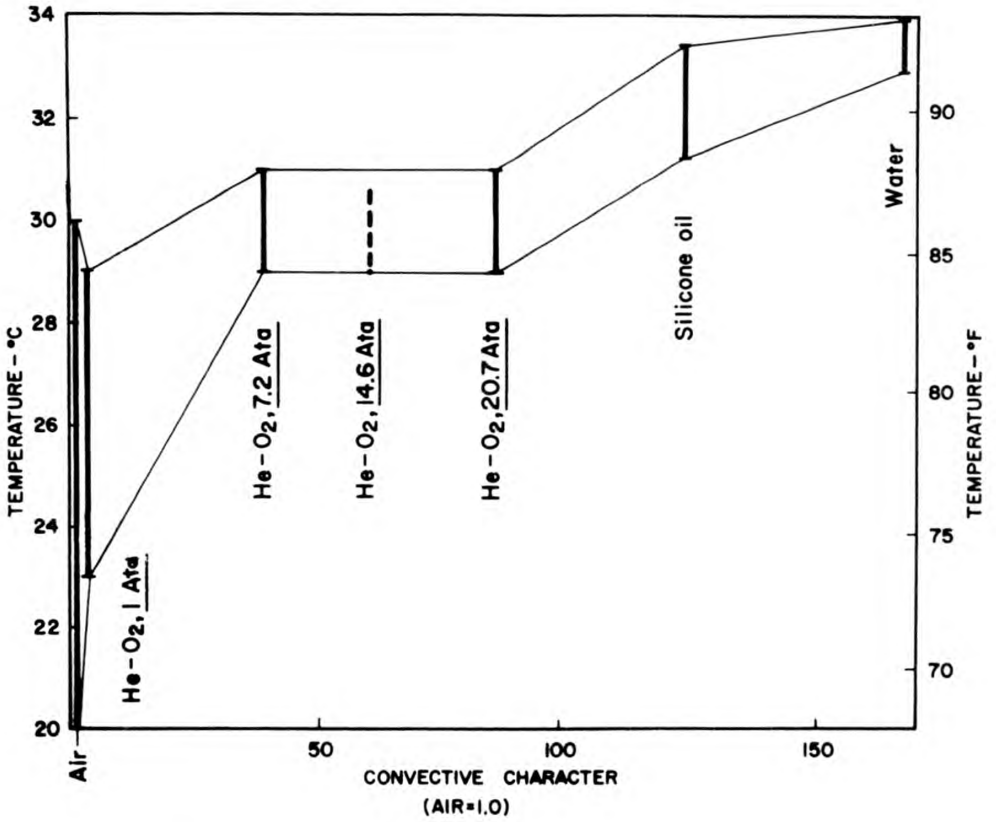

Figure 1 – Comfortable temperatures for prolonged stay in various fluids by men lightly dressed and mildly active. Based on data of Epperson, et al; Hamilton, et al; Hock, et al; Raymond et al; and Webb and Annis.

resting metabolism, despite the small temperature gradient. It that data can be extrapolated, the suggestion is that with fluids which are more convective – for example, the helioxygen at 1200 feet – convective drain would be higher than the resting metabolism despite the presence of a thermally comfortable gas temperature.

Let me describe the environment we observed in the 1200-foot saturation dive. At this pressure of 37 Ata, the temperature of the walls and various structures inside the chamber was virtually equal to gas temperature. The velocity of gas motion at several locations in the chamber was so low as to be undetectable using a wind vane anemometer. Significant gas motion was measurable only at the intake and discharge of the blower which circulated gas to the CO_2 scrubber. One could even see with the naked eye the leisurely gas motion and lethargic gaseous diffusion; when a different gas from that in the chamber – for example, a breathing mixture containing neon or nitrogen – spilled from a mask being held by a subject, the new gas with a different refractive index from that of helium could be seen falling slowly toward the floor, rather than immediately mixing and diffusing as one expects at lower

TABLE 1
Comfort Temperatures for
Normoxic Helium-Oxygen Mixtures
as a Function of Pressure

Gas Pressure Ata	Gas Temperature °C
1.5	28.7
2.3	29.6
4.4	30.0
8.4	30.7
13.1	28.5-31.5
16.1	29.0-31.8
22.2	29.0-31.5
28.3	30.0-32.0
30.8	32.4
37.4	32.5-33.5

pressures. We attempted to describe the evaporative character of the gas by measurements with a resistance hygrometer, with a wet bulb-dry bulb thermistory pair, and with a dewpoint hygrometer. All agreed that the humidity was high, probably above 90% saturation, despite the fact that dry gases were being added throughout the day and night and the fact that there were no large water surfaces or wet equipment in the chamber. We also observed the rate of weight loss of an open Petri dish and noted that it evaporated some 5 to 10 times more slowly than the same Petri dish would in air at 1 Ata. Low gas velocity and low diffusivity in a hyperbaric gas would explain the poor evaporative rate and the sense of high humidity which our subjects and those in similar dives report. In summary, the hyperbaric gaseous environment was warm, transferred heat well, did not move or mix easily, and prevented evaporative cooling on the skin.

The most direct evidence of an increased metabolic heat production is an increase in oxygen consumption. Such measurements have been made in four saturation dives in chambers, but while a small increase is consistently reported, it has not been enough to show that there is a significant rise in metabolism. However, these measurements have all been for brief 3 or 5 minute periods. What is needed is long term monitoring—preferably for 24 hours a day. Such data we do not have yet.

The most tangible evidence of thermal drain is the body weight loss observed in men who live in hyperbaric environments. Table 2 shows body weight losses from four saturation dives in laboratory chambers and four saturation dives in the sea. All dives were conducted in comfortable temperatures except for Aegir and Helgoland, both of which involved some exposure to cold. From the table it is evident that the higher the pressure and the longer the dive the greater the weight loss. The Aegir and Helgoland experiments are somewhat out of order in this sequence, but their higher weight loss for the pressure and duration shown can be ascribed to the increased heat drain of the cold environment. The table also shows what was known about food intake. Where estimates were made, the dietary consumption was generous. During the University of Pennsylvania 1200-foot dive, a serious effort was made to count calories, and the average level of 3510 per man per day should have prevented weight loss in young men who were cooped up in the small space of a hyperbaric chamber.

There is a bit of biochemical evidence that suggests increased metabolism in hyperbaric helium. In saturation dives in U.S. Navy chambers at San Diego and at the Experimental Diving Unit in Washington, D.C., a reduction of the level of blood glucose during saturation dives was reported, along with an increase in serum lactic acid and a decrease in serum free fatty acids. Such changes in blood chemistry are consistent with an increased carbohydrate metabolsim.

One additional curious observation may be part of this picture of increased metabolic activity. The body temperature, measured either in the rectum or by mouth, was reportedly about 1°C higher than normal during the Tektite and Sealab II experiments. In the 1971 University of Pennsylvania dive to 1200 feet, early morning rectal temperatures were found to be consistently elevated in all four subjects. However, midday rectal temperatures were not higher than expected. In fact, when two of the subjects exercised rather vigorously for 30 minutes, their rectal temperatures did not rise, suggesting that the increased heat production of exercise was rapidly drained in the highly convective environment. If the early morning rectal temperatures are high, then perhaps this indicates a higher-than-normal level of metabolism during the night. Further, as a guess, it may be that the usual diurnal variation of body temperature does not occur if the hyperbaric environment drives metabolic heat production to a constant, slightly high level.

Such are the lines of evidence to indicate that subjectively comfortable hyperbaric environments represent a thermal drain. That drain is met by an increased metabolic heat production in order to maintain body temperature. Despite high levels of food intake, men are not in caloric

TABLE 2
Body Weight Loss in Several Hyperbaric Saturation Dives

	Gaseous Environments	Mean Weight Loss (kg)	Food Intake (kcal/day)	No. of Subjects	Duration	
					At Depth (days)	Total Dive (days)
Tektite I (Caribbean)	Air-2.15 Ata	1.6	"adequate"	4	60	
Helgoland (North Sea)	Air-3.3 Ata	3-5	6000	9	10	
Genesis E (dry)	HeO_2-7 Ata	0.6	4200	3	12	
U. of Hawaii (dry)	HeO_2-16.1 Ata	0.6	> 4000	6	2	9
Sealab II (Bermuda)	HeN_2O_2-7.2 Ata	2	> 4000 (est)	28	15	
Aegir (Hawaii)	HeO_2-16.6 Ata	2.9	as desired	6	6	14
USN-EDU (dry)	HeO_2-19.2 Ata	1.2	as desired	7	8	16
U. of Penna. (dry)	HeO_2-37 Ata	4	3510	4	6	21

balance and they lose weight. Definitive experiments are needed to establish the actual pathway or pathways of increased heat loss, the magnitude of the metabolic response, and the physiological nature of what appears to be a real nonshivering thermogenesis in man.

Finally, we might consider the implications of the persistent loss of body weight observed in men who are apparently unwilling to eat enough food to meet their caloric requirements. Let us assume that the men in the 1200-foot saturation dive at the University of Pennsylvania needed approximately 3000 kcal/day to maintain their weight in the confined space of the chamber in the gas had been air at 1 Ata. Judging from the weight they lost in the 37 Ata heliox environment, they had a caloric deficit of about 1500 kcal/day; in other words, they should have been eating about 4500 kcals per day instead of the 3500 they actually consumed. If this had been an ocean dive, one would have to allow for the caloric demands of the exercise of excursion diving and possible extra heat loss in cold water, and the caloric need might well have risen to 6000 kcal/day—an amount that the divers in the German Helgoland habitat managed to consume. Such intakes are not unheard of for lumberjacks, who work hard and regularly consume such quantities, but with the exception of the divers in the Helgoland project men in undersea shelters have shown no desire to eat this heavily. In actual diving, a way must be found to supply such quantities and to encourage men to eat them, especially as saturation dives become longer. The weight loss is not necessarily bad for men who carry excessive body fat, but it could be a problem for thin men who need the insulation of subcutaneous fat for protection when diving in cold water. Supplying adequate nourishment to divers could become an increasing problem as the depth and duration of saturation dives continues to increase.

Navy Research Supports Auto, Aircraft Safety

Scientists at the Naval Research Laboratory (NRL) report that results of their studies of Navy problems have had side benefits in aircraft and automobile safety.

NRL recently gave its data on radar cross sections of aircraft to the aircraft industry, where it is being used to evaluate the effectiveness of radar controlled systems intended to precent mid-air collisions. Infomation on the relative strengths of radar reflections from different kinds of aircraft, such as is contained in the NRL data, is important in designing collision avoidance systems for commercial aircraft.

(Continued on Page 30)

Chronic Heartburn: Causes and Remedies

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At the junction of esophagus and stomach there exists a smooth muscle sphincteric mechanism which forms the functional pressure barrier normally preventing reflux of highly acid gastric material into the esophagus. This gastroesophageal sphincter is illustrated schematically in Figure 1. Clinical research on the mechanisms controlling the action of this sphincter and its incompetence in patients with gastroesophageal reflux has been in progress for the past three years at the Naval Hospital Philadelphia under the support of Bureau of Medicine and Surgery. These studies were initially undertaken because of the high incidence of symptomatic reflux in military personnel, and the frequent resulting loss of time from duty secondary to this problem.

The gastrointestinal hormone gastrin has been well established as a primary factor in stimulating acid secretion by the stomach. Gastrin has also been identified as important in the control of pressure in the gastroesophageal sphincter. Teleologically, it seems quite reasonable that this hormone secreted by the stomach should regulate sphincter closure and thereby maintain an effective barrier against acid reflex in the esophagus (1). Increase in sphincter pressure should occur concomitantly with gastrin stimulation of acid output (Figure 1).

These studies were quickly followed by the observation that this sphincteric mechanism could be strengthened by the administration of alkalinizing agents of various kinds into the stomach (2). Thus, not only sodium biocarbonate and sodium hydroxyide but also commercial antacid agents, the mainstay of therapy for patients with gastroesophageal reflux, were shown to increase pressure in this sphincteric barrier. The studies were initially performed in normal volunteers, but subsequently pursued in a group of patients with symptomatic incompetence of this sphincter having the clinical hallmark of this abnormality, chronic heartburn. In the latter, the administration of usual clinical doses of antacids produced considerable increases in the sphincter pressure, so that the effective pressure was elevated from a low or incompetent level to a level similar to that found in the resting normal subject. These results indicated that

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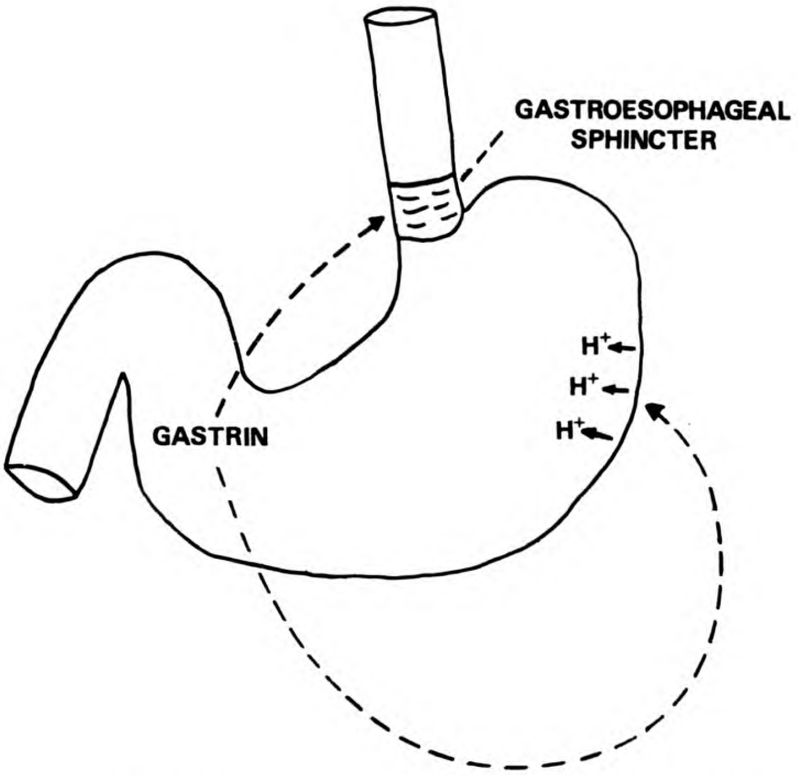

Figure 1 — Schematic representation of the relationship of the hormone gastrin to hydrogen ion concentration and gastroesophageal sphincter pressure.

the therapy of the heartburn patient with frequent alkalinization had a dual rationale, not only the neutralization of the acid gastric contents but also the strengthening of the gastroesophageal sphincter pressure barrier.

Because of the common problem of heartburn being produced by certain specific foods, smoking, and possibly also by coffee ingestion, a series of investigations was undertaken to clarify the mechanism for these observations. LCDR Otto T. Nevel, MC USN working in the Gastrointestinal Laboratory at the Naval Hospital Philadelphia has completed an extensive study of the effect of food on the gastroesophageal sphincter mechanism (3). The results of these studies indicate that a relatively high protein meal produces an increase in the sphincter pressure. This effect is not surprising and is consistent with the initial studies on the effect of the hormone gastrin on this sphincter, since protein has long been known to be an effective stimulator of endogenous gastrin release. A pure carbohydrate meal was shown to produce a slight increase in the pressure in the sphincter. The effect of the ingestion of a pure fat meal was most dramatic. Almost immediate marked decreases in pressure in the gastroesophageal sphincter were produced after the ingestion of a fat meal or after administration of the same meal directly into the duodenum. The decreases in pressure were so marked

that normal subjects noted the appearance of symptoms of gastric reflux (heartburn) during the course of these studies. In addition, the effect of fat ingestion was shown to persist for at least one hour after the ingestion of this meal.

A more physiologic form of a meal would include a combination of foods rather than pure protein or fat. Therefore, Dr. Nebel subsequently studied the effect of combining the protein and fat meals into a single meal (4). The ingestion of the combined protein/fat meal by normal subjects resulted in slight decreases in sphincter pressure. In other words, it appeared that the fat combined with protein had the effect of abolishing the normal protective action of protein in increasing pressure in the gastroesophageal sphincter. It was concluded, that calorie for calorie, fat had a more definite effect on this sphincter than did protein.

As stated previously the mainstay in the therapy of gastroesophageal reflux has been gastric alkalinization, with the express purpose of neutralizing the acid gastric material. Our initial studies had indicated that simple alkalinization of the stomach did also increase the sphincter pressure, apparently through the release of endogenous gastrin from the antrum of the stomach. Therefore, the effect of antacid therapy on the inhibitory action of fat on the gastroesophageal sphincter seemed of clinical importance. These effects were investigated in other normal subjects by giving the fat meal as used in the previous studies followed by the usual therapeutic dose of antacid medication at a time when the inhibitory effect of fat was well established. These studies indicated that, although, the fat consistently produced marked decreases in sphincter pressure, the subsequent ingestion of antacid produced a rise in pressure up to the previous resting levels (4). Thus, the gastrin releasing effect of alkalinization blocked the fat inhibition of sphincter pressure. In more detailed studies, Dr. Nebel has shown that the mechanism for this effect is through the competitive interaction of the gastrointestinal hormones gastrin and cholescytokinin (5). Of more importance to the clinician is the fact that antacid therapy should have a very positive action in the postprandial symptoms of gastroesophageal reflux, at least those produced by fat ingestion.

Since many patients with symptomatic reflux complain of increased symptoms when smoking and possibily when ingesting coffee, we have pursued clinical investigations into the effects of these agents on the gastroesophageal sphincter. Lt George W. Dennish, MC USN working in the Gastrointestinal Laboratory has shown that cigarette smoking has a very rapid deleterious effect on sphincter pressure in normal subjects (6). This effect was shown to produce decreases in pressure into a range seen in patients with chronic heartburn within three to four minutes after the initiation of smoking. The effect, however, was quite transient, and sphincter pressures returned to normal within five minutes

of terminating smoking. Further studies by Dr. Dennish on the effect of caffeine and coffee ingestion indicated less striking, but slight, decreases in sphincter pressure produced by caffeine (7). The clinical importance of this latter observation would appear to be that, although, the sphincter pressure does not decrease markedly, caffeine does have a well established action on the gastric parietal cell to increase gastric acid secretion. This effect, combined with the slight lowering of sphincter pressure, may well explain why patients with an already incompetent gastroesophageal sphincter note increased symptomatology after coffee ingestion. In fact, the common habit of having a coffee and cigarette after a meal seems to be particularly disadvantageous to the heartburn sufferer.

Further studies on the effect of foods have revealed an intriguing inhibition of gastroesophageal sphincter pressure produced by chocolate ingestion. We have long observed chocolate to be one of the factors producing symptoms in many of our patients, and during the past year these effects have been studied by LCDR John C. Babka, MC USN. The results of Dr. Babka's investigations indicate that, similar to fat ingestion, there are very striking decreases in sphincter pressure within the first few minutes after chocolate ingestion, and that this effect persists for at least a full hour (8). Although we initially believed the effect to be due to the fat content of the chocolate, it would appear that this is not the case since defatted chocolate syrup produces the same marked decreases in sphincter pressure. The mechanism for this action is less clear, but is believed to result from the ability of the caffeine and theobromine in chocolate to stimulate internal hormone actions, probably

TABLE 1
Factors Known to Effect Gastroesophageal Sphincter Pressure

Increased Pressure		Decrease Pressure	
Agent	Mechanism	Agent	Mechanism
Gastrin/Pentagastrin	Direct Effect	Secretin	Blocks Gastrin
Alkali Protein Carbohydrate	Gastrin Release	Acid	Gastrin Inhibition and Secretin Release
		Fat	Probably Cholecystokinin Release
Bethanechol	Direct Effect and Gastrin Release	Smoking	Probably Nicotine Effect
Edrophonium	Acetylcholine Production	Caffeine (coffee) Chocolate	Probably Cyclic AMP Production

working through the production of increased tissue cyclic 3′ 5′ adenosine monophosphate (cyclic AMP). Further studies on the interrelationship of gastrin, gastric alkalinization, and chocolate ingestion are in progress.

Having detailed much of the mechanisms by which the gastroesophageal sphincter tends to lose its effective pressure, and thus contribute to the reflux of gastric material into the esophagus, we next turned our attention to other mechanisms for promoting increases in sphincter pressure. LCDR Raymond L. Farrell, MC USN and CDR Gerald T. Roling, MC USN have shown that marked increases in sphincter pressure occur in normal subjects following parenteral injection of parasympathomimetic agents, particularly bethanecol (9). In this study, following the injection of 5 mg of bethanecol gastroesophageal sphincter pressures in normal subjects rose from a mean value of 15.0 mm Hg to a peak of 31.5 mm Hg within thirty-five minutes after injection. The pressure remained elevated for at least one hour following the injection. Further studies on the mechanisms of this action would appear to indicate that the cholinergic stimulation is in some way interrelated with endogenous gastrin release. Since various maneuvers to inhibit gastrin were shown to decrease the effectiveness of bethanecol in raising sphincter pressure (9).

More recent studies with various means of stimulating an increased pressure in the gastroesophageal sphincter have been applied to patients with clinical incompetence of this smooth muscle pressure barrier. Doctors Farrell and Roling have shown that patients with low resting sphincter pressures and chronic symptomatic reflux, that is chronic heartburn, will respond to various stimuli by increasing their effective pressure to a level consistent with that found in normal subjects (10). This effect has been produced by injection of the hormone gastrin or by the administration of alkali into the stomach producing endogenous gastrin release. In addition, Dr. Farrell has recently shown that protein ingestion in patients with reflux symptoms will result in considerable increases in sphincter pressure (11).

Of even greater importance is the effect of the cholinergic agent bethanecol on sphincter pressure in these patients. Initial studies with bethanecol injection indicated that resting pressures could be increased from a low level of approximately 5 mm Hg to a peak of almost 20 mm Hg within thirty minutes following the injection. This potentially useful therapeutic effect was further evaluated using an oral form of this same drug. In the same subjects 25 mg of bethanecol orally produced changes in sphincter pressure from an incompetent level of 7 mm Hg to a peak level of 6.4 mm Hg within forty-five minutes after ingestion. More importantly, the pressure was maintained above the excepted lower limit of normal (10 mm Hg) for a full two hour period after ingestion of the drug. These results indicate that the patient having an incompetent

gastroesophageal sphincter might receive therapeutic benefit from attempts to elevate the pressure. In fact, the remarkable ability of these various stimulating agents to increase the pressure in these subjects from abnormal to a "normal" level strengthens the hypothesis of a possible therapeutic use for such drugs.

The goal of any clinical investigator should be to develop his observations on basic physiology in the laboratory to the point where they have potential application to diagnostics or therapeutics at the bedside. To this end our studies on the use of various stimulators of gastroesophageal sphincter pressure have lead to the realization that cholinergic stimulation may result in an effective long-lasting medical treatment for chronic gastroesophageal reflux. At the present time this hypothesis is being tested at the Naval Hospital, Philadelphia through the mechanism of a double blinded controlled trial supervised by Dr. Farrell on patients with chronic reflux who are referred to the Gastrointestinal Unit of this hospital for evaluation and management.

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Vacuum Breakdown

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It is usually desirable in many scientific devices to operate electrodes at high voltage and close spacings. To avoid breakdown it is necessary to know the maximum voltage gradient that can be maintained without destructive breakdowns. For example when voltage is applied between two electrodes, as those shown in Figure 1, breakdown occurs at about 32 KV/cm for dry air at normal atmospheric pressure and 1 cm electrode spacing. If the air pressure decreases, as it does in an ascending airplane, then the dielectric strength of air also drops and the breakdown voltage reaches a minimum of 0.4 KV/cm at 1 mm pressure (1 torr). This low breakdown gradient or low dielectric strength makes encapsulation, potting, or immersion of electrical components essential in such an environment. However, if the pressure is decreased still further until high vacuum is reached, the dielectric breakdown rises to about 200 KV/cm. This allows close spacing of electrodes, but it is highly desirable to employ even closer spacing if possible. The dielectric breakdown strengths of air, vacuum, and other media given in Table 1 illustrate that vacuum has one of the highest values. Because vacuum breakdown effects many devices used by the Navy, the Office of Naval Research has been supporting research in this field.

Vacuum breakdown imposes design limitations on a surprising number of electron devices. Among these are high-power microwave tubes, electrostatic gyroscopes, vacuum capacitors, rectifier and modulator tubes, electrostatic lenses in electron microscopes, van de Graaff generators, and electrostatic particle separators. Devices utilizing vacuum breakdown are vacuum interrupters for high-voltage transmission lines (1), triggered vacuum gaps (1), and pulsed high-current electron guns for X-ray apparatus (2). Even though vacuum breakdown has been studied extensively for more than 50 years (3-4), there is still no single theory that explains all the experimental facts.

Experimental Facts

In gases a chance ionization within the gap between the electrodes can cascade into a full breakdown more or less independent of the electrode materials. In high vacuum, however, the mean free paths of electrons, ions, molecules, and microparticles are large compared to the

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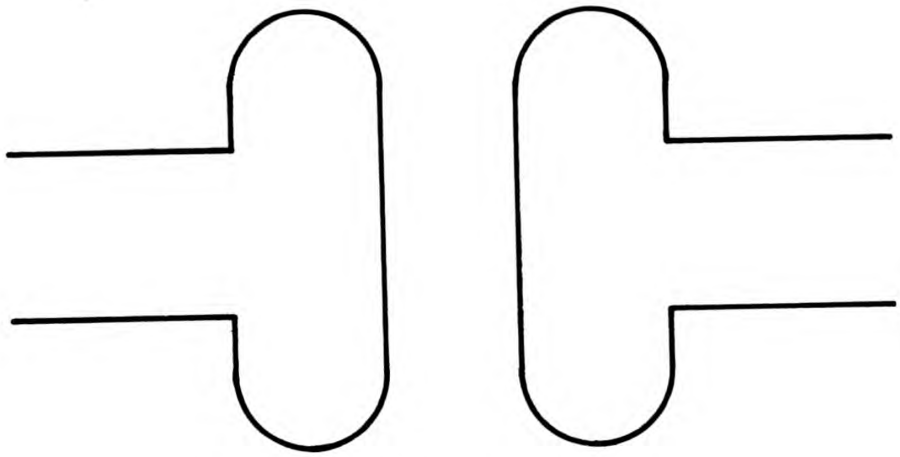


Figure 1 — Breakdown electrodes in vacuum

TABLE 1
Dielectric Strength — 1 cm Electrode Spacing

Air ... 27 atmospheres	500. KV/cm
Air ... 1 atmosphere	32. KV/cm
Air ... 10^{-3} atmosphre (1 mm Hg or 1 torr)	0.4 KV/cm
High Vacuum 10^{-7} to 10^{-15} atmosphere (10^{-4} to 10^{-12} torr)	200. KV/cm
Transformer Oil, atmosphere pressure	160. KV/cm
Aluminum Oxide — bulk	92. KV/cm

gap. Therefore, as long as the pressure remains low, the chances for collisional multiplication processes to occur within the gap are negligible, and all of the charge carriers must originate at the electrode surfaces. This means that the surface conditions of the electrodes are all-important in determining the breakdown threshold. This is consistent with the experimental fact (3) that, with clean electrodes, vacuum breakdown is essentially independent of tube pressure between 10^{-5} and 10^{-12} torr (1 torr equals 1 mm Hg), and that the surface conditions of the electrodes have a major influence on the breakdown properties of the gap.

Ideally, one would expect a vacuum gap to have nearly infinite dielectric strength with cathode electric fields reaching nearly 10^8 volts/cm, eventually limited only by gross field emission from the cathode surface. In practice, however, currents begin to flow and catastrophic breakdown occurs at much small gross fields (around 10^5 volts/cm). Experimentally, if one places clean (hydrogen and/or vacuum fired), polished, lint-free metallic electrodes into an oil-free vacuum system and pumps to a low pressure of 10^{-6} torr or better, the following events usually will occur

for electrode spacings less than 2 mm. (For larger gaps and higher voltage only the last event is likely to be observed.) At a gross field of approximately 10^5 volts/cm a few intermittent self-quenching discharges are observed. These *microdischarges* may have currents up to several milliamperes and durations up to 50 μs. depending in part upon the power supply impedance. After each microdischarge a crater is observed on the cathode surface and, directly across from the crater, there is a burned area on the anode (Figure 2). After many discharges and breakdowns a few craters are also observed on the anode and burned areas are found directly opposite the craters on the cathode. This can be seen in Figure 3.

After the first microdischarge a *prebreakdown current* of a few microamperes is usually observed. This prebreakdown current obeys a relation of the same form as that predicted by the Fowler-Nordheim equation for field emission and has been shown (3-4) to originate from one or more microprotrusions on the cathode surface. Electron microscope views of two such microprotrusions are shown in Figure 4. They are usually located on the rim of a cathode crater.

When the gap voltage is increased by only a small amount (to the point where the field emission is perhaps 1 to 10 μA), a sudden high-current discharge will occur seemingly limited by the power supply (as high as 20,000 amps) and with rise times measured in nanoseconds. The term *vacuum breakdown* is used to denote this power-supply-limited, high-current flow. After the first few vacuum breakdowns the threshold voltage for vacuum breakdown progressively increases to a level approximately 30% higher than the initial value. This so-called *conditioning* process leaves the initially smoothly polished electrodes eroded

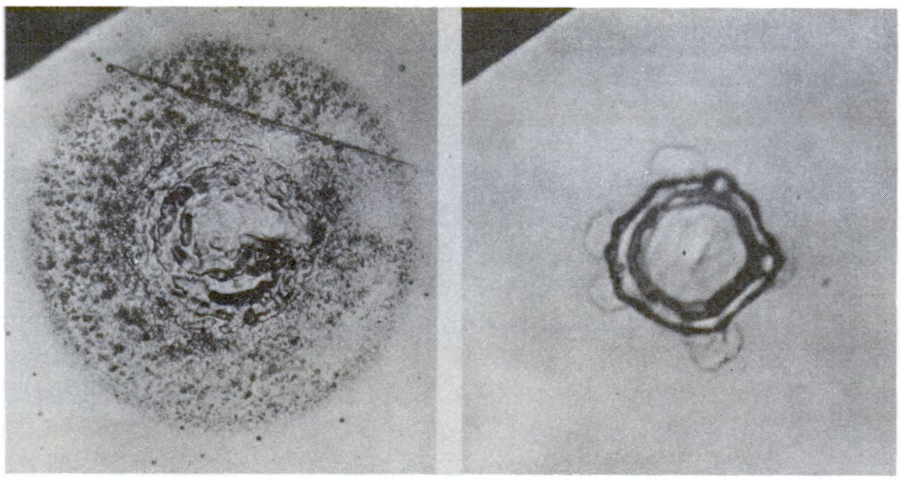
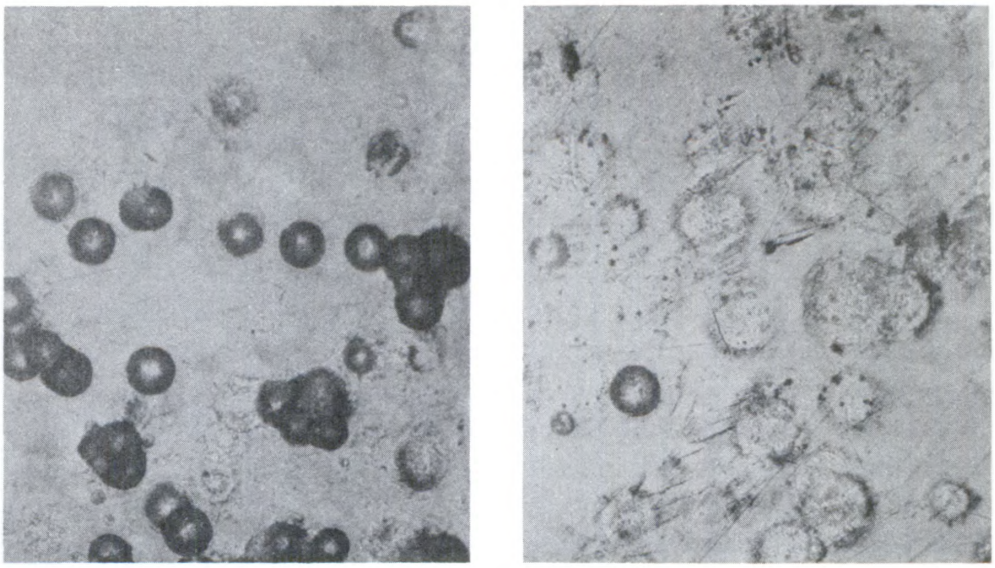


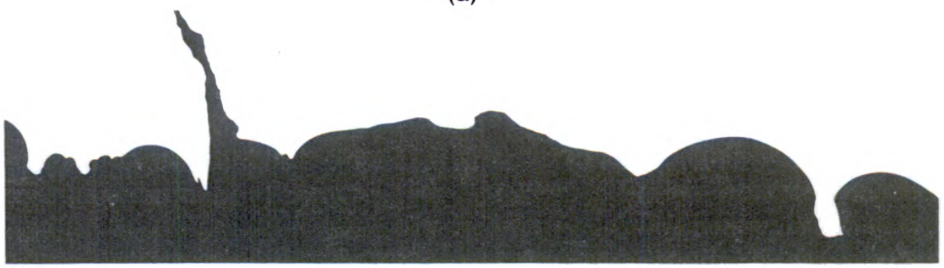
Figure 2 — Right photo shows a crater in an aluminum cathode surface. Left photo shows the anode burn on an aluminum anode opposite this cathode crater.



CATHODE ANODE

Figure 3 — Typical crater characteristics of anode-cathode pairs tested (Cu Sample)

(a)



(b)

Figure 4 — a. Shadow-electron-microscope photographs of the surface of a type 6061 aluminum cathode. Magnification approximately 1000X. This surface had been optically polished with a 0.5 micron diamond abrasive and ultrasonically cleaned. Projection produced after applying a voltage of 10 kv to obtain a prebreakdown current of 10^{-6} amperes across a gap of 0.010 inch. b. Shadow-electron-microscope photographs of the surface of a Grade "a" 99% pure electronic nickel cathode. Magnification approximately 1000X. This surface had been optically polished with Linde-C and ultrasonically cleaned. Projection produced after applying a voltage of 9 kv to obtain a prebreakdown current of 10^{-6} amperes across a gap of .010 inch.

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with craters and burned areas, but "conditioned" to withstand approximately 30% higher breakdown voltage. This "conditioning" is destroyed if the electrodes are exposed to air and another conditioning process is required to restore it.

Theories

It is generally agreed that a vacuum breakdown is a vapor arc, taking place in material evaporated from the electrodes (5). This is supported by the observation of light within the gap during the breakdown, and the fact that electrode material is transferred across the gap. A number of theories have attempted to explain the physical mechanism by which the high temperature necessary for vaporization is produced.

The most widely accepted theory of vacuum breakdown is based on field emission from the whisker-like microprotrusions (Figure 4) on the cathode electrode. It has been determined by observation of small fluorescent spots on the anode directly across the gap from the cathode microprotrusions, that the protrusions are the sources of the prebreakdown current. Resistive heating of a protrusion by the field-emitted current flowing through it and/or localized heating of the very small anode area bombarded by the current from the protrusion can cause a thermal runaway condition leading to melting and vaporization of the protrusion and/or localized anode evaporation and the consequent liberation of gas. (The bombarded anode area is only a few microns in diameter). The difficulties with this theory are: (1) the field emission and protrusions do not seem to be present until microdischarges have occurred; (2) the buildup of breakdown current to thousands of amperes in nanoseconds is difficult to explain; (3) the theories cannot adequately explain the electrode-conditioning process; and (4) the theory predicts a breakdown-voltage *vs* gap spacing relationship having an exponent of one or greater; whereas the experimental value is less than unity (see Eq. (1)).

The *ion-exchange theory* seeks to explain the buildup of the breakdown state by a regeneration process growing from a single event. An electron emitted from the cathode strikes the anode and causes the ejection of A positive ions and C photons. The A positive ions strike the cathode and produce B secondary electrons, while the C photons also strike the cathode and produce D secondary electrons. A runaway condition and spontaneous growth are established when $AB \times CD \geqslant 1$. It has been shown that the production coefficients $(AB + CD)$ do not exceed unity at voltages below about 100 kV but at voltages near 200 kV and higher, and vacuum gaps of 1 cm and more the production coefficients of electrons and ions are higher, and the explanation becomes more plausible.

The *microparticle theory* assumes that loosely adhering microparticles are drawn across the gap by the electric field so as to strike the opposite electrode with enough energy to produce vaporizing temperatures at the point of impact. The energy dissipated at impact is, of course, the product of the microparticle charge and the gap voltage. For uniform gaps this leads to the prediction that the breakdown voltage should vary as the half power of the gap spacing. Experimentally, however, the breakdown voltage for conditioned electrodes in near uniform-field geometry varies as the 0.7 power of the gap spacing. An equation for prediction of breakdown which is an approximation of published data, is:

$$V = 312 \times 10^3 \times d^{0.7} \tag{1}$$

where V is the breakdown voltage in volts and d is the space in centimeters between the planar, parallel electrodes.

The *ion perturbation theory* attributes the current increases to field emission which produces ions which in turn enhance the field emission into a runaway process. Although several experimenters have shown that deliberate introduction of either microparticles or a burst of gas into the vacuum gap serves to trigger a vacuum breakdown at fields well below the usual threshold breakdown field, the difficulty is explaining the source of ions.

Recent Experiments

Breakdown behavior similar to that expected from ideal surfaces has recently been achieved by E. M. Lyman at the University of Illinoise (under a Tri-Service contract). He heated tungsten electrodes at 2050°C for 4 hours in a clean, well-pumped vacuum system and observed no microdischarges or prebreakdown current as such. Breakdown occurred at 2.4×10^7 v/cm only after gross field emission from the cathode surface became excessive and heated the anode. This is about 100 times the breakdown field that is usually obtained, but in practical devices, is it not usually possible to outgas electrodes in this extreme.

Under Navy sponsorship, Raytheon Co. studies of conditioned tungsten electrodes have shown (10) that unpolished, porous surfaces produce about 35% poorer breakdown voltage than solid surfaces, but that polishing increases the breakdown voltage of the porous surfaces to about that of their solid counterparts. Breakdown reduction in the porous case is attributed to gas content trapped near the electrode surface and released by field-emission prebreakdown currents.

Researchers at Ion Physics Corp. under an Army contract (9) have shown for high-energy discharges (low impedance power supply) and

for conditioned electrodes that anodes of high-strength refractory metals such as tungsten, molybdenum, tantalum and chromium yield the highest breakdown voltages. The cathode material is of secondary importance because the cathode becomes coated with the anode material during the conditioning process.

R. L. Kuston (7) under the Atomic Energy Commission sponsorship performed a definitive experiment to show that microparticles and ions move too slowly to play the dominant role in vacuum breakdown. He carefully measured vacuum breakdown with the applied voltage at frequencies of both 60 Hz and 21 MHz using various gap spacings. In all cases, he found nearly the same breakdown voltage for both frequencies. His calculations show that the transit times of microparticles and ions across the gap are long enough to show a definite frequency dependency which was not observed. Therefore, the conclusion is to favor field emission theories of vacuum breakdown based on electron flow rather than microparticle or ion exchange mechanisms. While employing the RF voltage, Kurston experimentally obtained the usual fractional power relationship for breakdown voltage *vs* gap spacing (Eq. (1)), thus negating microparticles as responsible for this relationship.

G. A. Mesyats, *et al,* (8) have photographed the ionization light with 2 nanosecond exposure time during pulse breakdown. They found that the light from the breakdown begins as a cathode flare within a few nanoseconds after application of the voltage and that the ionization light moves towards the anode at about 2×10^6 cm/sec. They attribute the rapid rise in current to the explosive destruction of field-emitting microprotrusions.

Friedman and Ury (2) at Cornell under an ONR contract developed an electron gun utilizing a vacuum arc as the electron source. It produces a hollow electron beam of about 16 kA at 678 kV or about 10^{10} watts of power for a few nanoseconds. The gun can be used many times because melting of the anode is prevented by magnetically deflecting the current away from it.

Conclusions

Insulation of high voltage in vacuum depends primarily on electrode geometry and surface conditions of the electrodes. The electrode surfaces are altered by application of high electrical stress such that microdischarges occur and field emission currents flow. These result in craters, burned area, and evaporation of electrode material. The processes eventually lead to vacuum breakdown consisting of a vapor arc. The precise details of the processes are not yet fully established. Nonporous, outgassed, polished electrodes of high-strength metals such as tungsten, molybdenum, tantalum, and chromium provide the highest breakdown voltages.

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NRL Developing High Performance Signal Processor Computer

Scientists at the Naval Research Laboratory (NRL) have designed a very high performance programmable digital computer as a signal processor.

The functional specifications of the NRL Microprogrammed Control Unit (MCU) are being incorporated in a pilot model which is being built at the Laboratory this year, and engineered to have low life-cycle costs.

NRL researchers say signal processing is favored in military systems because the digital domain permits maintainability, stability, and reproducibility not afforded by the analog domain.

Until now, designers of such systems have had to choose between incorporating a standard military computer with marginal signal processing performance or developing a special-purpose hard-wired digital processor with all the inflexibilities, costs, and risks attending this approach.

The Laboratory's MCU is a high-speed, user-microprogrammable, executive, input-output processor and interrupt handler for its Signal Processing Element (SPE). The unit employs A MIcroprogramming Language (AMIL), which is Fortran-like and allows MCU users to write microprograms in a convenient format instead of binary bit patterns which the MCU will execute.

Research Notes

Giant Experimental Buoy Marks Third Year Reporting Atlantic Storms

On the first day of February 1973, a 100-ton experimental data-reporting buoy marked up the third anniversary of its anchoring in the Atlantic Ocean where it has been keeping tabs on ocean-spawned storms which could endanger the mid-Atlantic states and New England.

In doing so, it established a record for longevity in the deep sea for a buoy of such size. The device is the first of a series of giant experimental environmental data reporting buoys being developed and tested by the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce. Similar experimental buoys are reporting data from the Gulf of Mexico and the Gulf of Alaska, where they were anchored last year by the National Data Buoy Center, a facility of NOAA (National Oceanic and Atmospheric Administration). The center is located at NASA's Mississippi Test Facility near New Orleans, La.

The Atlantic buoy is anchored in the Gulf Stream approximately 125 nautical miles southeast of Norfolk, Va., in 9900 feet of water. The buoy was deployed February 1, 1970, and since that time has been overhauled, refurbished, and refitted on two occassions with new and improved components and sensors.

The buoy was originally developed for the Office of Naval Research and was transferred to the Coast Guard and then to the National Data Buoy Center when that group was formed within NOAA's National Ocean Survey to develop a national system of environmental data reporting buoys.

The Atlantic buoy (designated EB-01 for Environmental Buoy Number 1) has already made noteworthy contributions to the weather watch along the densely-populated east coast. In the three-year period in which it has been functioning, the buoy has been one of the prime sources of data which revealed the formation of more than 50 major storms off the mid-Atlantic and New England coasts.

The data from the buoy contributed significantly to more accurate and timely predictions of heavy snowfalls, flooding rains, high winds and seas, and destructive tides and storm surges, with a resultant savings in life and losses in property, business, and transportation.

Originally, the buoy was instrumented with meteorological, limited oceanographic and engineering sensors, an on-board computer system, propane generators and, for self-preservation, radar reflectors and navigational lights. As refitted, the buoy's instrumentation now monitors global radiation, precipitation rate, air temperature and pressure, dew point, wind speed and direction, surface water temperature and current velocity, wave action and surface turbulence, as well as pertinent engineering data on such matters as fuel consumption and battery power.

The buoy is programmed to check all its sensors once per hour, record the acquired data and transmit the stored data every three hours to the Coast Guard Radio Station, Miami, Fla., and from there to NOAA's National Meteorological

Center in Suitland, Md., and finally to other users *via* the regular weather networks. The buoy is capable of more frequent interrogation on request when needed for critical monitoring period.

Experience gained from the Atlantic buoy has contributed to the development of the buoys anchored in the Gulf of Mexico and the Gulf of Alaska. The EB-10 buoy in the Gulf of Mexico, located about 225 miles southeast of the National Data Buoy Center at Bay St. Louis, Miss., has been periodically reporting environmental data since it was anchored in June 1972.

This massive buoy is designed to withstand severe weather and sea conditions, including 150-knot hurricane winds, 60-foot waves, and 10-knot currents. Its platform carries a meteorological sensor package at levels of 15 and 30 feet, a hull-mounted oceanographic sensor package, and 12 oceanographic sensor packages at various levels down to 1500 feet. These packages will sense more than 76 individual measurements of environmental data during a routine weather reporting cycle.

The buoy in the Gulf of Alaska (EB-03), deployed in the sub-Arctic waters in October 1972, is similar in design to the EB-10. Its stationing in the Gulf of Alaska is providing an on-site test of the ability of the experimental buoys to withstand particularly severe environmental conditions. Meteorological information transmitted by this buoy aids weather forecasting for Alaska and the west coast of North America.

Navy Pilots May Learn to Fly by Instruments They "Feel"

The Navy is investigating the feasibility of conveying some flight information to aircraft pilots by having them feel it rather than see it. The concept is that tiny sensors would be attached to the bodies of pilots. These would produce coded vibrations or other stimulations that would tell him what his aircraft is doing.

The study, directed by the Office of Naval Research with funds provided by the Defense Advanced Research Projects Agency, is aimed at finding a way to reduce the dependence of the modern pilot on the maze of instruments that are part of a military aircraft cockpit.

In current aircraft nearly all the information that must be constantly assimilated by a pilot is displayed on instruments panels that he must scan visually. It has been recognized that scanning merely the essential instruments is a fatiguing task. An additional complication is the fact that the pilot must maintain some visual contact with the scene outside, requiring him to look away from the cockpit display. In shifting his attention back and forth, the pilot is apt to overlook vital information.

Furthermore, there is an increasing realization of the need for the pilot in certain situations to maintain continuous attention ot the scene outside, such as a landing approach, in reconnaissance, or in combat. A substantial percentage of midair collisions have been blamed on the failure of pilots to maintain sufficient surveillance of the external scene.

The main objective of the present study is to determine whether it is possible to substitute bodily stimulation for some of the visual displays used for aircraft

control. These devices, attached to the hand, back, chest or other sensitive areas, could transmit information to the pilot by means of vibrations, tiny electrical currents, or similar stimulation. Through a "vocabulary" of different patterns, intensities and rates of stimulation, the pilot would be given information about such flight parameters as roll, pitch, or angle of approach.

The concept of using tactual stimulation to convey information has been investigated before both in military and civilian technology. One successful application that is presently utilized consists of a reading aid for visually handicapped persons.

The first step in the Navy study has been to obtain all available information about the state of the art of research and materials development in bodily sensory stimulation. This will determine the best approach toward the design, fabrication and evaluation of several different configurations of tactual displays. The most promising configuration will then be tested in a laboratory situation using a mock-up plane cockpit. Eventually field tests will be conducted in real flight situations.

The study is being conducted by Sanders Associates, Inc., Nashua, New Hampshire.

NRL Develops More Efficient Infrared Sensor

Scientists at the Naval Research Laboratory (NRL) have developed an inexpensive chalcogenide glass thermistor bolometer for use as an infrared detector.

Potential applications of the new device include burglar alarms, fire detection, pedestrian or vehicular traffic detection, and atmospheric pollution detection; and they say, it is economically competitive with available state-of-the-art room temperature infrared detectors.

A thermistor bolometer is a device whose electrical conductivity changes with changing temperature. When infrared radiation is absorbed by such a sensor, the resultant heating causes a detectable change in its electrical conductivity.

Semiconducting chalcogenide glasses are disordered alloys consisting partially of various combinations of the elements sulfur, selenium and tellurium. Recently these materials have been the subject of intensive research, primarily because of the switching effect which they exhibit. However, it is the strong temperature dependence of their electrical conductivity which makes these materials useful as thermistor bolometer elements.

The glassy nature of these materials allows them to be cast or hot-pressed into any shape or thickness or vacuum deposited (sputtered) into thin film form with very little effect on their dc electrical conductivity. Furthermore, the electrical conductivity of the chalcogenide glasses is determined primarily by alloy composition rather than by trace impurities as in the case of crystalline semiconductors.

Fabrication of the NRL-developed device by r.f. sputtering and photolithographic masking techniques has been demonstrated, which, Laboratory scientists say, means that it is possible to produce large scale two-dimensional imaging arrays of these bolometers at relatively low cost.

French-American Mid-Ocean Undersea Study

Deep diving research submersibles from France and the United States will plumb the depths of the mid-Atlantic Ocean for the first time, in a three-year international scientific program announced by the Commerce Department's National Oceanic and Atmospheric Administration (NOAA) and the Woods Hole Oceanographic Institution.

The program, called FAMOUS (French-American Mid-Ocean Undersea Study), will make a detailed study of the Mid-Atlantic Ridge in an area some 200 miles south of the Azores. The submerged ridge is a major feature of the earth's surface but has not yet been studied at close range. First-hand study of the ridge is expected to furnish direct knowledge of how the earth's continents and oceans were formed, information that bears directly on the formation of metallic ore deposits and oil accumulation.

The Mid-Atlantic Ridge is a giant undersea mountain range that extends from the Arctic Ocean the entire length of the North and South Atlantic, and continues around Africa into the Indian Ocean. It is at an average depth of 7,200 feet, with a maximum depth of about 12,000 feet.

Up until now, man's knowledge of the ocean floor has been obtained from indirect measurements from surface ships and deepsea coring and dredging. By using submersibles, scientists will obtain samples direct from the rift valley in the center of the Atlantic ridge, much as the astronauts went to the moon to obtain samples of its surface.

The submersibles will also emplace instruments on the ocean floor to provide a continuous supply of precise data on the dynamics of seafloor spreading and the emergence of new crustal material.

FAMOUS is one of several scientific programs being undertaken as a result of a bilateral agreement between France and the United States. United States coordination in the field of oceanography is the responsibility of NOAA. Scientific coordination of FAMOUS is being handled by the Woods Hole Oceanographic Institution, with financial support from the National Science Foundation, the Office of Naval Research, and NOAA.

The scientific program follows a plan recommended by an international group of scientist convened by the National Academy of Sciences at Princeton in January 1972 under the sponsorship of the United States Office of the International Decade of Ocean Exploration. Focus of the study is exploration of the mid-ocean rift system, which comprises a network of cracks in the seafloor up to 10 miles wide and two miles deep, virtually girdling the globe. A major objective of the research is to obtain evidence of volcanic-like activity apparently causing seafloor spreading and the gradual drifting of North America and Europe away from each other.

Co-Scientific leaders for U.S. participation in the mid-Atlantic study are Dr. George Keller, Director of the Marine Geology and Geophysics Laboratory at NOAA's Atlantic Oceanographic and Meteorological Laboratories, Miami, and Dr. James Heirtzler, Chairman of the Department of Geology and Geophysics at the Woods Hole Oceanographic Institution.

Following two years of site surveys and training, a fleet will assemble at the site selected, in the summer of 1974. The French bathyscaphe *Archimede* and

French submersible *SP-3000,* the American submersible *Alvin,* and four surface ships will carry out the most extensive deep ocean manned submersible study ever undertaken. Some 40 divers will be made at that time, with special missions for each submersible. The submersibles will be detailed mapping of the area, collect special bottom samples, and place instruments on the seafloor.

Each of the deep-diving research vehicles will have special assignments to make best use of their differing capabilities. The *SP-3000,* which has a high degree of maneuverability, will be used for rapid visual reconnaissance and for studies within the rift valley of the midocean ridge. *Archimede*, a bathyscaphe designed for maximum depths and heavy payloads but in relatively gentle terrain, will explore the fracture zones of the seafloor. The highly maneuverable *Alvin,* owned by the Office of Naval Research and operated by the Woods Hole Oceanographic Institution, will explore both terrains as well as the rift valley wall.

In describing the FAMOUS project, Dr. James Heirtzler said that ships and personnel from France, Great Britain, Canada, and several institutions in the United States, including the Woods Hole Oceanographic Institution, Scripps Institution of Oceanography, University of Rhode Island, Naval Research Laboratory, NOAA's Atlantic Oceanographic and Meteorological Laboratories, and others, will work together in exploring the related area.

A regional site survey has been completed by aircraft and surface ships. Last month a French team conducted a field trip in Iceland to study some of the volcanic features believed similar to those of the midocean ridge. Late in August, *Alvin* conducted training dives in the Gulf of Maine with a team which included a participating French scientist. One purpose was to test instrumentation and techniques to be used in the Mid-Atlantic Ridge Study over somewhat similar seafloor terrain.

Survey work of the region was carried out in August by the University of Rhode Island's research vessel *Trident,* and in September by the French oceanographic research vessel *Jean Charcot*. Further surveys will be undertaken in November by Woods Hole's *Atlantis II;* and later in the year by the U.S. Naval Ship *Mizar*. The surveys will include accurate measurements from surface and deeply-towed instruments and extensive sonar and bottom photographic mapping operations.

Next year, additional survey work will be done by naval research ships, including *Knorr,* operated by the Woods Hole Oceanographic Institution, and the British oceanographic research vessel *Discovery,* utilizing a huge long-range side-scan sonar system of the United Kingdom's National Institute of Oceanography. The French bathyscaphe *Archimede* also will make an initial reconnaissance dive in the area.

A special training program is already underway for the scientific divers. This includes practice dives in all three submersibles, field trips by divers and pilots to Iceland and Eastern Africa where similar terrain is located, and workshops for establishing priorities on the types of observations to be made during the various dives. Navigation and sampling instrumentation is being developed that will be interchangeable among the submersibles.

Presently, *Alvin* can dive to 6,000 feet, and a new ballast system was installed last spring at Woods Hole as an initial step towards operation at greater depths.

This coming winter a new titanium personnel sphere, provided by the U.S. Navy, will be installed to replace the existing steel sphere. The new sphere, which will hold the three-man crew, could virtually double *Alvin's* deep-diving capabilities.

Fewer Humpback Whales than Previously Estimated

A University of Rhode Island marine biologist has determined by a recent survey that the actual Northwest Atlantic population of humpback whales—an endangered species—is about half that of previous estimates.

Numbering 300 to 500 whales, this population is one of only eleven such groups remaining in the world, said Howard E. Winn, professor of oceanography and zoology.

Dr. Winn and several graduate students surveyed the Northwest Atlantic population this year in an area near the West Indies where humpbacks gather yearly to breed. The survey was conducted by visual methods and by listening for the humpback whale "song" with an underwater microphone—the first time such a method has been used to survey whale numbers. Dr. Winn and several graduate students have studied humpback and other whale species on nine cruises, five to the West Indies and four to Newfoundland. The Office of Naval Research has funded the studies aboard various research vessels as part of a broad general program to understand the noises made by porpoises and whales. These noises produce bad interference on submarine sonar receivers.

Even though humpback whales have been nearly hunted to extinction over the past 75 years, the scientists give them a good chance of recovery.

Scientists believe that humpback whales will be able to rebuild their numbers—if they are not hunted. Humpbacks have been protected from hunting by factory ships in the Atlantic since 1955 and in the world since 1968.

For the survey the scientists recorded the "song" of the humpback whale, which consists of a complex series of high-pitched wailing and low guttural noises. The song may enable herds of humpback whales to stay together and help individual whales find one another for mating.

All whales produce sounds. However, no other whale is known to utter a sound pattern as complicated as that which the humpback makes during the late winter and early spring.

The survey of Northwest Atlantic humpback whales was taken during the most recent cruise early this year near Venezuela and the West Indies. Algis Taruski and Richard Edel, students in the University of Rhode Island Graduate School of Oceanography, assisted in the survey.

The research vessel was maneuvered close enough to some whales for the scientists to fire a special "biopsy dart" into them. The dart takes a small sample of skin and blubber and is pulled back to the boat with an attached line. The technique, used for the first time, enabled the researchers to determine DDT content of the fat and the sex of the sampled whales.

DDT levels were high in several of the analyzed blubber samples of live whales. Some scientists have suggested that high DDT levels in whales might adversely affect reproduction. Dr. Winn said the few samples he had with high DDT levels might be considered a "warning" and would warrant further investigation.

The studies on humpback whales seem to indicate they may have a primitive type of sonar that enables them to perhaps determine depth of water and location of other whales.

Scientists have found that humpback whales of the Atlantic spend most of their time in north Atlantic waters where they feed on small fish and small crustaceans. In the fall, the mammoth creatures migrate to an area around the West Indies and Bermuda.

From January to March, humpback whales stay near the West Indies where they give birth to young and mate. Only during this time do they emit the characteristic "song" that may help males establish territories and warn other males away. The "song" may help females find the males for mating.

Humpback whales, which grow as long as 50 feet, surface about every 12 to 14 minutes for air. During the mating season, much of the entire time under water is spent in emitting the "song."

Scientists feel they have only begun to understand the "song" of the humpback whale. Dr. Winn said the "song" may be an identification of individual whales. Furthermore, he believes there could be dialects of the "song" that are different in the various geographical areas of the ocean.

Office of Naval Research Sponsors a Workshop in Chemical Oceanography

The major operating area of the Navy is the open ocean. Also, ports and harbors are important naval locations possessing a wide range of marine environmental characteristics are also utilized extensively. In order to operate in these areas effectively, the Navy must possess a high degree of knowledge of this marine environment. It is for this reason that the Office of Naval Research supports a diverse research program in the Ocean Sciences.

Chemical Oceanography occupies a central role in gaining an understanding of the multifaceted problems of the marine environment. There are very few properties and processes of the ocean that do not involve its chemical characteristics. Even its movements, which may indeed not be accompanied by a change in chemical composition, are generally observed and measured by the distribution of its mass as calculated from salinity and temperature data. In addition, the physics, biology, geology and chemistry of the ocean are so intimately intertwined that knowledge from all these fields is essential if the properties and processes in the marine environment are to be understood. As a result, chemical oceanographic research forms a part of this Ocean Sciences Program along with the other disciplines.

Unfortunately, most of the basic chemical processes occurring in the marine environment, their controls, mechanisms, alterations by outside influences such as pressure and their effects upon man's utilization of the ocean, are not well understood. The variety of the organic compounds in the sea far exceeds that of all inorganic species combined, yet very little is known of their involvement in trace element equilibria and little use has been made of organic analysis in Oceanography. At the present time we possess only an extremely crude understanding of how the chemistry of the marine environment effects sound attenuation in the oceans. We know virtually nothing of the basic mechanisms and

interrelationships of the chemical and bacteriological processes combining to form the basis for the corrosion of material in the marine environment. Little is known of the effects of anti-fouling material such as copper on the welfare of a semi-enclosed body of water supporting heavy ship traffic. These are but a few examples.

The primary reason for this lack of knowledge is that until only recently have appropriate analytical methods been available which are sufficiently sensitive and rapid enough to permit sophisticated chemical analyses of the marine environment to be conducted. Such analyses are now leading the way to quantitative rather than the qualitative chemistry that was being largely practiced until recently. These technological advancements have allowed the chemical oceanographer to begin to investigate the entire spectrum of physical and chemical processes which are responsible not only for the composition of the ocean itself, but also for the properties of the various interfaces (air-sea, sea-bottom and suspended material-sea). These considerations are beginning to embrace not only the occurrence and distribution of the elements in the ocean and the types of reactions that occur between the various chemical species in solution, but also the rates and mechanisms of supply and removal for each component found in the oceans (the routes and reservoirs).

The objective of the research financed by the Office of Naval Research in Chemical Oceanography is to take advantage of this change of direction in the field. This change will allow the establishment of an understanding of the controls and mechanisms maintaining the chemical characteristics of the ocean environment. Problem areas of naval relevance which will benefit from research being conducted along these lines are the corrosion and deterioration of materials in the marine environment; the monitoring, assessment, and possible control of pollutants in the sea; the interchange of materials across the air-sea and sea-bottom boundaries; the chemical effects on the properties of sound transmission, absorption and scattering in the marine environment; and improved understanding of the bulk thermodynamic and transport properties of seawater to allow for a more accurate physical description of adiabatic mixing and deep sea stability; as well as the use of tracers for the identification of water masses in order to study ocean circulation and mixing mechanisms. All these problem areas share a common basis of chemistry.

Due to the nature of Chemical Oceanography's emerging maturity as a field of research, the degree of success the Navy will enjoy in solving the numerous marine environmental problems it faces with the aid of chemical oceanographic research, will be directly related to the status and future direction of research in this field. As a result, to determine where Chemical Oceanography stands at the present time, and what are the pressing problems that should be attacked during the next several years, a group comprised of prominent United States chemical oceanographers were assembled under the sponsorship of the Office of Naval Research, at the Naval Postgraduate School, in Monterey, California. Over thirty chemical oceanographers representing many of the major oceanographic institutions and universities, including the National Science Foundation, participated. Dr. Neil Andersen, of the Ocean Sciences and Technology Division of the Office of Naval Research convened the meeting, where four days of deliberations and discussions were conducted in three major areas of concern:

(I) Processes and Mechanisms Governing the Inorganic Composition of Seawater, (II) Marine Environmental Fluxes: Air-Sea and Sediment-Sea, and (III) Impact of Life Processes on the Chemistry of the Ocean. Dr. F. J. Millero, University of Miami, Dr. E. D. Goldberg, Scripps Institution of Oceanography and Dr. F. A. Richards, University of Washington were the respective Discussion Leaders of the three sessions. The specific objectives of the conference were: (1) To promote the exchange of information, especially between ONR supported scientists; (2) To promote any cooperative research that is possible; and (3) To assess the future areas of investigation in Chemical Oceanography and thereby make recommendations for the future direction of research in this field generally. The first two of these objectives were accomplished during the gathering. The third objective, recommendations of the participants, are contained in a document under final review and editing for distribution in the near future.

One of the conclusions of the participants was that more research needs to be conducted on the mechanisms regulating chemical concentrations in the oceans as well as where this regulation is occuring. It was suggested that the continental margins and the photic zone would be good locations to investigate. Particularly emphasized were the transformation reactions such as absorption occuring between suspended particulate matter and dissolved material; forms of the ehemicals such as species as they exist in seawater; and the thermodynamics and kenetics of these reactions. It was also pointed out that the bulk thermodynamic properties of seawater (PVT data, viscosity, conductivity, specific heat, enthalpy, sound absorption) need further research.

It was recommended that more be found out about the properties of plutonium in the marine environment. This consideration was felt to be particularly important due to the expected expansion of the use of plutonium as a fuel in various platforms.

The workshop participants recommended research regarding the chemical processes occuring under and near ice; regional and mesoscale air-sea transport of gases, particularly determining the transfer coefficients of both reactive and unreactive gasses; the distributions, fluxes and chemical characteristics of organic matter in the ocean; and diagenetic processes resulting in the formation of gases in sediments and resulting fluxes into the overlying waters.

(Continued from Page 7)

Another group of NRL scientists applied methods used to minimize damage to Navy ships during combat to the problem of automobile collisions. They issued an NRL report showing how the energy of a collision could be absorbed so as to decrease damage to the automobile from a low-speed collision and increase safety of the passengers during a high-speed collision. The report showed the best possible protection which could be supplied and indicated the tradeoffs necessary between deformation of the structure of the automobile and acceleration loads applied to the passengers. Both single-car and two-car collisions were considered in detail.

The NRL scientists also recommended practical energy-absorbing structures which could be used to decrease the damage and injury from automobile collisions. Some of these structures had been designed and tested in Navy and DOD laboratories for application to ships and military vehicles. The NRL scientists also recommended design methods which had been developed by the Navy to make combat ships more shock-resistant. The NRL report also included specific recommendations in the areas of passenger compartments of automobiles, seat belts, matching of bumpers, and energy-absorbing front bumpers.

Navy Studies Use of Air Bags to Save Helicopter Crews Downed at Sea

When a helicopter crash lands at sea, it usually turns over and sinks, frequently drowning all aboard. The Navy is testing the concept of using inflatable air bags to keep the vehicle afloat long enough to allow personnel aboard to escape and perhaps permit the helicopter to be salvaged. This research, sponsored by the Office of Naval Research, is being conducted by the Southwest Research Institute, San Antonia, Texas.

Helicopters are inherently top heavy and unstable principally because of the large rotor and engine. A tilt of a few degrees from the vertical can cause the craft to flip over, especially during a ditching at sea. Careful tests and analyses have shown that a helicopter usually overturns in less than a second after it hits the water.

A recent survey of helicopter crash landings on water indicates that many crashes are survivable because of the cushioning effect of the water. Most of the fatalities are due to drowning when the vehicle overturns before the personnel can get out. Furthermore, the helicopter often then fills with water and sinks rapidly preventing salvage.

The concept of air bags to stablize helicopters on water was investigated by the Navy as far back as 1958. At that time, however, materials and technology were not advanced enough to permit the development of an effective system. Recent advances in the air bag industry has now made such a development a promising possibility.

The concept is being tested on a "stability model" of the Sikorsky CH 53A Marine helicopter. The model consists of a structure that faithfully simulates the mass and weight distribution of the actual helicopter. To simulate the ditching at sea, the model was repeatedly dropped in a tank full of water from predetermined heights and angular orientations. Air bags, stowed in tubular structures projecting from the sides of the model, were inflated prior to being dropped into the water. Tests were conducted with and without the air bags deployed.

Preliminary results show that the air bags stablize the model to roll angles of about 30 degrees from the vertical without overturning. Further drop tests from various angles are planned to obtain precise characteristics of roll as well as determine the best locations for the bags. Data will also be obtained on the proper pressure and inflation time as well as the best mechanism to deploy the air bags.

This information will be used to plan and conduct tests with an actual helicopter and eventually to develop and incorporate an air bag system in Navy helicopters. Such a development promises to benefit not only the Navy but other agencies, such as the Air Force and Coast Guard as well as local police departments that operate helicopters over water.

Nd-Doped Ceramic Rods Triple Optical Quality

Polycrystalline ceramic laser rods with optical quality three times better than ceramics now on the market have been produced at the General Electric Research and Development Center, Schenectady, New York.

The reproducible synthesis of neodymium-doped Yttralox rods and the demonstration of their lasing ability was achieved by Dr. Charles D. Greskovich and Joseph P. Chernoch.

Yttralox polycrystalline ceramics are prepared from yttrium oxide plus thorium oxide. In laser applications, the doped material offers a potentially higher average power output than neodymium-doped glass, and could be made inexpensively in large sizes and useful shapes, since it is produced by conventional cold pressing and sintering techniques.

The undoped Yttralox ceramics may find applications as infrared "windows" for carbon monoxide lasers and other devices that could make use of their optical transparency from the ultraviolet to the infrared, their high temperature capability, and their chemical inertness.

"Tests conducted during the past two years have revealed that the neodymium-doped Yttralox laser rods have a gain intermediate between glass and yttrium-aluminum-garnet (YAG), with potentially high energy storage for Q-switching applications," according to Chernoch. Typical rods studies in the project to date have been approximately three inches long and one-quarter inch in diameter.

Yttralox laser material has previously been limited in usefulness by high scattering losses. Greskovich's research has shown that the two most conspicuous optical defects—pores and a variation in the refractive index called "orange peel"—can be virtually eliminated by changes in processing of the ceramic material.

The composition of the Yttralox laser material is 89 mole percent yttrium oxide, 10 percent thorium oxide, and 1 percent neodymium oxide. In earlier fabricating techniques, the constituent powders that compose the ceramic had been manipulated as little as possible in order to avoid contaminating them, since impurities are a serious problem in laser rod materials. Greskovich found, however, that milling the powders in a rubber-lined ball mill for several hours was an important step in achieving high optical quality in the finished rods.

Ball-milling accomplishes three things: reduces the size of the particles, it mixes and disperses the components on a more intimate basis, and it breaks down powder agglomerates that could result in large pores in the finished material.

As a result of sharply reducing the pore density and "orange peel" in the material, the optical quality of the rod is improved to the point where it is possible to sight through a rod and resolve an object several miles away. With material

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that has not been ball-milled, it is hardly possible to resolve an object at the end of the three-inch rod.

Porosity is not the limiting factor in achieving good optical quality with porosity and orange peel virtually eliminated, we are in a position to direct further research toward what we believe are submicroscopic scattering defects which have not yet been identified.

In addition to the goal of achieving a high average energy output laser, the collection of new information on the development of the ceramic microstructure is being emphasized. This should result in new fundamental insight into the fabrication of a variety of other ceramic materials.

The lasing slope efficiency of the neodymium-doped Yttralox laser rod is presently about 43 percent that of a comparable glass laser rod. Its lasing threshold is only eight joules, compared to nine joules for glass, an indication of the high optical quality achieved in the polycrystalline ceramic.

The development, which is continuing, has been partially supported by the Defense Department's Advanced Research Projects Agency and monitored by the Office of Naval Research.

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Cover Caption

The diver seated in an environmental chamber is dressed in a dry suit. Underneath the suit is a garment of plastic tubes to warm the diver when returning to the chamber. *See page 1.*

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