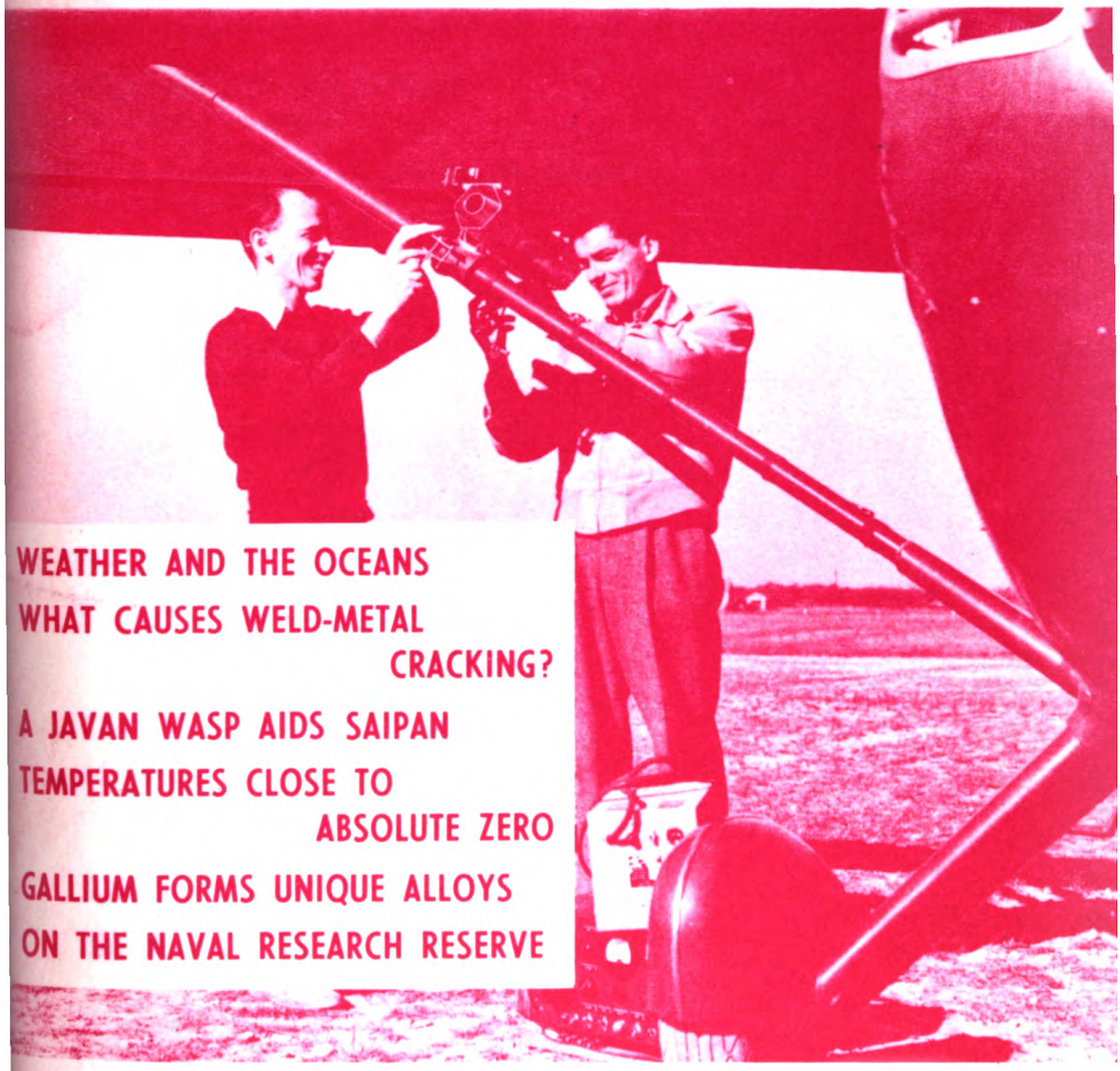
NOVEMBER 1949



# RESEARCH REVIEWS



WEATHER AND THE OCEANS

WHAT CAUSES WELD-METAL CRACKING?

A JAVAN WASP AIDS SAIPAN

TEMPERATURES CLOSE TO ABSOLUTE ZERO

GALLIUM FORMS UNIQUE ALLOYS

ON THE NAVAL RESEARCH RESERVE

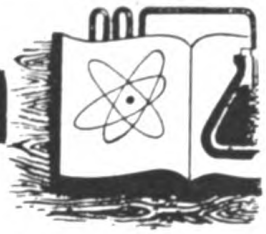
OFFICE OF NAVAL RESEARCH
DEPARTMENT OF THE NAVY
WASHINGTON, D. C.

NAVEXOS P-510

**COVER PHOTO:** A plane is fitted with a psychograph--a self-recording instrument for measuring the amount of moisture in the atmosphere. This is but one of the devices being used to gain more knowledge of WEATHER AND THE OCEANS. See story on page 1.

RESEARCH REVIEWS

● *Informs the Fleet of ONR-sponsored Research*



# Contents

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# Editorial Notes

Dr. Karl Spangenberg recently returned to Stanford University after a year as Head of the Electronics Branch of the Office of Naval Research. Dr. Spangenberg is one of several eminent scientists throughout the country who arranged for university leave to spend a year or two with the Office of Naval Research.

Similarly, ONR has granted leaves of absence to members of its permanent scientific staff to spend some time in active research with an outside laboratory. Dr. E. R. Piore, Director of the Physical Sciences Division, has just completed a year of work at the Massachusetts Institute of Technology Research Laboratory in Electronics. He has returned to ONR to serve as Deputy for Natural Sciences.

This interchange of scientists between ONR and university and industrial laboratories is one means of fulfilling a guiding principle of ONR--the encouragement and stimulation of basic research. Scientists coming to the Branches under the "exchange of personnel" policy not only contribute directly to the administration and progress of ONR's research, but return to their laboratories with a more complete understanding of the Navy's efforts and a clearer picture of specific naval problems. ONR gains immeasurably in procuring for a time the services of outstanding men who will spend a year or so in the public service, but would not be willing to give up their academic careers for permanent Government employment.

ONR's Physics Branch has been particularly active in pursuing such a policy. Dr. Robert Maurer, of the Carnegie Institute of Technology, spent a little more than a year as Head of the Branch, after which he returned to the Institute to continue his research under ONR contract. Dr. E. W. Montroll, presently in charge of the Physics program, is on leave from the University of Pittsburgh.

The scientists who come to ONR are eminently qualified for the jobs they assume; they bring with them an immediate knowledge of the laboratory and its special problems. Their work within ONR gives them a broader grasp of the research program in their field. The relationships of various projects at different institutions are seen as a whole and integrated picture. Frequently, when the scientists return to their laboratories, their services are still available to ONR on a consultant basis.

ONR personnel who go to outside laboratories take with them an intimate knowledge of the Navy's program, problems, and needs, along with administrative understanding of broad research planning. During their stay at the laboratories, they come into direct contact with the immediate problems of a working research project. They return to ONR with a keener appreciation of the individual efforts of the contractors.

This policy of exchanging personnel is a dual highway over which travel the philosophy and mutual understanding needed for effective relations between the research scientist and the science administrator. Does it pay? We think so. Primary evidence is a closely-knit research network linking some of the finest minds in America; secondary but even more convincing evidence is found in results achieved. Research Reviews records a small portion of this evidence.

# Weather and the Oceans

by
Patricia A. Langwell
Woods Hole Oceanographic Institution

Webster says that meteorology is "the science, . . . treating of the atmosphere . . ., especially of its variations of heat and moisture, . . ." This definition quite carefully avoids any mention of weather-forecasting. Before attempting to say anything about what the weather will do, it is necessary to know how to define its components and how to measure them. This problem is complicated by the continual movement of the air. It is, unfortunately, impossible to take a cloud into the laboratory and work with it. Not only is the weather continually moving; it is always changing. For example, as a storm passes over the Rocky Mountains, it is sometimes completely altered in type, intensity, and speed of movement. The ocean has the advantage of having no mountains on it. It has neither cities nor green fields, whose temperatures vary by widely differing amounts from night to day. A storm crossing the ocean is subjected to the forces of other weather phenomena, and to the effects peculiar to a salt-water surface, but not to the frictional drags of terrain. For this reason, it would seem that the description of weather over the ocean would be considerably simpler than for land-weather. However, at this point, another difficulty arises. Even though weather ships and islands are utilized, there are few convenient places for making observations over the ocean. The net result is that the more complicated type of weather, land-weather, is better known. In an attempt to increase the body of information about the influence of the oceans on the atmosphere, ONR is sponsoring a project in marine meteorology at the Woods Hole Oceanographic Institution, Woods Hole, Mass.

Before an air mass may be said to be typical of ocean-weather, it undergoes modification, mostly in the lower few thousand feet, due to the facts that the ocean is wet, and that it is salty. To study these changes, the project is essentially divided into two sections, one of which is attempting to describe the state of the lower atmosphere after it has traveled over a water surface sufficiently long to have the characteristics of ocean-weather; and the other group, attempting to discover in what manner, and how rapidly, a typically dry air mass is changed in its first passage over the ocean.

There is no one single factor which dominates the changes in the elements of the atmosphere. At different times the determining factor in a change of weather may be the speed of rotation or the shape of the earth, the proximity of storms, the strength of a given storm (as

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Patricia A. Langwell, research associate in meteorology at the Woods Hole Oceanographic Institution, has been working with the ONR-sponsored project in marine meteorology since July, 1947. She received her B. A. from Barnard College in 1943, and her M. A. from Duke University in 1947. Both degrees are in mathematics. In 1943, Miss Langwell was an instructor of mathematics and aerial navigation at the U. S. N. Flight Preparatory School at Wesleyan University, Middletown, Conn. During the war, she served as an aerological officer in the Navy. She is at present a candidate for the Ph. D. in meteorology at New York University.

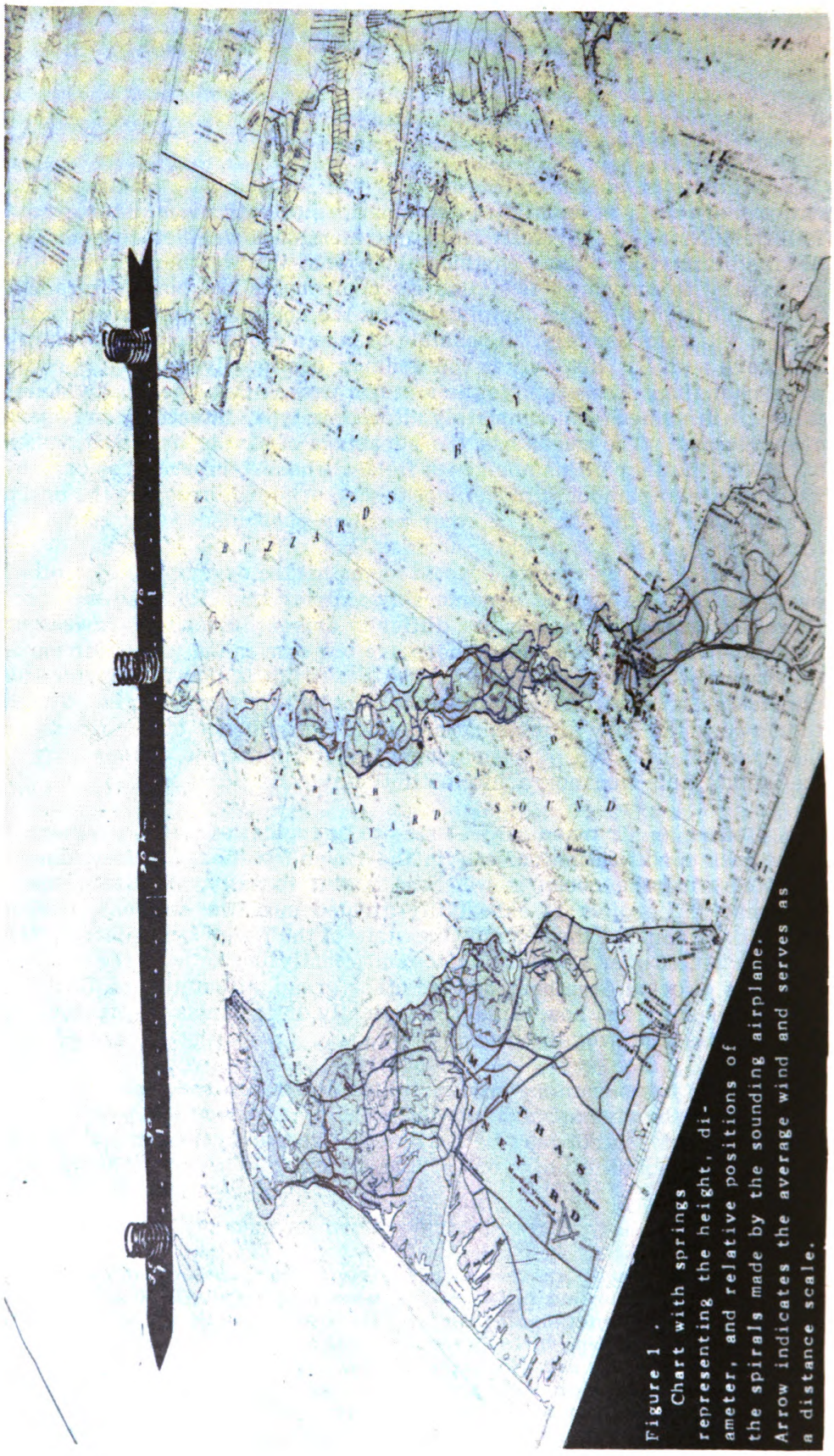


Figure 1 .
Chart with springs representing the height, diameter, and relative positions of the spirals made by the sounding airplane. Arrow indicates the average wind and serves as a distance scale.

measured by its precipitation, its winds, or its pressure gradient), the terrain, or the force of gravity. Since simultaneous consideration of all these things leads to hopelessly complicated mathematics, it is customary to choose for each problem an aspect permitting omission of as many factors as possible. One way is to choose so small a section of the atmosphere that only local factors need be considered. Another method, at the opposite extreme, is to choose so large a section that factors which effect only small regions may be omitted.

The former method has been used to deal with the changes in a dry air mass as it passes out over the ocean. First, an air mass distinctively continental in origin is selected. One type of air which fulfills this qualification is the cold dry air whose origin is northern Canada. Clear skies and winds from the west or northwest are the usual signs of this weather. It is more easily followed, in its passage over land, during the colder months of the year. At this time, the sea water near Cape Cod is several degrees warmer than the land surface. As a result, when the air first passes over the water, the lowest layers of the air are heated, and as they are stirred up, moisture is absorbed from the ocean to the atmosphere. One aim of the marine meteorology project is to determine the amount of this moisture.

In order to do this, a plane is fitted with a type of psychrograph, (an instrument which measures temperature as a function of electrical resistance). The plane ascends in spirals, trying to stay as nearly above a given spot on the surface as possible. The temperature and moisture are measured at 100 foot intervals. A collection of readings of this sort is called a sounding. Two to four soundings are made, depending on the exact wind direction and speed, and the limitations of the plane and terrain. Figure 1 shows a schematic representation of a typical day's flights. One sounding is made over land; one over the water, near land; and a third, to seaward.

By calculating the time that the air takes to travel the measured path, and the amount of moisture added to the air, it is possible to find the rate of diffusion of moisture into the atmosphere.

The moisture received by the air through evaporation is not the only effect of the ocean on a dry air mass. When the wind is strong enough to cause the waves to form "whitecaps," foam and spray are thrown up into the air. In this way, the air acquires, not only more moisture, but small salt particles. The importance of the role of these particles in the ocean's weather should not be judged by their size. They are probably most important as nuclei on which rain and fog drops form. Over the land, the small smoke and dirt particles which are introduced into the air primarily over industrial regions also fill this role. However, simply hypothesizing the presence of salt nuclei is not sufficient. Measurements of their size and number are necessary. The problem of describing their presence more accurately is largely one of instrumentation. Two types of instruments are needed; one to catch the salt, and the other to show the amount caught.

Once again, the study is limited to a small section of any given air mass, in order to cut down the number of factors to be considered. Figures 2 and 3 show the instruments which were designed for the sampling. The instrument in Figure 2 has a glass slide, about 0.04 inch

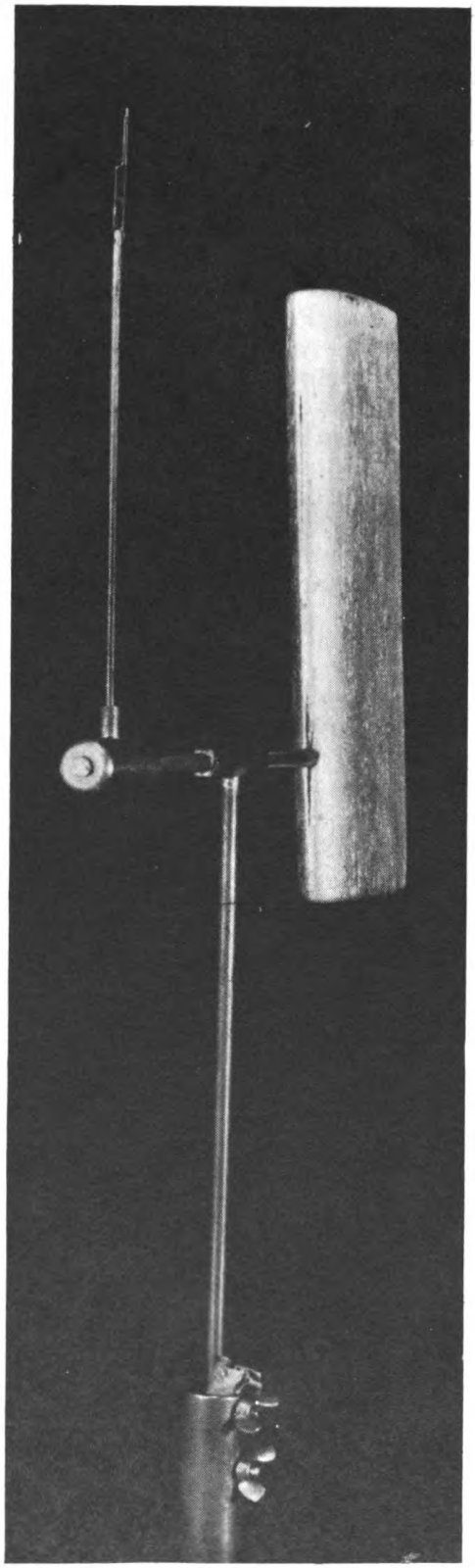

Figure 2. A glass slide for catching salt nuclei.

wide. From the wind speed at the sampling height the time necessary to expose the slide can be calculated. Under average wind conditions, it is found that the glass should be exposed to about 1000 yards of air. The instrument in Figure 3 serves for checking on the first sample. It has 20 silver rods, of the same width as the glass slide, and four inches long; they are exposed to 100 to 200 times as much air as the glass slide. The captured salt is determined by chemical analysis to check on the first values. These instruments seem rather small, until it is realized that the salt crystals contained in the drops are of the order of 0.0001 inch in diameter, or about 1/50 the diameter of a fine human hair.

Samples taken with the glass slide are evaluated by means of a complicated and carefully controlled attachment to a microscope. Under average wind conditions at Bermuda, which has a long over-water trajectory, about 15 to 20 salt nuclei per cubic inch are found. Another indication of their size is that their total weight per cubic inch is only 0.000000000035 ounce. This probably represents the average condition in the lowest layers of the atmosphere over the ocean.

It is to be expected that stronger winds would support more and larger crystals. Actual measurements, made near a hurricane, in winds of 60 knots, showed 10 times the numerical concentration of crystals, with size distribution shifted toward the heavier nuclei. The largest crystals were 10 times larger than in the average conditions. Hence the total weight per cubic inch was 25 times the value found at Bermuda.

It is customary, when something new, like sea salt, has been

measured, to see how it "fits into the picture." Unfortunately, in the case of ocean-weather, there has been no real "picture" for it to fit. The description of weather which has been thoroughly modified by passage over water has been handicapped by the small number of observations. During the war, this lack became especially obvious. In an attempt to remedy the situation an expedition went down to Puerto Rico in the spring of 1946, under the sponsorship of the Bureau of Ships, Navy Department, to make airplane flights over the water north of the island. This group, now sponsored by ONR, collected a great deal of data about the usual ocean-weather in that region. The marine meteorology project is now attempting to interpret and amplify this information.

The lower atmosphere over the ocean can be most easily discussed in terms of three layers. The lowest, about 2000 feet thick, is thoroughly mixed; its humidity remains constant with height. It has been found possible to stipulate the efficiency of mixing necessary to maintain this condition in the atmosphere, and to describe the layer mathematically in this manner. Variations in its thickness have been discussed, and a method for forecasting them advanced.

The top of this layer represents the base of most of the clouds. These clouds, which extend to varying heights up to 9000 feet, are of the cumulus type, which has a cauliflower-like appearance. Larger than their equivalent seen over the United States, the broadest measured was three miles across. They commonly appear in patches with broad clear areas between them. As a result, some regions may seem to be nearly overcast, while a few miles away, only scattered clouds appear on the horizon.

The third layer, above the cloud tops, was in general higher than the airplane was flown. Above this height the air appears to be warmer and drier than in the cloud layer, and the wind shifts from the east, or "trade," wind to the strong westerly flow which circles the earth at higher latitudes in the belt of the prevailing westerlies.

These observations represent at best the ocean-weather in the spring, near Puerto Rico. Many more observations must be taken, before a clear picture will emerge of what happens to the weather over the ocean.

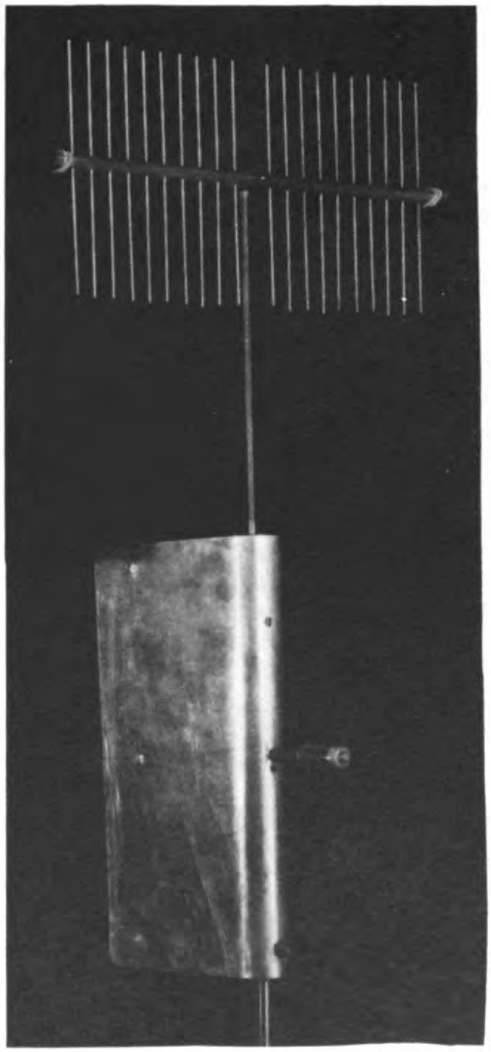

Figure 3. An instrument which also catches salt nuclei to check on samples caught by the glass slide.

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# What Causes Weld-Metal Cracking?

by

Robert D. Williams
Battelle Memorial Institute

This is the second in a series of articles prepared by members of the staff of Battelle Memorial Institute who are conducting research for ONR on heat-resisting alloys.

Since the advent of the turbo-supercharger and the jet engine the problem of weldability of high-temperature alloys has increased in importance. One application of particular interest is the metal-arc welding of buckets to the rims of turbine wheels. Most of this welding has been done with austenitic stainless-steel electrodes, although several high-temperature alloys have also been tried experimentally as electrodes. The major problem encountered in this application has been weld-metal cracking, although some underbead cracking has also been found.

Weld-metal cracking was not unexpected, because joints made with both austenitic and high-strength electrodes (those containing high percentages of alloy) are generally more crack-sensitive than those made with ordinary low-carbon steel electrodes. The high-alloy weld metals are particularly prone to crack where there are stress concentrations.

Certain relations between the proportions of alloying elements and weld-metal cracking have already been established for welds made in the stainless steels. Weld metals whose compositions are such that they do not form a completely austenitic structure form delta ferrite which decreases the cracking tendency during welding. Production experience has shown that certain other elements, such as phosphorus and sulfur, must be kept at lower levels than in ordinary low-carbon steel welds. Also various investigations on the effects of other elements, both in weld metals and base metals, have suggested that they might affect the crack sensitivity of austenitic weld metals, although for many of these the evidence is not conclusive.

Many of the causes of cracking in welds in stainless steels are understood. Unfortunately, as this study has shown, the same causes do not all apply to welds in the high-temperature alloys, even if made with the same electrodes. The reason for this is that highly complex alloys are formed in the welds immediately adjacent to the fusion lines.

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Robert D. Williams is a supervisory engineer on welding research at Battelle Memorial Institute, Columbus, Ohio. He is a graduate of Harvard University and holds a Master of Science degree in physical metallurgy from the Massachusetts Institute of Technology. Prior to joining the Battelle staff in 1942, he taught welding engineering and heat treatment for five years at the University of Illinois. Mr. Williams has been a frequent contributor to the literature on welding technology, and in 1946, was co-author of a paper on resistance welding which won third place in the contest of the Resistance Welders Manufacturer's Association.

The structures of these complex alloys are not known, much less their physical and mechanical properties. Consequently, this investigation has been largely devoted to finding out how welded joints made with certain combinations of known electrode and base-metal alloys will behave with regard to weld cracking, and to determining, for these materials, a few of the physical properties which would be expected to have the greatest effect on such cracking. The welded joints studied were prepared by depositing various types of electrodes, particularly Types 316 and 349 stainless steels, on different high-temperature alloys, particularly Timken Alloy and Vitallium.

Two principal types of weld-metal cracking have been found: (1) cracking within the body of the weld; and (2) cracking associated with the interfaces between adjacent buckets, known as interbucket-junction-extension or notch-extension cracking. The second type has been by far the more serious. It occurs as radial cracks progressing inward from the weld lines as extensions of the planes of contact of adjacent buckets. Little was known about this type of cracking beyond the fact that some combinations of wheels, buckets, and electrodes displayed very severe junction-extension cracking in the weld metal, whereas other combinations produced much smaller extension cracks, which could be safely tolerated.

During the first two years of work, it was found that weld-metal cracking, at least the interbucket-extension type, occurred at temperatures well above 2000° F. Microscopic examinations of welded joints demonstrated that, because of the sluggishness of the alloys involved, the weld metals were frequently inhomogeneous; consequently, the determination of the chemical and physical properties of these weld metals would have been extremely difficult. Sections through the centerlines of some of the welded specimens revealed that marked shrinkage of the weld metal had occurred; this tended to concentrate severe shrinkage stresses in the weld metal adjacent to the abutting faces of the buckets.

The tests also confirmed observations made by others that the weld-metal compositions could not be readily calculated from the geometry of the welded joint. Most of the data on the effect of various elements on weld cracking were qualitative.

Although variations in the amount of cracking were observed in the weld metal deposited under the several conditions of different electrode metals, electrode coatings, or elements inserted into the weld metal, neither an explanation of the causes of weld-metal cracking nor a cure for this type of cracking was found.

At this point in the investigation, it was realized that the welding tests and the chemical and metallographic studies of welds were not providing any definite clues as to the fundamental causes of cracking in high-temperature alloys. One of the reasons for the inconclusive results was recognized to be the lack of fundamental metallurgical information on the base materials and electrodes. Without this information, it was not possible to establish the particular physical property of a weld metal that determined its cracking characteristics.

To develop the desired information, a metallurgical test program was begun including thermal expansion and contraction tests, solidus-liquidus temperature-range determinations, and hot-shortness tests.



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The materials selected for these studies were high-temperature alloys Vitallium, Timken Alloy, Inconel "X," and S-816; electrode core-wire alloys Types 316, 349, and 310, and weld metals from combinations of these.

Although these studies did not positively establish any of the fundamental causes for cracking of welds in the high-temperature alloys, several points were brought out which suggested that continued studies along these lines might ultimately prove more fruitful than those made earlier. For example, while the expansion and contraction curves for the test materials showed no significant differences in the properties of the test materials, the solidus-liquidus temperature ranges were found to vary considerably. It was observed that the narrowest solidus-liquidus temperature ranges were those for S-816 and Type 310 core-wire alloy, both of which have been associated with greater-than-normal weld cracking.

The high-temperature, hot-shortness studies also produced some significant data. They showed that certain of the materials retained appreciable strength above the temperature at which tensile fractures became brittle, while others remained ductile, though weak, at temperatures above 2400°F.

Although not an objective of this investigation, the test results frequently indicated that there was great need for further study of the design of the welded joints. From the point of view of stress concentration, the present design could not well be much worse, for between every bucket there lies a line of very high stress concentration--in effect, a notch. Much work has been done on this problem in the various plants fabricating turbine rotors. But the design engineers of these plants are not likely to deny the possibility of improvement in resistance to weld-metal cracking through a comprehensive and fundamental investigation of joint design, and possibly of the welding procedures and processes involved. In many ways, an investigation of this sort appears to promise a more satisfactory solution to the present problems of weld-metal cracking than any attack on the fundamental metallurgical factors involved.

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# A Javan Wasp Aids Saipan

by

C. E. Pemberton
Insect Control Committee
Pacific Science Board

Coconut trees that once grew luxuriantly on the island of Saipan, Mariana Islands, formed a vital element in the economy of the natives. About 20 years ago a small, flat, brown beetle appeared on the coconut trees for the first time. It is probable that the Japanese unintentionally introduced this beetle into Saipan from some other island in Micronesia where it is now known, but where conditions do not so greatly favor its development. The beetle found conditions suitable and multiplied prodigiously. It fed on the leaves and damage was so severe that the trees lost their lush green color and assumed a brownish, sickly appearance. This was not a temporary visitation. The plague continued during the ensuing years. Large numbers of the affected trees were cut down by the Japanese. The natives, who depend largely upon the coconut for food and for other purposes, suffered accordingly.

In May, 1947, Admiral Chester W. Nimitz requested the Pacific Science Board to select scientists to undertake a study of the Saipan coconut beetle and several other pests in Micronesia to determine methods of control. An Insect Control Committee of the Pacific Science Board was formed and held its initial meeting in Honolulu in September, 1947. Dr. W. H. Lange, a competent and experienced entomologist of the University of California, was assigned to the Saipan beetle problem.

Dr. Lange began his work in October, 1947. In Saipan he made a thorough study of the beetle to determine its habits. He estimated the extent of damage caused by the beetle and looked for local natural enemies on the island. Finding none, he decided to go to countries where closely related beetles were known but where epidemic outbreaks did not occur. It is generally believed by entomologists that most insect pests have in their native habitat important natural enemies which feed on them and do nothing else. As a rule, if the place of origin of an insect can be found, there will also be found in that same region one or more enemies that live naturally upon the insect and depend on it for actual existence. Usually these natural enemies are other insects and they always hold the pest in partial check, sometimes so completely as to prevent any serious damage.

Dr. Lange chose the Malay Archipelago for this study. Entomological literature had already recorded beetles somewhat like the Saipan coconut beetle in the Malay Peninsula, in Java, in the Philippines, in the Solomon Islands and in New Guinea. There was evidence that the

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C. E. Pemberton, chairman of the Insect Control Committee, Pacific Science Board, serves as chief entomologist, Experiment Station, Hawaiian Sugar Planters' Association. He has been engaged in entomological work in the Pacific for 36 years. Much of this time has been spent in explorations for beneficial insects in Fiji, Australia, New Guinea, Java, Borneo, Philippine Islands, Celebes and the Malay Peninsula.

beetles were native to these regions and in some cases natural enemies had previously been found by other entomologists. Dr. Lange visited the Philippines, but most of his attention was confined to the Malay Peninsula and Java. The leading Dutch entomologist in Java informed Lange of a microscopic, black wasp, hardly 1/25 of an inch long, that was an important enemy of a coconut beetle in Java quite similar to the Saipan coconut beetle. Lange found enemies of coconut beetles in the Malay Peninsula also and one species was sent to Saipan and liberated. However, this introduction failed and Dr. Lange felt that the chances for success with the little Javan wasp would be better.

From his headquarters at Kuala Lumpur, Federation of Malaya, Dr. Lange corresponded with the Dutch entomologist in Java and received from him on January 14, 1948, a small consignment of the Javan wasp. This was immediately forwarded by mail to Saipan, but these arrived dead. A week later Lange went to Java, obtained quantities of the beneficial insect, and brought them back to Saipan for release among the coconut trees. The Dutch entomologist also sent more to Saipan on several occasions. Altogether, 2,525 little wasps were obtained from Java and set free in Saipan, and some were released on the island of Rota, south of Saipan, where the coconut beetle was also a serious pest.

The entomologists then anxiously awaited results. Would these little wasps take kindly to Saipan conditions and multiply at the expense of the coconut beetle? On February 14 Lange discovered that the wasps were actually multiplying in the field and destroying the immature stages of the beetle. This phase of the project was thus completed.

A year or more must elapse before the beneficial wasp could be expected to multiply to millions and destroy sufficient numbers of the pest to allow the coconut trees to regain their original healthy condition. To follow the wasp's progress in this development, Dr. R. L. Doutt, another able entomologist of the University of California, was sent to Saipan by the Pacific Science Board in July, 1948. A careful survey of the situation both on Saipan and Rota was made by Dr. Doutt. He found the wasp widespread and abundant, and progress against the coconut beetle was so satisfactory that he recommended replanting of coconuts on both islands. There are thus indications that the battle to control this pest is being won. More time must elapse before it can be said that victory is complete.

The method by which the useful Javan wasp destroys the pest is of interest. The female wasp seeks out a full-grown beetle larva, stings it, and deposits 16 to 35 eggs in its body. The eggs hatch into minute larvae which feed upon the interior fluids of the pest, thus killing it. Within 18 days, under Saipan conditions, these larvae mature to new wasps which bore out of the cadaver of the pest to repeat the cycle. These facts were determined by the entomologists engaged in the study. The wasp was found to produce two generations for one beetle generation.

The successful termination of this problem, in so short a period of time, was only possible through full cooperation by the U. S. Navy, which supplied transportation and other necessary facilities when needed.

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# Temperatures Close to Absolute Zero

by
John G. Daunt
Ohio State University

The absolute zero of temperature is -459° F but it is a fundamental axiom of physics that the absolute zero can never be reached. Despite this, however, scientists have been able to get very close to it, the lowest recorded temperature ever attained being 0.003° F above the absolute zero.

Although we believe that temperatures still lower than this can be attained and indeed work to that end is now being carried out at Ohio State University, the primary purpose of research at these extremes of cold is not merely to establish records. The aim of research at low temperatures is to study the properties of matter at such extremes with a view to discovering more about its structure. The large scale structure of matter which accounts, for example, for cohesion of solids and the behavior of liquids is involved. So is the submicroscopic structure of matter which gives information on its nuclear and atomic properties.

Two of the most puzzling effects in modern physics which have defied any complete explanation for many years and which still await final elucidation, occur when temperatures are reached which are only about 7° F above the absolute zero. The first effect concerns the conduction of electricity through metals. It is well known that as the temperature of a metal wire is reduced, its electrical resistance diminishes. With the decrease of resistance, the amount of heat which a flow of electric current produces also decreases. In general, however, no matter how low a temperature is reached there always remains a small resistance and with it a small heating effect. On the other hand, it was known as long ago as 1911 that a few select metals, when cooled to sufficiently low temperatures, lose their electrical resistance altogether. The first substance found to show this extraordinary "superconductivity," as it is called, was mercury, which loses all sign of electrical resistance below 7.5° F. This effect, in which all heating effects disappear, means that once an electric current is set up in a superconducting ring of one of these select metals, it will flow indefinitely, since there is no resistance to its motion. Such persistent currents have in fact been observed for many hours. The reasons why such an extraordinary effect can occur are still obscure. Their determination is important, not only to clear up this particular problem itself but also for the light it would throw on the mechanism of normal electrical conduction. Consequently this is one of the many problems being attacked by experimental methods at low temperatures.

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John G. Daunt, now in the Department of Physics at Ohio State University, came to this country three years ago from Oxford University, England, where he taught and engaged in research for many years. He obtained his B.A., M.A., and Ph.D. at Oxford University, and prior to the war was one of the foremost investigators of problems of liquid helium in England.

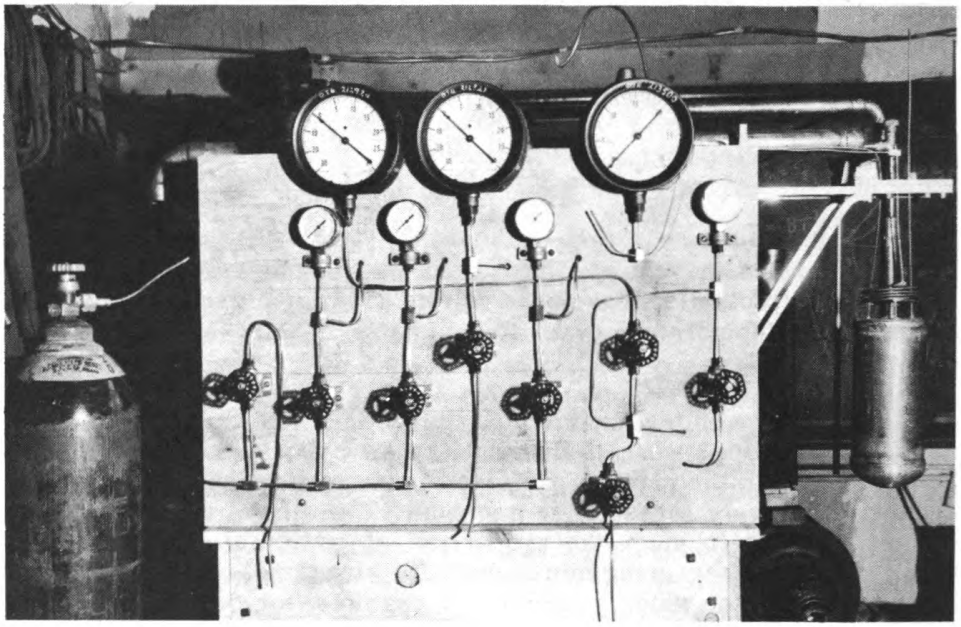

Figure 1. A helium liquefier through which temperatures from -452° F to -457° F can be reached.

The second extraordinary effect which occurs at very low temperatures (below -455° F) is somewhat analogous to superconductivity. At these temperatures helium is liquid, but all other substances, including hydrogen, are in the solid state. The liquid helium at such temperatures is found to be "superfluid"; that is to say, it can flow through tubes and channels without any sign of friction. Matter in the form of liquid helium can be transported in the same effortless way as electricity can flow in a superconductor. This effect is of much more recent discovery, having been found in 1938. Despite the fact that it has been known for more than 10 years now, it is still difficult to understand why it should happen. It seems that at these low temperatures the normal processes by which we characterize the everyday happenings around us no longer hold, and we are instead in a kind of quantum world in which quantum effects take place on a gigantic scale. Such an extension of the pattern of the quantum theory from its usual domain of atomic and nuclear particles into the greater world of large scale tangible objects is of vital and startling importance. To understand it more fully is the goal of the low temperature program, for it will reflect knowledge on other happenings at temperatures to which we are more accustomed.

The technique of obtaining these extremes of temperature in the laboratory is somewhat complicated, depending in the main on the production of liquid helium. By liquefying helium, temperatures can be reached (from -452° F to -457° F) at which every other substance is already solid. Figure 1 shows one of the three helium liquefiers in use in the Physics Department at Ohio State University.

The Office of Naval Research is helping to support this work, by which it is hoped to elucidate the fundamental problems of physics which have been briefly outlined here.

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# Gallium Forms Unique Alloys

by

John P. Denny, J. Hugh Hamilton, and John R. Lewis
University of Utah

Gallium is a metal with a low melting point, 29.78°C, and a high boiling point, of the order of 2000°C. Its commercial applications are few at present although it has been used to a limited extent in high temperature thermometry, dental alloys, and as an excitant for phosphors for fluorescent lighting. Suggested uses include optical mirrors, fire alarm systems, and as an alloy with aluminum to produce the cathode material for metal vapor lamps.

If a demand existed, gallium could be produced in substantially larger quantities than at present. Widely distributed over the earth, it occurs as a rule in minute amounts; extraction costs are therefore high. One study established its presence in 12 out of 14 zinc blendes, in all of 15 aluminum ores, in four out of 12 manganese ores, in 35 out of 91 iron ores, and in all of seven magnetite ores. Recent quotations run from $2.50 to $7.50 per gram, making gallium three to six times as expensive as gold.

Gallium and gallium-rich alloys exhibit a strong tendency to supercool, to remain liquid at temperatures below the melting point. Additional peculiarities are its expansion on freezing, its wetting behavior, and its corrosive character.

As an initial step in the study of alloys that are liquid at room temperature it was necessary to find a suitable containing material for the melts. If wetting occurred, expensive gallium would be lost. In addition, since wetting is selective, there would remain a question as to whether the final alloy truly retained the original melt composition.

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John P. Denny received his B. S. degree in metallurgical engineering at the Colorado School of Mines in 1942. In 1945 he joined the staff of the Battelle Memorial Institute as research engineer. Mr. Denny received the M. S. degree in metallurgical engineering in June 1948 from the University of Utah and expects to receive his Ph.D. in June 1950. While at the University of Utah, his research work has been largely on gallium and its alloys under ONR contract.

Dr. J. Hugh Hamilton is director of the Utah Engineering Experiment Station at the University of Utah. He received his Ph.D. degree from California Institute of Technology in 1928. From 1928 to 1935 Dr. Hamilton was an assistant and an associate professor of electrical engineering, University of Utah. He was research engineer and chief physicist for the Western Precipitation Corp. for nine years, and in 1944 he returned to the University of Utah where he is associated with several ONR projects.

Dr. John R. Lewis received his Ph.D. degree from the University of Wisconsin in 1924. He remained there as an instructor in chemistry until 1929 and then served as an associate professor and professor of chemistry, University of Utah. In 1941 Dr. Lewis was appointed head of the Department of Metallurgical Engineering at the University. He is also actively engaged in research on the physical chemistry and physical metallurgy of metals and alloys.

Qualitative tests established that a 76 percent gallium--24 percent indium alloy wets many substances, including glazed porcelain, quartz, glass, nickel, carbon, Plexiglas, ferric stearate, and Alundum. Little or no wetting occurred on paraffin, lead foil, or paper. It was eventually established that melting could be conducted in a Pyrex tube, under a cover of distilled water or paraffin, without wetting of the glass, and this has become standard practice.[1]

In the experimental work, it has been necessary to modify standard experimental techniques or to develop new ones, because of the low melting point, the cost, and the supercooling properties of gallium. The melting point has necessitated the development of techniques applicable below room temperatures; the cost has necessitated the use of small samples (of the order of one gram); and because of the marked supercooling tendency, it has been found that the most reliable thermal analysis data are obtained by studying melts of these systems. The reverse phenomenon, superheating, is apparently slight or non-existent.

The preparation of the alloys is simplified by the low melting points involved. The solution of gallium-indium alloys can be effected at temperatures below 100°C; accordingly, the metals are weighed, placed in an alloy tube under a cover of distilled water, and the tube is heated in boiling water. For lead-, bismuth-, or tin-containing alloys, a cover of liquid paraffin is used, and the metal mixture heated to above the melting point of the highest-melting constituent. In all cases, the resulting liquid alloys are homogenized by stirring.

Thermal analysis is an excellent method for determining the temperatures at which freezing (or melting) begins. For thermal analysis, the alloys are solidified within the Pyrex tubes, the tubes are placed in a cold Dewar flask, and the unit transferred quickly into a hot, constant temperature bath. The temperature of the alloy is then measured periodically, and plotted either as a function of time or as a function of difference in temperature between the alloy and a neutral body. In the absence of any phase changes--such as a change from solid to liquid--a smooth time-temperature curve results, which approaches the temperature of the bath asymptotically. Should the alloy melt, however, it tends to remain at constant temperature due to absorption of the heat of fusion. Analysis of the melting curves then leads to a determination of the temperatures at which melting begins and ends.

Temperatures have been measured with a 30-gage iron-constantan thermocouple, immersed directly in the alloy. To prevent contamination of the melt, the leads and thermocouple junction are coated with Lucite, applied by painting with a solution of Lucite in ethylene dichloride; after about 30 minutes, sufficient ethylene dichloride has evaporated to permit

[1] The mechanism by which distilled water prevents wetting is thought to be the combination of water with surface gallium oxides, to form small amounts of gelatinous $Ga_2O_3.nH_2O$. Boyer had previously concluded that wetting is caused by the presence of gallium oxides in the metal. A rather striking experiment along this line was performed in this laboratory; a liquid gallium-indium alloy, after being placed on Plexiglas and spread over the surface as a thin, adherent film, was found to contract quickly into a spherical mass, when a drop of hydrochloric acid was placed on the Plexiglas at distances up to three inches from the film. The apparent explanation is that hydrochloric acid vapor effects a surface reaction, principally attacking the gallium oxides, and decreasing the surface adhesion.

handling. In most studies of this nature, the low softening point of Lucite would be prohibitive, but in the present instance, it has been found quite suitable. The low thermal conductivity does not induce an appreciable time lag, since only a thin coating is employed.

It is noteworthy that the described procedure exactly reverses normal thermal analysis procedure, in which alloys are allowed to cool to room temperature. Further, the present technique eliminates fluctuations in furnace heating rate, which is a common objection to the use of melting curves.

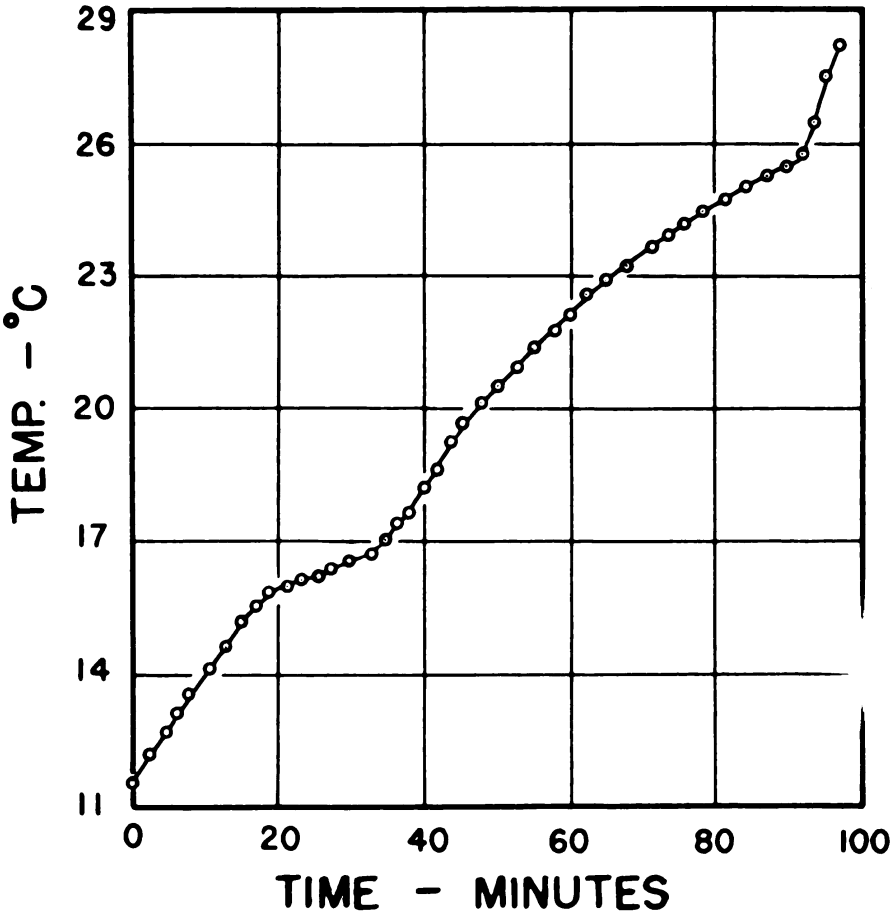


Figure 1. Melting curve at composition 95 percent gallium, five percent indium.

Just as addition of alcohol to the water in a car radiator lowers the freezing point of the water, a similar lowering of the freezing point often occurs on the addition of one metal to another. The temperature of initial solidification is progressively lowered up to a certain critical composition, after which it increases again. In developing low-melting alloys, this critical composition, called the eutectic, is determined. The melting characteristics of eutectic alloys are similar to those of a pure metal, in that melting occurs at constant temperature, rather than over a range. As will be subsequently illustrated, the addition of a third metal to the system may result in further decreases in the freezing point.

A typical melting curve obtained in the present study is shown in Figure 1, which is a plot of temperature versus time. An initial inflection is to be observed in the melting curve at 15.70°C, followed by a final inflection toward the vertical at 25.9°C. These temperatures represent the melting range of the particular alloy investigated, in this case gallium plus five percent indium. By means of this and melting curves at other compositions, it is possible to construct the phase (or equilibrium) diagram of the system. The point of intersection of the descending "liquidus" curves (the curves joining the points of completion of melting) is the eutectic composition. In the system gallium-indium, the eutectic temperature is 15.7°C (as may be deduced from Figure 1), and the eutectic composition, as reported by French and co-workers in J. Phys. Chem. 42, 265 (1938), is 76 percent gallium, 24 percent indium.

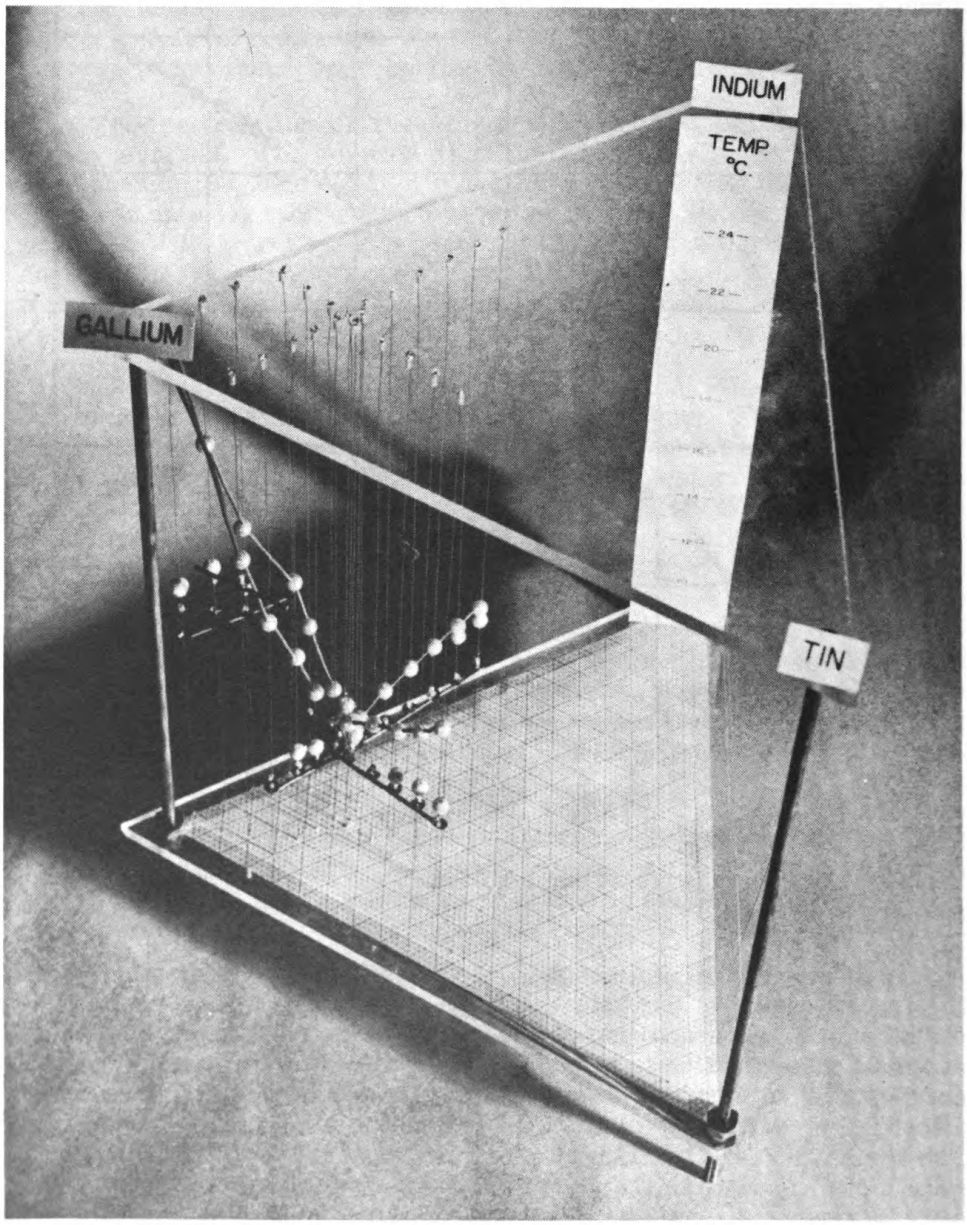


Figure 2. Gallium-Indium-Tin constitution.

Tin is similar to indium in that it also lowers the melting point of gallium. The gallium-tin eutectic temperature is approximately 20.3°C, and the alloy containing 12 percent tin is close to eutectic composition. On the addition of both indium and tin to gallium, we find a ternary eutectic which melts at a lower temperature than either the gallium-indium or the gallium-tin eutectic. This composition is 65.7 percent gallium, 20.9 percent indium, 13.4 percent tin, with a melting point of 10.7° C. The alloy is definitely liquid at room temperatures; its supercooling properties are such that it can be held for lengthy periods at 0°C without solidification, and in working with it, standard procedure is to use dry ice baths (-78°C) to insure solidification. The solid is ductile, and can be hammered into thin plates.

To assist in interpretation of three-dimensional data, the model shown in Figure 2 was used during the course of the work. The construction is relatively simple, and similar models could be used in other fields of investigation requiring three-dimensional configurations. Colored beads, glued to fine vertical wires, are used to plot experimental points. The top and bottom of the model are of 1/4 inch Plexiglas, supported by means of 3/16 inch rods at the corners. The vertical wires, 30-gage (.010 inch) constantan, are passed through small holes in the upper plate and attached to small glass beads. They are kept taut by means of rubber bands, connected to the lower end of the wire, and stretched, under the base, to the rods at the corners. In drilling the holes in the Plexiglas sheet, slow drilling speeds and soapy lubricant are advisable to prevent cracking.

In the model, temperature is represented by the vertical axis, and composition by the horizontal, equilateral triangle. Accordingly, the pure components, gallium, indium, and tin, are represented by the vertical rods at the corners; the binary systems gallium-indium, gallium-tin, and indium-tin are represented by the lateral faces of the prism; and all ternary compositions lie within the prism. Percentage composition of any particular constituent is measured, in the horizontal triangle, as the perpendicular distance from the point under consideration to the side opposite the constituent. The method is based on an equilateral triangle of unit altitude, a property of any point within such a triangle being that the sum of the perpendiculars to the three sides, from the point, is equal to unity.

In Figure 2, the rounded beads, representing liquidus points, are seen to descend within the prism to the eutectic point, lying at the composition 65.7 percent gallium, 20.9 percent indium, 13.4 percent tin. Liquidus surfaces may be visualized. The flat beads represent the point of initial melting at any particular composition. Within the prism, these are seen to form a horizontal plane, the "solidus," which passes through the eutectic point. The melting range of any particular alloy is given by the vertical distance between the solidus and the liquidus surfaces.

Investigation of the gallium-lead-bismuth system has indicated that the addition of lead or bismuth to gallium does not effect any substantial lowering of the melting point. Liquid lead and bismuth, in contrast to indium and tin, are only slightly miscible with liquid gallium. This slight solubility is associated with a eutectic temperature of 27.5°C, and since the eutectic alloy would be solid at room temperatures, gallium-lead-bismuth has not been investigated as thoroughly in

the present study as gallium-indium-tin. The behavior of gallium-lead-bismuth is seen to be similar to the system mercury-water, in which two liquid layers are observed; when gallium-lead-bismuth mixtures are melted, a gallium-rich liquid lies on top of a lead-bismuth alloy.

Breakage of the Pyrex tubes, caused by expansion on solidification, has been somewhat of a problem in all of the alloy systems studied. To minimize breakage (and to conserve on size of sample), centrifuge tubes have been used; the lower portion of this tube tapers to a snub-nosed point. Tubing of a reasonably thick wall has been employed; in some recent work, breakage has been further reduced by wrapping the tubes tightly with rubberized tape, prior to immersion in the freezing unit.

An interesting phase of the present study is an attempt to examine the alloys metallographically (microscopically). Of all the methods for studying phase diagrams, the use of the microscope is the most suitable for revealing the distribution of the phases in a solid; therefore, methods of metallographic examination of gallium alloys are desirable. To conduct a successful investigation, a solid sample must be given a high polish, etched with a suitable chemical reagent to reveal the grain structure, and photographed. In the present study, each of these items necessitates the use of special techniques.

Both casting and microtome methods have been found to give a satisfactory polish. The casting method appears superior, due to rapid surface preparation and the formation of a surface which is not cold worked. In this method, the liquid alloy is spread on a clean glass plate, and subsequently solidified by placing the plate in contact with dry ice. Although liquid gallium wets glass, solid gallium is readily detached by means of a razor blade; the side adjacent to the glass is found to be in a highly polished condition, and readily adapted to metallographic examination. It is possible that the cast surface is non-homogeneous due to selective wetting of oxides and alloy, but this film is no doubt extremely thin, and could be removed by a suitable etching reagent.

The microtome is a rigid instrument, on which is mounted a sharp blade capable of cutting very thin sections. In polishing a specimen, a number of horizontal sections are cut from the top of the specimen, until sufficient area is exposed for microscopic examination. The technique used is essentially a biological one for examining thin sections of plants; the only difference is that the specimen proper, rather than the thin section, is subsequently examined. Best results are obtained when the thickness of the section is one to two microns (.00004 to .00008 inches).

The application of pressure to a gallium-containing specimen, in order to hold it in position during the microtome cut, causes melting. Accordingly, the specimen is mounted on a serrated plate, covered with water, and both specimen and water frozen. The ice backing then lends rigidity to the specimen, and enables it to resist the impact of the blade. A number of cuts are made with the microtome, first through the ice, and finally through the top portion of the specimen.

Etching and photographic techniques to be used in this work are still in the development stage. Common etching reagents for aluminum,

which is chemically somewhat similar to gallium, have been tried without success. Other reagents now show promise, however. In the photography work, close control of temperature is essential. Too high a temperature will permit melting, and too low a temperature will permit frost to form on the specimen. At high magnifications, the heat from the microscope light may cause melting. Preparations are being made for enclosing the specimen and the objective of the microscope in a separate chamber, and desiccating the atmosphere to prevent frost formation. This would permit the maintenance of lower temperatures.

Brief mention has been made of the corrosive character of gallium and its alloys. This property was strikingly brought to the attention of the investigators when, in weighing a small pellet of gallium, it melted on the laboratory balance pan. Although the melt was removed immediately, the pan was found to be severely pitted.

Gallium and gallium alloy systems are well suited to an investigation of supercooling, owing to the marked supercooling properties and to the low melting points involved. Closer experimental control is possible at room temperature than at elevated temperatures, and many precision experiments can be conducted in this range which could not be conducted at higher temperatures.

A systematic study of supercooling has not been made in the present research. It is indicated, however, that the amount of supercooling is proportional to the highest previous temperature of the melt. Solid gallium, melted and heated to 35°C, but not higher, supercools to approximately 26°C before solidifying. Heated to higher temperatures, it may remain liquid when cooled to temperatures as low as 0°C. The observation supports theories that a so-called "liquid" actually contains solid particles in a continuous liquid network. The solid particles serve as nucleation centers during freezing, and the resultant mass, called a solid, actually contains liquid areas in a continuous solid network. To explain the experimental observation (supercooling is a function of the highest previous temperature of the melt), it is postulated that heating above the melting point progressively eliminates the solid particles in the liquid. At high temperatures, only a few nucleation centers will be present, and, on subsequent cooling, the amount of supercooling is substantial.

A means of preventing supercooling would be of great value in phase diagram determinations, and the relatively new field of supersonics offers interesting possibilities. It is reported that the crystallization of paraffin may be induced by ultrasonic vibrations, and a similar effect on such metals as gallium would not be surprising.

During the course of the present work, many additional research possibilities have been apparent. The field of gallium and gallium alloys remains largely unexplored, and many interesting investigations will be conducted. Present research is continuing along several lines. Studies to determine the stability of the newly developed liquid alloys are being conducted, and additional gallium base systems are to be investigated.

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# On the Naval Research Reserve

## ONR Welcomes Units 1-4 and 1-5

Two new Volunteer Research Reserve units were formally activated the early part of October. The formal activation of Unit 1-5 took place in Stratton Hall, Worcester Polytechnic Institute, Worcester, Mass. on Monday evening October 10. Unit 1-4 was formally activated in Coburn Hall, University of Maine, Orono, Maine, on October 11.

CAPT J. A. Jordan, USN, Deputy for Naval Sciences and Acting Director, Naval Sciences Division, ONR-Washington, represented the Chief of Naval Research at both activation ceremonies. He assured the units of the continued cooperation of the Office of Naval Research and pointed out the service the units could render to ONR by their work on specific research problems at the University and at the Institute.

LCDR H. Wray Rohrman, USNR Research Reserve Program Officer for the First Naval District, outlined for the two units the purpose and policies of the Research Reserve program.

CDR Emerson A. Wiggin, USNR, Commanding Officer of the Worcester unit, thanked the visiting dignitaries for their interest and cooperation in getting VRR Unit 1-5 under way. LT Francis J. Sullivan, USNR, Commanding Officer of the Orono unit, expressed appreciation to the visitors for their attendance and share in the activation ceremonies of Unit 1-4.

Pictured at the activation of VRU 1-4, Orono, Maine, are left to right: LCDR M. P. Shaw, USNR, assistant inspector instructor Naval Training Center, Bangor, Maine; CAPT J. A. Jordan, USN, ONR-Washington; LT F. J. Sullivan, USNR, Commanding Officer VRU 1-4; and LCDR H. W. Rohrman, USNR, ONR-Boston.

## Formal Activation Meeting of Unit 5-3

Volunteer Research Reserve Unit 5-3 held its formal activation meeting at Camp Detrick, Frederick, Md., on September 23. The Fifth Naval District was represented at the meeting by CAPT O. L. Livdahl, Director of Naval Reserve. The Office of Naval Research was represented by CAPT C. W. Shilling, USN, Deputy for Biological Sciences. Also present were LCDR T. R. Harrington, USNR, Program Officer for Research Reserve in the Fifth Naval District, and LCDR W. P. Warren, USNR, ONR Reserve Program Officer for the Southeastern Area. Approximately 25 Research Reservists were present at the activation meeting. The Commanding Officer of Unit 5-3 is CAPT LeRoy D. Fothergill, MC,(S), USNR, and the Executive Officer is CDR Herbert H. Fell, MSC, USNR.

## Reduction of Annual Training Duty for Volunteer Reservists

During the first quarter of the current fiscal year more than 50 percent of the annual training funds were expended. As a result BuPers has discontinued until further notice the issuance of annual training duty orders to members of the Volunteer Naval Reserve with the following exceptions:

(a) Orders to annual training duty without pay are authorized without limitation;

(b) Orders for annual training duty issued by addressees prior to receipt of this directive shall not be cancelled. Funds for duty performed in accordance with such orders will be provided.

Subject to approval by the Chief of Naval Personnel orders may also be issued to:

(c) Individual officers and enlisted personnel to whom definite commitments have been made prior to receipt of this directive;

(d) Orders may be issued to fill reserve quotas approved by the Chief of Naval Personnel for previously established courses and seminars covering annual training duty which cannot or should not be filled by members of the Organized Reserve. Under this provision, Volunteer Research Reservists can still apply for training duty at activities where seminars or programs have been previously established. Such training programs and seminars already approved include: Field Economic Mobilization, December 5-16, January 16-27; Public Relations in January, and NOL March 26.

It is hoped that this curtailment of training will be a temporary measure and that some modification will be made before the end of the fiscal year. Research Reservists will be kept informed of any changes in the situation.

# Officially Activated

# Volunteer Research Reserve Units

| Designation | Time and Place of Meeting | Commanding Officer and Mail Address |
|---|---|---|
| 1-1 | 2000, 1st & 3rd Mon.<br>Auditorium, Navy Bldg. 60<br>495 Summer St.<br>Boston, Mass. | CAPT J. W. Hammond, USNR<br>ONR Branch Office<br>495 Summer St.<br>Boston, Mass. |
| 1-2 | 1930, 2nd & 4th Tues.<br>USNROTC Bldg.<br>Brown University<br>Providence, R. I. | CDR C. J. Fish, USNR<br>Oceanographic Institute<br>Woods Hole, Mass. |
| 1-3 | 1900, 1st & 3rd Tues.<br>University of Massachusetts<br>Amherst, Mass. | LCDR E. D. Emerson, USNR<br>Mechanical Eng. Department<br>University of Massachusetts<br>Amherst, Mass. |
| 1-4 | 2000, 1st & 3rd Tues.<br>Coburn Hall<br>University of Maine<br>Orono, Maine | LT Francis J. Sullivan, USNR<br>25 Myrtle St.<br>Orono, Maine |
| 1-5 | 2000, 1st & 3rd Mon.<br>Stratton Hall<br>Worcester Polytechnic Inst.<br>Worcester, Mass. | CDR Emerson A. Wiggin, USNR<br>25 Bay State Rd.<br>Worcester, Mass. |
| 3-1 | 1930, Alt. Thurs., from 8 Sept.<br>Auditorium<br>Cornell University Medical College<br>1300 York Ave.<br>New York, N.Y. | CDR J. D. Hardy, USNR<br>Cornell University Medical College<br>1300 York Ave.<br>New York 21, N.Y. |
| 3-2 | 1930, 2nd & 4th Mon.<br>Special Devices Center<br>Engineering Bldg.<br>Sands Point, Port Washington,<br>Long Island, N.Y. | CDR L. E. Yoder, USNR<br>Special Devices Center<br>Sands Point, Port Washington,<br>Long Island, N.Y. |
| 3-3 | 2000, 1st & 3rd Mon.<br>USNR & MCRTC<br>3 Porter Ave.<br>Buffalo, N.Y. | LCDR Ralph Bloom, Jr., USNR<br>USNRTC & MCRTC<br>3 Porter Ave.<br>Buffalo, N.Y. |
| 3-4 | 1930, 1st & 3rd Tues.<br>USNR & MCRTC<br>900 East Main St.<br>Rochester, N.Y. | CDR Henry C. Sheve, USNR<br>USNR & MCRTC<br>900 East Main St.<br>Rochester 7, N.Y. |
| 3-5 | 1930, 2nd & 4th Thurs.<br>USNRTC<br>Fort Nathan Hale Park<br>New Haven, Conn. | CDR D. S. Rowell, USNR<br>USNRTC<br>Fort Nathan Hale Park<br>New Haven 13, Conn. |
| 3-6 | 2000, 2nd & 4th Mon.<br>USNRTC<br>Syracuse (Liverpool) N.Y. | LT A. O. Quinn, USNR<br>USNRTC<br>Syracuse (Liverpool) N.Y. |
| 3-7 | 2000, 2nd & 4th Thurs.<br>USNRTC<br>Scotia, N.Y. | LCDR. Earl E. Vezey, USNR<br>USNRTC<br>Scotia, N.Y. |

| Designation | Time and Place of Meeting | Commanding Officer and Mail Address |
|---|---|---|
| 4-1 | 2000, 1st & 3rd Wed.<br>Nassau Tavern<br>Princeton, N.J. | LCDR Paul Busse, USNR<br>Aeronautical Eng. Bldg.<br>Princeton University<br>Princeton, N.J. |
| 4-2 | 1930, Alt. Thurs.<br>Franklin Institute<br>20th St. & Parkway<br>Philadelphia, Pa. | LCDR Wm. G. Amey, USNR<br>Electronics Section<br>Franklin Institute<br>20th St. & Parkway<br>Philadelphia 3, Pa. |
| 4-3 | 2000, 2nd & 4th Thurs.<br>303 Thaw Hall<br>University of Pittsburgh<br>Pittsburgh, Pa. | CDR Neil D. Cole, USNR<br>Office of Naval Research<br>University of Pittsburgh<br>303 Thaw Hall<br>Pittsburgh, Pa. |
| 4-4 | 1930, 1st & 3rd Wed.<br>Elec. Eng. Bldg., Rm 110<br>Pennsylvania State College<br>College Station, Pa. | CDR E. R. Queer, USNR<br>c/o Eng. Experiment Station<br>Pennsylvania State College<br>College Station, Pa. |
| 4-5 | USNRTC<br>Foot of Madison St.<br>Wilmington, Del. | LCDR Donald MacCreary, USNR<br>USNRTC<br>Foot of Madison St.<br>Wilmington, Del. |
| W-1 | 2000, 1st Thurs.<br>Navy Dept. Bldg. T-3, Rm 1515<br>2000, 3rd Thurs.<br>Auditorium, Interior Dept.<br>Washington, D.C. | CDR W. M. Richardson, USNR<br>ONR, Bldg. T-3, Rm 2602<br>Washington, D.C. |
| W-2 | 1900, 1st Thurs.<br>NRL Auditorium, Bldg. 8<br>2000, 3rd Thurs.<br>Auditorium, Interior Dept.<br>Washington, D.C. | LCDR H. A. Tanner, USNR<br>Naval Research Laboratory<br>Bldg. 8, Rm 152<br>Washington 20, D.C. |
| W-4 | 2000, 2nd & 4th Wed.<br>Navy Dept. Bldg. T-3, Rm 1803<br>2000, 3rd Thurs.<br>Auditorium, Interior Dept.<br>Washington, D.C. | LCDR Lawrence Gardiner, USNR<br>Atomic Energy Commission<br>Public Health Bldg., Rm 102<br>Washington, D.C. |
| 5-1 | 1930, 1st and 3rd Wed.<br>Rouss Physics Lab.<br>University of Virginia<br>Charlottesville, Va. | LTJG Gilmer T. Fitchett, USNR<br>Cobb Chem. Laboratory<br>University of Virginia<br>Charlottesville, Va. |
| 5-2 | 1915, 1st & 3rd Fri.<br>Virginia Polytechnic Institute<br>Bldg. 364<br>Blacksburg, Va. | LCDR E. D. Harrison, USNR<br>P. O. Box 575<br>Blacksburg, Va. |
| 5-3 | 2000, each Tues.<br>Camp Detrick<br>Frederick, Md. | CAPT LeRoy D. Fothergill, USNR<br>Camp Detrick<br>Frederick, Md. |
| 6-1 | 2000, Alt. Thurs.<br>103 Physics Bldg.<br>Georgia Institute of Technology<br>Atlanta, Ga. | CDR J. E. Boyd, USNR<br>Physics Bldg.<br>Georgia Institute of Technology<br>Atlanta, Ga. |
| 6-2 | 1915, 1st & 3rd Mon.<br>204 Ross Lab.<br>Alabama Polytechnic Institute<br>Auburn, Ala. | LTJG J. E. Land, USNR<br>Chemistry Department<br>Alabama Polytechnic Institute<br>Auburn, Ala. |

| Designation | Time and Place of Meeting | Commanding Officer and Mail Address |
|---|---|---|
| 6-3 | 2nd & 4th Tues.<br>A.E.C. Townsite<br>Oak Ridge National Lab.<br>Oak Ridge, Tenn. | LCDR D. J. Mallon, USNR<br>P. O. Box P<br>Oak Ridge, Tenn. |
| 6-4 | 1930, 1st & 3rd Tues.<br>Engineering Bldg.<br>University of Florida<br>Gainesville, Fla. | LCDR E. G. Rietz, USNR<br>Chemistry Department<br>University of Florida<br>Gainesville, Fla. |
| 6-5 | USNRTC<br>Gulfport, Miss. | LT V. O. Smallwood, USNR<br>2412 East Ave.<br>Gulfport, Miss. |
| 6-6 | 1945, 2nd & 4th Thurs.<br>USNROTC Armory<br>University of North Carolina<br>Chapel Hill, N.C. | LCDR R. F. Stainback, USNR<br>317 W. University Drive<br>Chapel Hill, N.C. |
| 6-7 | 2000, 2nd & 4th Thurs. (Irregular)<br>Biology Bldg.<br>Duke University<br>Durham, N.C. | LCDR John H. Roberts, USNR<br>2813 Legion Ave.<br>Durham, N.C. |
| 8-1 | 1930, 1st & 3rd Tues.<br>USNROTC<br>Tulane University<br>New Orleans, La. | LCDR John M. Scott, USNR<br>Chemistry Department<br>Tulane University<br>New Orleans, La. |
| 8-2 | 1930, 2nd & 4th Wed.<br>USNRTC<br>Baton Rouge, La. | LCDR W. R. Edwards, Jr., USNR<br>Chemistry Department<br>Louisiana State University<br>Baton Rouge, La. |
| 8-3 | 1930, 2nd & 4th Mon. &<br>2nd Thurs.<br>P & M A Bldg.<br>Texas A & M College<br>College Station, Tex. | LCDR Norman F. Rode, USNR<br>Electrical Eng. Dept.<br>Texas A & M College<br>College Station, Tex. |
| 8-4 | 1930, Alt. Wed. (14 Sept.)<br>USNROTC Bldg.<br>Rice Institute<br>Houston, Tex. | LTJG John J. Banewicz, USNR<br>4811 Mt. Vernon St.<br>Houston, Tex. |
| 8-5 | 2000, Alt. Tues. & Wed.<br>(14 Sept.)<br>Physics Bldg., Rm 201 or<br>Chemistry Bldg., Rm 15<br>University of Texas<br>Austin, Tex. | LCDR G. H. Ayers, USNR<br>Chemistry Department<br>University of Texas<br>Austin, Tex. |
| 8-6 | (Meetings irregular)<br>USNRTC<br>Galveston, Tex. | LTJG C. N. Sechrist, USNR<br>1235 3rd Ave. North<br>Texas City, Tex. |
| 8-7 | Albuquerque, New Mexico | LCDR Sherman A. Wengard, USNR<br>USNR Training Center<br>Albuquerque, New Mexico |
| 9-1 | 1900, 2nd & 4th Tues.<br>Navy Pier Campus<br>University of Illinois<br>Chicago, Ill. | CAPT George C. Lamb, USNR<br>Technological Institute<br>Northwestern University<br>Evanston, Ill. |

| Designation | Time and Place of Meeting | Commanding Officer and Mail Address |
|---|---|---|
| 9-2 | 1930, 1st Wed. (Irregular)<br>319 Gregory Hall<br>University of Illinois<br>Urbana, Ill. | LCDR A. C. Williams, Jr., USNR<br>Psychology Department<br>University of Illinois<br>Urbana, Ill. |
| 9-3 | 1930 (Irregular)<br>Angell Hall, Rm 18<br>University of Michigan<br>Ann Arbor, Mich. | CDR C. M. Davis, USNR<br>Geography Department<br>University of Michigan<br>Ann Arbor, Mich. |
| 9-4 | 1930, 2nd & 4th Tues.<br>Old Armory, Rm 107<br>Ohio State University<br>Columbus, Ohio | LCDR Karl E. Krill, USNR<br>Engineering Exp. Station<br>Ohio State University<br>Columbus, Ohio |
| 9-5 | 1930, 1st & 3rd Wed. (Irregular)<br>NROTC Bldg.<br>Iowa State College<br>Ames, Iowa | LCDR O. C. Kreider, USNR<br>Mathmetics Department<br>Iowa State College<br>Ames, Iowa |
| 9-6 | 1930, 1st Mon. & 3rd Tues.<br>Murphy Hall Auditorium<br>University of Minnesota<br>Minneapolis, Minn. | LCDR J. A. Wise, USNR<br>220 Experimental Eng. Bldg.<br>University of Minnesota<br>Minneapolis, Minn. |
| 9-7 | 1930, 2nd & 4th Thurs. (Irregular)<br>111 Stanley Coulter Hall<br>Purdue University<br>Lafayette, Ind. | LT L. M. Baker, USNR<br>Psychology Department<br>Purdue University<br>Lafayette, Ind. |
| 9-8 | 2000, 1st Wed. (Irregular)<br>101 Crew Hall<br>Washington University<br>St. Louis, Mo. | CDR R. M. Varney, USNR<br>Physics Department<br>Washington University<br>St. Louis, Mo. |
| 9-9 | 1930, Alternate Thurs. (13 Oct.)<br>204 Mechanics Hall<br>Missouri School of Mines & Metallurgy<br>Rolla, Mo. | CDR R. A. Cooley, USNR<br>Missouri School of Mines & Metallurgy<br>Rolla, Mo. |
| 9-10 | 1930, 1st & 3rd Wed.<br>USNRTC<br>Peoria, Ill. | LCDR F. C. Albers, USNR<br>108 Devon Lane<br>Peoria, Ill. |
| 9-11 | 2000, 1st & 3rd Mon. (Irregular)<br>USNRTC<br>1089 E. Ninth St.<br>Cleveland, Ohio | LCDR Viktor Schreckengost, USNR<br>2366 Noble Road<br>Cleveland 21, Ohio |
| 9-12 | (Time & Date Not Established)<br>Botany Bldg. Annex<br>Colorado A & M College<br>Ft. Collins, Colo. | LTJG W. D. Thomas, USNR<br>Botany & Plant Pathology Dept.<br>Colorado A & M College<br>Ft. Collins, Colo. |
| 9-13 | 1930, Wednesdays<br>USNRTC<br>9th & Pleasant Sts.<br>Des Moines, Iowa | LCDR John R. Maloney, USNR<br>2920 48th St.<br>Des Moines 10, Iowa |
| 9-14 | (Time & Date Not Established)<br>USN Armory<br>University of Wisconsin<br>Madison, Wis. | CDR W. B. Sarles, USNR<br>University of Wisconsin<br>Madison 6, Wis. |
| 9-15 | (Time & Date Not Established)<br>Community Center<br>Midland, Mich. | LTJG D. D. McCollister, USNR<br>1220 Michigan St.<br>Midland, Mich. |

| Designation | Time and Place of Meeting | Commanding Officer and Mail Address |
|---|---|---|
| 9-16 | (Time & Date Not Established)<br>Michigan State College<br>East Lansing, Mich. | LT Elbert S. Churchill, USNR<br>Bacteriology Department<br>Michigan State College<br>East Lansing, Mich. |
| 11-1 | 2000, 1st & 3rd Tues.<br>1030 E. Green St.<br>Pasadena, Calif. | LCDR Frederick P. Dillon, USNR<br>1030 E. Green St.<br>Pasadena, Calif. |
| 11-2 | 2000, Alt. Thurs.<br>USNROTC Armory<br>Pasadena, Calif. | LCDR J. H. Biggar, USNR<br>680 E. Colorado Dr.<br>Pasadena, Calif. |
| 11-3 | 2000, 1st & 3rd Mon.<br>USNR & MCRTC<br>851 Chavez Ravine Rd.<br>Los Angeles, Calif. | CDR L. P. Delsasso, USNR<br>Physics Department<br>University of California<br>Los Angeles, Calif. |
| 11-4 | (Time & Date Not Established)<br>USNRTC<br>San Pedro, Calif. | LCDR. Myron S. Allen, USNR<br>3130 East Second St.<br>Long Beach, Calif. |
| 11-5 | (Time & Date Not Established)<br>USNRTC<br>San Diego, Calif. | CDR Gifford C. Ewing, USNR<br>1205 Muirlands Drive<br>La Jolla, Calif. |
| 12-1 | 2000, 2nd & 4th Mon.<br>801 Donahue St.<br>San Francisco, Calif. | CDR J. E. Laurance, USNR<br>ONR Branch Office<br>801 Donahue St.<br>San Francisco, Calif. |
| 12-2 | 1945, 2nd & 4th Mon.<br>Donner Lab., Rm 201<br>University of California<br>Berkeley, Calif. | LCDR Nello Pace, USNR<br>Life Science Bldg., Rm 2519<br>University of California<br>Berkeley, Calif. |
| 12-3 | 2000, 2nd & 4th Wed.<br>Engineering Corner, Rm 208<br>Stanford University<br>Stanford, Calif. | CDR L. S. Jacobsen, USNR<br>Mechanical Engineering Dept.<br>Stanford University<br>Stanford, Calif. |
| 12-4 | 2000, 2nd & 4th Thurs.<br>McLane Hall, Rm M-103<br>Fresno State College<br>Fresno, Calif. | CDR Ralph A. Jack, USNR<br>Physics Department<br>Fresno State College<br>Fresno 2, Calif. |
| 12-5 | 1930, 2nd & 4th Wed.<br>LeConte Hall, Rm 208<br>University of California<br>Berkeley, Calif. | CDR C. F. Garland, USNR<br>Engineering Design Division<br>University of California<br>Berkeley, Calif. |
| 12-6 | 1945, 2nd Mon.<br>Animal Science Bldg.,<br>Tower Room<br>University of California<br>Davis, Calif. | LT Arthur H. Smith, USNR<br>Animal Husbandry Division<br>University of California<br>Davis, Calif. |
| 13-1 | 1930, 2nd & 4th Mon.<br>Anatomy Bldg., Rm 108<br>University of Washington<br>Seattle, Wash. | CDR H. S. Bennett, USNR<br>Anatomy Department<br>School of Medicine<br>University of Washington<br>Seattle, Wash. |
| 13-2 | 1900, 2nd & 4th Tues.<br>American Legion Hall<br>Richland, Wash. | LT W. W. Gonder, USNR<br>General Electric Co.<br>Richland, Wash. |

| Designation | Time and Place of Meeting | Commanding Officer and Mail Address |
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| 13-3 | 1930, 2nd & 4th Mon.<br>YMCA<br>Pullman, Wash. | LCDR W. G. Gnaediger, USNR<br>Community College Serv.<br>State College of Washington<br>Pullman, Wash. |
| 13-4 | 1930, 1st & 3rd Mon.<br>Swan Island<br>Portland, Oreg. | LCDR Richard F. Stevens, USNR<br>811 N. E. Oregon St.<br>Portland, Oreg. |
| 13-5 | (Time & Date Not Established)<br>Oregon State College<br>Corvallis, Oreg. | LCDR Albert V. Logan, USNR<br>Chemistry Department<br>Oregon State College<br>Corvallis, Oreg. |



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