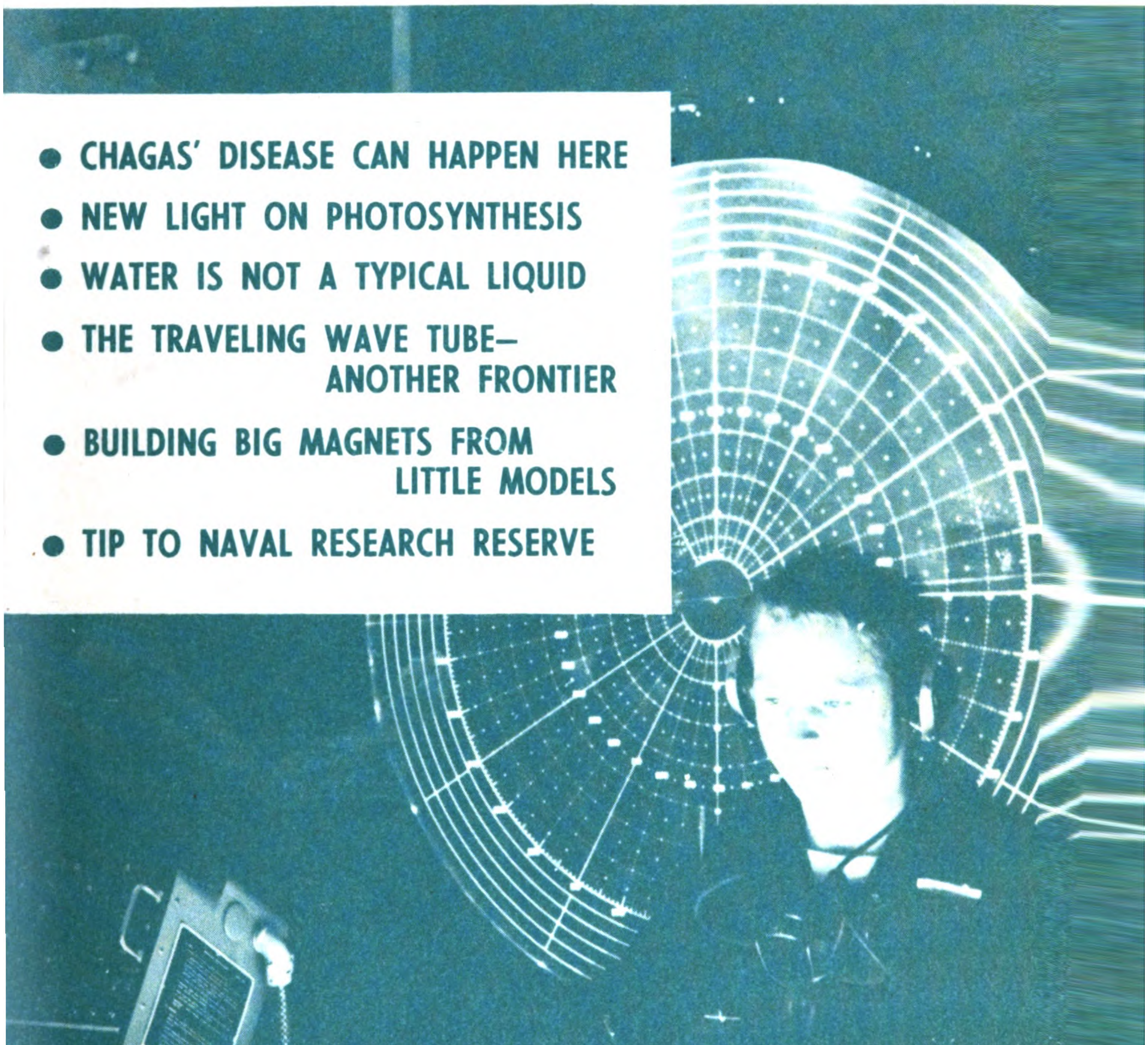
JANUARY 1949 RESTRICTED

RESEARCH REVIEWS



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OFFICE OF NAVAL RESEARCH
DEPARTMENT OF THE NAVY
WASHINGTON, D. C.
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COVER PHOTO: One of the electronics mates who spend long hours studying intricacies of electronics. The article in this issue on the traveling wave tube describes a new frontier in the field of electronics.

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Approved by Bureau of Budget, 13 April 1948

RESEARCH REVIEWS--

A monthly journal devoted to ONR-sponsored research

Write Code 484, Office of Naval Research, Department of the Navy, Washington, D. C.

LETTERS

Letters have been received from contractors expressing their distress over the "Restricted" classification of Research Reviews. The purpose of this classification is to permit contributors to retain their right to publish elsewhere. The Navy's security manual gives a number of examples of "Restricted" matter, one of which is (3) "training and technical documents for official use only or not intended for release to the public." If it is determined that most contributors would prefer that Research Reviews be unclassified, and are not concerned about publication elsewhere, then we agree that Research Reviews should be declassified. The matter is now under consideration, and the editors hope it will be resolved to everyone's satisfaction. Meantime comments on this subject are invited.

To the editor:

RESEARCH REVIEWS is doing a fine job of keeping the Reserve informed of research projects under the Office of Naval Research, but these articles are general and nontechnical (as they should be). How can a scientist in the Research Reserve obtain technical reports and other detailed information concerning Navy-sponsored research in his particular specialty?

Sincerely,
Herbert S. Bailey, Jr.
Lieut., USNR

Research Reviews does not attempt to give technical detailed information regarding projects but it does tell the what, how, or why of research which readers may then explore further either by inquiry to this Office or to the research worker himself. A Research Reserve scientist may obtain technical reports and other information on ONR-sponsored research in his particular field of specialization by writing the Chief of Naval Research. (See page 26 of this issue.)

By a recently adopted plan, a copy of "TIP" (Technical Information Pilot) will now be sent to each Naval Research Reserve Unit. This pamphlet is one of the tasks of the Science and Technology Project sponsored by the Office of Naval Research. "TIP" contains abstracts and indexes of all technical reports under the National Military Establishment, other government agencies, and of some independent research workers and is the only abstracting service for these reports. It is distributed to military agencies, academic institutions, and industry qualified to receive such information through work on a Naval contract.

Also in this connection it might be worth noting that the Office of Naval Research has an agreement with the Library of Congress whereby if ONR considers that a technical report should receive wider distribution than it is receiving, the Card Division of the Library includes a reference to it in their printed cards issued in subject classes to 7000 subscribers. These cards state what the report is about, where it can be obtained, and the price. All interested persons can subscribe, or consult the cards in a subscribing library.

The Editors

EDITORIAL MUSINGS

Physicists know everything about everything, as is well known. They, however, now find themselves in a serious quandary where a whole group of new phenomena has been found which do not fall into the straight forward categories to which physicists are accustomed. For a long time all matter was thought to be composed of electrons and protons. Physicists have now found new particles called mesons which have entirely different characteristics from electrons and protons as far as mass is concerned; indeed, several kinds have been found. For lack of a better method of identifying them,these new particles are designated by means of Greek letters - pi, mu, etc. That physicists have a sense of humor about their sad state is evidenced by this poem, which is the result of one physicist's effort to describe this state of affairs. This poem by an ONR contractor was read at a meeting of world authorities on physics-- the Solvay Congress, in September of this year. You might find it amusing too.

There are mesons π, there are mesons μ
The former ones serve as a nuclear glue
There are mesons τ, or so we suspect
And many more mesons which we can't yet detect

Can't you see them at all?
Well, hardly at all
For their lifetimes are short
and their ranges are small

The mass may be small, the mass may be large,
We may find a positive or negative charge,
And some mesons never will show on a plate
For their charge is zero, though their mass is quite great

What, no charge at all?
No, no charge at all!
Or, if Blackett is right
It's exceedingly small

Some beautiful pictures are thrown on the screen,
Though the tracks of the mesons can hardly be seen,
Our desire for knowledge is most deeply stirred
When the statements of Serber can never be heard

What, not heard at all?
No, not heard at all!
Very dimly seen
And not heard at all!

There are mesons λ at the end of our list
Which are hard to be found but are easily missed
In cosmic-ray showers they live and they die
But you can't get a picture, they are camera-shy

Well, do they exist?
Or don't they exist?
They are on our list
But are easily missed.

From mesons all manner of forces you get
The infinite part you simply forget,
The divergence is large, the divergence is small,
In the meson-field quanta, there is no sense at all.

What, no sense at all?
No, no sense at all!
Or, if there is some sense
It's exceedingly small.

Adapted by: Edward Teller, Professor of Theoretical Physics, Institute For Nuclear Study, University of Chicago

CHAGAS' DISEASE CAN HAPPEN HERE

Ardzroony Packchanian
Department of Bacteriology and Laboratory of Microbiology
University of Texas School of Medicine

Chagas' disease is an infectious disease which has been found in South America and Mexico, occurring in either an acute or chronic form. The acute form, most frequently found in infants and young children, is characterized by fever and enlargement of the lymph nodes. When the infection takes place through the eye, as it often does, the above symptoms are preceded by swelling of the eyelid and engorgement of the blood vessels in the mucous membranes of the eye which persist for several days. In the chronic form, occurring in older children and adults, there may be enlargement of the heart, various electrocardiographic changes, fatigue, low grade fever, or apparently no symptoms at all.

Since 1909 when the disease was first reported in Brazil, a great many cases have been reported in the South American countries. Up to the present time, however, no cases have been reported in the United States, although the epidemiological factors necessary for its occurrence are present in numerous sections of the Southwest.

Chagas' disease is caused by a parasite, Trypanosoma cruzi. The parasite has a body which is ribbon-like with tapering ends and a long delicate tail attached to the body by means of a thin membrane, usually called the "undulating membrane." When found in the blood of the infected individual, the parasite is in this form. However, in the early stages of the disease, most of the trypanosomes leave the blood stream and invade the tissues. In the tissues, it loses the ribbon-like shape and becomes more spherical, losing the tail in the process. This spherical form multiplies in the muscle cells until the muscle cell ruptures and the liberated trypanosomes invade other cells.

A. Packchanian, Professor of Bacteriology and Parasitology and Director of the Laboratory of Microbiology, University of Texas School of Medicine, is conducting research on Chagas' disease and Weil's disease under the sponsorship of the Office of Naval Research. Dr. Packchanian received his Ph. D. (1933) from the University of Michigan while working under the direction of Prof. F. G. Novy. He was formerly with the U. S. Public Health Service as protozoologist at the National Institute of Health where he conducted research in tropical infectious diseases for six years. In 1941, Dr. Packchanian joined the faculty of the University of Texas School of Medicine. During the last war, he served in the Armed Forces as laboratory officer and post medical inspector. On his return from service to the University of Texas School of Medicine, he assumed his former duties as teacher and research investigator.

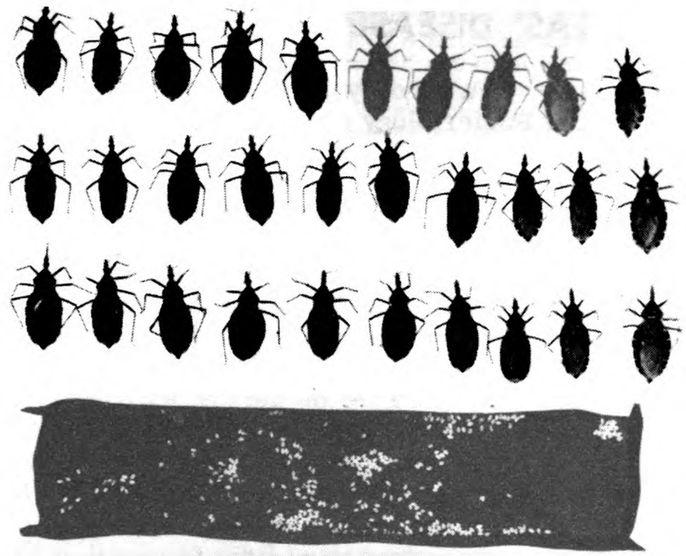

Fig. 1. Adult blood-sucking insects (Triatoma) and eggs.

The parasite is carried in the intestines of a group of insects which are commonly called "kissing bugs," "blood suckers," "Mexican bed bugs," and are classified scientifically as Triatoma. If the "kissing bugs" bite an infected animal or human, the trypanosomes lodge and multiply in the intestine of the insect. When the infected insect bites a normal human, the human will not contract the disease from the bite itself. However, the infected insect, after taking a full blood meal, excretes fecal material containing the trypanosomes in or around the bite. If such material is rubbed into the bite, the eye, or some other broken skin, the infection may take place.

The kissing bugs are widely distributed in southwestern United States, but the naturally infected bugs have so far been reported only in four states of this region. The adult insect may be found in and around dens and nests of wild animals, such as wood rats, opossums, and armadillos, which are reservoirs of trypanosomes. During the summer, the adult insects fly to sites of human and domestic animal habitation where they sustain themselves by blood feeding on the hosts. Inasmuch as this insect is widely distributed in certain parts of the Southwest, particularly Texas, Arizona, California, and Nevada, military personnel on bivouac in these states should take special precautions against this insect.

For the absolute diagnosis of Chagas' disease, the parasite must be isolated from the patient. Isolation may be done in a variety of ways. In the acute stages of the disease, the ribbon form can occasionally be demonstrated microscopically in the blood. However, there are usually so

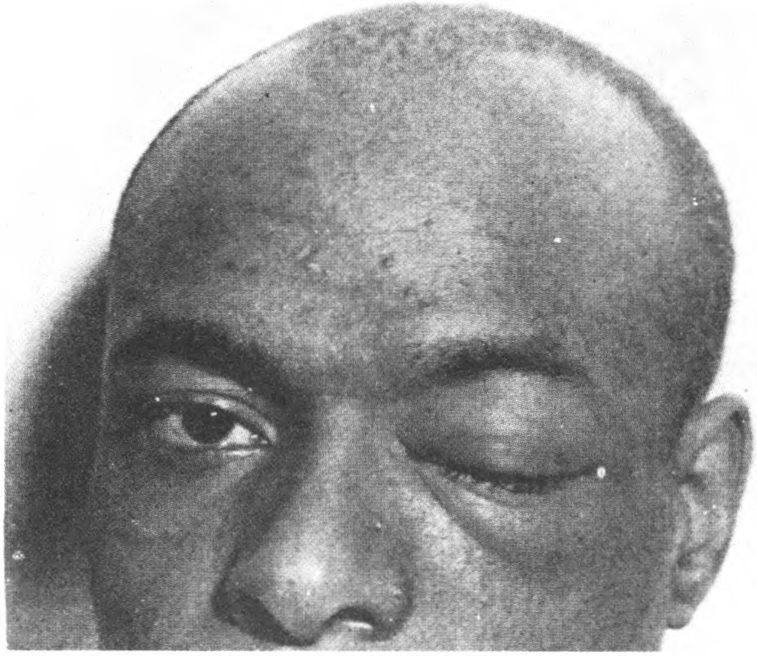

Fig. 2. Infection of a male Negro (age 26) with Trypanosoma cruzi (U. S. Texas strain). Note swelling of the left eyelid.

few of them in the blood that the blood must be concentrated in order to demonstrate a single trypanosome. The cultural method should always be utilized. This cultural method is a 5 to 10 cc inoculation of the patient's defibrinated blood into 10 or 12 tubes of Novy-MacNeal's medium, which consists of an agar base and normal rabbit's blood. Positive cultures can be obtained from the second to fourth week on incubation at room temperature. Animal inoculation tests are also valuable to diagnose the disease. As much as 10 cc of defibrinated blood should be injected into guinea pigs and mice. In positive cases, a few trypanosomes may be demonstrated in the peripheral blood by microscopic examination after two weeks. However, the test animal should be subjected to cultural tests for final diagnosis.

Our laboratory has been exploring the value of the cardiac condition in Chagas' disease as a possible aid in diagnosis. Experimental animals infected with the disease have undergone electrocardiogram examinations to determine a definite pattern particular to the infection.

In chronic cases where the usual methods of microscopic examination, cultural test, and animal inoculation are often negative, serological methods will be of diagnostic value. During the past few years, the writer has been working on this problem. Although serological studies such as complement fixation tests were performed as early as 1913 by

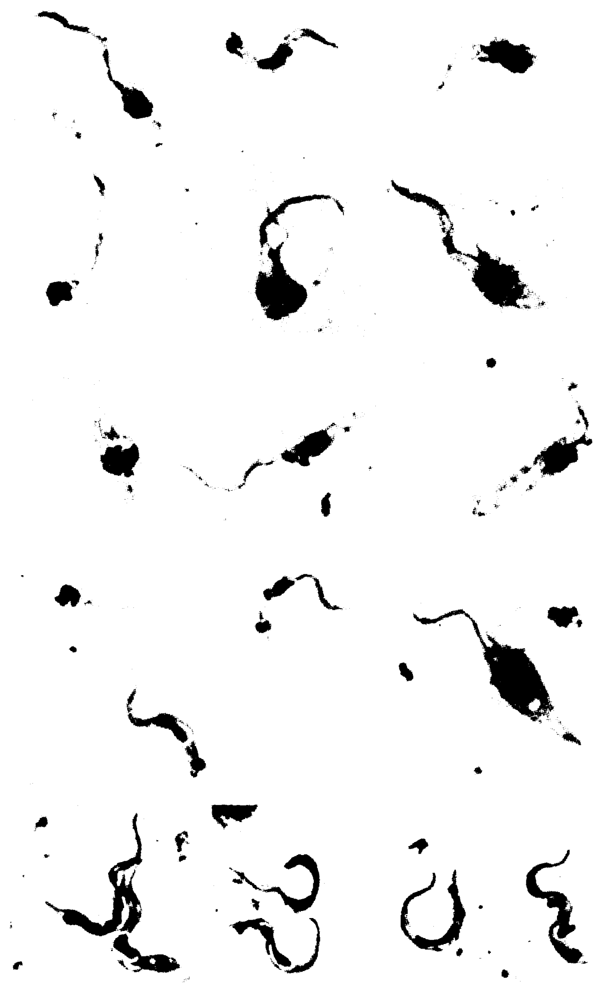

Fig. 3A. The parasite, Tr. cruzi, as found in intestinal contents of a naturally infected "blood sucker" (Triatoma).

Guerreiro and Macchado and later by others, the antigen employed was organs of infected animals. In 1935, the writer was the first to utilize the Tr. cruzi organism itself, thus making serological tests more specific. The agglutination test was employed with good results. Following this, other workers used the complement fixation test, employing Tr. cruzi culture as antigen. However, the latter test proved to be too cumbersome for clinical use. In recent years, the precipitin test introduced by me in 1935 has been successful and has been modified many times with improved results. Originally, the antigen for the precipitin test consisted of one volume of packed, washed Tr. cruzi with nine volumes of sterile distilled water. The precipitation titer was low with this and other antigens, but the test was specific and of diagnostic value. Recently, the writer prepared the antigen by extracting the polysaccharides from Tr. cruzi by various methods. This polysaccharide antigen has given

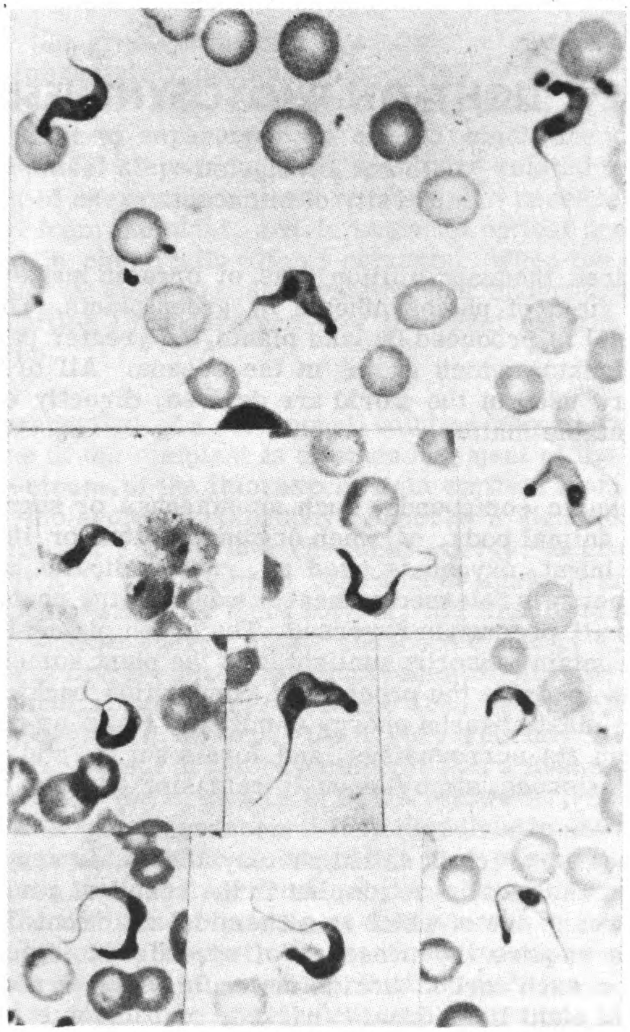

Fig. 3B. Tr. cruzi as found in the circulating blood of mammals.

strong positive results with Tr. cruzi antisera in high dilution from experimental animals and from known cases of human Chagas' disease.

Our research workers have undertaken a large-scale survey with the use of the precipitin test in an effort to find positive cases of Chagas' disease in the Southwest. In the meantime, constant efforts are being made to improve and standardize the precipitin and other serological tests for diagnosis of this important disease.

The first human case of Chagas' disease was not diagnosed in Uruguay until after sixteen years of search. Since then this disease has been diagnosed with increasing frequency and diagnosis is now quite commonplace in that country. In my opinion there have been cases of Chagas' disease in southwestern United States and with improvement of diagnostic techniques, the disease will be recognized.

NEW LIGHT ON PHOTOSYNTHESIS

Robert Livingston
University of Minnesota

One hundred thousand million tons of organic matter is the estimated annual yield of photosynthesis by green plants. Only about one fifth of this total is produced by land plants, the greater part being contributed by plankton which grows in the oceans. All of the foods and fuels which are used in the world are derived, directly or indirectly, from this vegetable matter.

When organic compounds, such as starches or sugars, are consumed in the animal body, or when organic matter or its degradation products are burnt, oxygen is used up, carbon dioxide and water are formed, and energy is released as heat or work. In the photosynthesizing plant this overall process is reversed. The green pigment, chlorophyll, which plants contain, absorbs sunlight, and the plant somehow uses this radiant energy to drive the process of combustion backwards. In the light, a green plant absorbs energy (sunlight), takes up carbon dioxide and water from its surroundings, and forms sugars and other organic material in its tissues, simultaneously releasing gaseous oxygen.

This process, which is called photosynthesis, is very complex. It is not a simple chemical reaction, but is the result of a number of successive steps, each one of which is a chemical reaction. Many of these reaction steps require the presence of specific biological catalysts, enzymes. For each carbon dioxide molecule which is reduced to form sugar, at least eight light quanta (packets of radiant energy) must be absorbed successively. Although photosynthesis has been studied actively for over one hundred years, many of its details are still obscure. In recent years, considerable progress has been made in the study of the sequence of chemical steps, by the use of radioactive and stable isotopic "tracers," by growing (simple) plants in flashing light, rather than illuminating them continuously, and by observing the effects of certain specific poisons on the rate of photosynthesis.

Robert Livingston, Professor, Division of Physical Chemistry, University of Minnesota, has been with the University of Minnesota since 1927. During 1938-39 he held the Laler Fellowship, working with Prof. James Franck at the University of Chicago. During three of the war years he worked under OSRD research contracts at the University of Chicago on gas detection problems and at the Maryland Research Laboratories, an OSRD project for OSS. He is a Californian, receiving his B. S. and Ph. D. degrees from the University of California.

Probably the greatest uncertainty exists in regard to those steps which follow immediately upon the absorption of a light quantum by a chlorophyll molecule. In a study of the intact plant, or even the plant cell, it is difficult to separate those effects which are caused by the sequence of chemical steps from those which are related to the transfer and conversion of energy. For these reasons it is necessary to remove the chlorophyll from the plant, and to study its optical properties when it is dissolved in chemically simple solvents. When the optical processes occurring in these simpler systems are understood, we will be in a better position to understand how the plant utilizes the energy which it absorbs.

Optical properties of a chlorophyll solution may be studied by various ways. One of the simplest is the measurement of the intensity and color, i.e., spectrum, of the fluorescent light emitted from such a solution. When a molecule of chlorophyll absorbs a light quantum, it can convert this radiant energy into chemical energy, degrade it to heat energy, or emit it as a quantum of fluorescent light. If the chlorophyll is dissolved in a chemically inert solvent, the first of these processes is impossible, and the energy of the absorbed quantum must either be degraded to heat or re-emitted as fluorescent light. In solvents such as ether or alcohol, about 10 percent of the absorbed light is re-emitted, the rest being degraded to heat. Until very recently it was believed that this 10 percent yield of fluorescent light was a fundamental characteristic of the chlorophyll molecule itself. However, it is now known that chlorophyll is only fluorescent if it is dissolved in alcohols, amines, or similar compounds. If it is dissolved in a pure dry hydrocarbon (such as benzene, isooctane, or heptane) its solution is practically non-fluorescent. The addition of as little as 0.01 percent of water or alcoh or simple amine to such a non-fluorescent solution restores the fluore cent intensity to its usual 10 percent. Further addition of the activat has little or no effect upon the fluorescent intensity. A quantitativ study of the effect of temperature and of a variety of mixed solvents on the fluorescence indicates fairly definitely that a chlorophyll molecule is capable of emitting fluorescent light only if it has first formed an addition compound with a molecule of water, alcohol, or some similar substance. The formation of this relatively weak addition compound produces a change in the spatial configuration of a few of the atoms which make up the chlorophyll molecule. It appears probable that this slight difference in configuration is responsible for a great change in the probability of the degradation of a quantum of energy which the molecule may absorb. How this new information is related to photosynthesis in the plant is still unknown. There is good evidence that the chlorophyll molecules in the plant are associated with molecules of proteins and possibly with water molecules. Therefore, the low fluorescence efficiency of chlorophyll in living plants is likely caused by some other factor, such as high concentration of the chlorophyll in the chloroplast or possibly the presence of specific quenchers.

Quenchers are substances which by their presence reduce the efficiency of fluorescence of a compound. Many examples of fluorescence quenching have been studied in solutions of relatively simple fluorescent dyes. Chlorophyll solutions also exhibit this phenomenon. However, unlike solutions of some simpler dyes, the fluorescence of chlorophyll is quenched only by a surprisingly limited group of chemicals. Chief among these are oxygen and nitro aryl compounds, such as nitrobenzene and TNT. There is some indication that substances, which can act as oxidizing agents in photochemical reactions sensitized by chlorophyll, are also efficient quenchers for the fluorescence of chlorophyll.

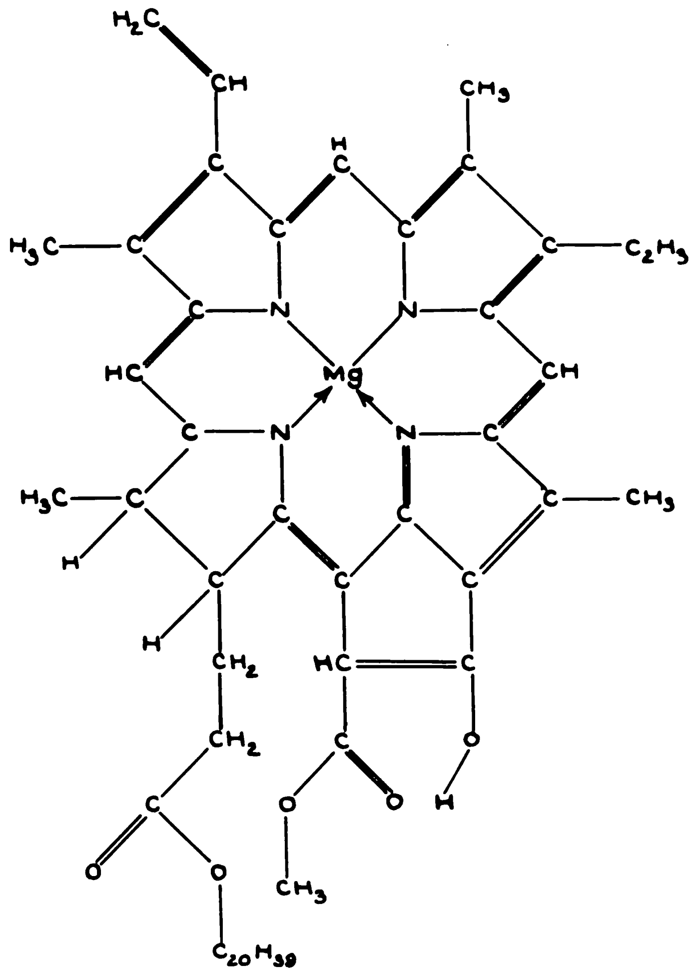

Fig. 4. The chemical formula of chlorophyll a in the chelated enolic form in which it probably exists when dissolved in dry hydrocarbon solvents. This conventionalized diagram shows the relative positions, projected on a plane, of the atoms which make up the molecule.

A photosensitized reaction is a chemical process which occurs only in the light and then only when a light-absorbing substance, like chlorophyll, is present. Photosynthesis itself is a photosensitized reaction. Other simpler reactions, photosensitized by chlorophyll, have been studied in solution. Those which are perhaps the best known involve oxygen as the oxidizing agent. An outstanding characteristic of these reactions is the fact that almost any active reducing agent can take part in the reaction. In marked contrast, the chlorophyll-sensitized reduction of certain nitrogen compounds (azo dyes) is highly specific in respect to the reducing agent. It is tempting, though perhaps premature, to speculate that this latter fact is closely related to the mechanism of photosynthesis. Further study of these simpler photosensitized reactions should be a very valuable guide in interpretation of observations on photosynthesis. Even if they do not lead us directly to an interpretation of the process of photosynthesis, they will provide a series of criteria by means of which postulated explanations of photosynthesis may be tested. Any suggested explanation of photosynthesis, which is not consistent with the results of studies on simpler systems involving chlorophyll, can be rejected, thereby saving many useless speculations.

Students of photosynthesis differ in their evaluation of the practical possibilities of their studies. Some of the more conservative believe the most that can be expected from a thorough understanding of photosynthesis is an improved control of the nature and rate of the growth of plants. A few of the more sanguine envision a day when man may be able to use solar energy to produce desired organic materials directly from carbon dioxide and water without the aid of plants.

The Science of Instrumentation

Instrumentation is a common denominator of all physical science, engineering, and technology. The problems of measurement and control are of fundamental importance in the practical methods and techniques of experimental research whereby the final goals of scientific progress are achieved.

The application of scientific research instruments to industry and warfare have made it clear that the problems of instrumentation are the same in applied technology as in basic scientific research.

This expanding field has given rise to experts in various phases of instrumentation, who are consulted for advice or cooperation. As more scientists have specialized in the general field of instrumentation, basic investigations have been undertaken on the broad principles and general theory of measurement and control devices and a recognizable science of instrumentation has emerged.

The steady growth of this science of instrumentation is proving valuable in serving all other sciences, through correlation and advancement of specialized knowledge of instruments, their performance and application.

WATER IS NOT A TYPICAL LIQUID

J. B. Hawkes
Stevens Institute of Technology

In any discussion of "pure" research the question is often asked, "Why are you investigating this?" The reply given is frequently vague, and commonly not convincing except to the investigator himself. In many cases research is a hobby on the same level as stamp collecting, model building, and other things that justify themselves to the hobbyist by the direct personal satisfaction they give him. Beyond this personal satisfaction there may lie the possibility of discovering facts having practical value. These statements apply to our investigations.

Although water is a common substance, it is a most untypical liquid. Its specific heat, density, surface tension, and other properties change with temperature in an irregular and mystifying way. Numerous attempts have been made to explain these peculiarities. One of the earliest suggestions was made by Roentgen, better known for his work on x-rays. He suggested that liquid water might be a "solution" of ice in water, much as brine is a solution of sodium chloride in water. This dissolved ice can break down into water, as well as preserve its individuality and dissolve in varying amounts depending on the temperature. If the density of dissolved "ice" is less than that of the water solvent, simple calculations indicate that the maximum density of ordinary water (at 4° C) can be explained if, at 0° C, there is about 20% "ice" dissolved in the water. This percentage appears to diminish more or less linearly as the ice breaks down with rising temperature, becoming zero at around 70°C.

If this oversimplified explanation has any truth in it, there should be a corresponding effect on the optical properties of water. Thus the study of the index of refraction of water near the freezing temperature may show something about the "mechanics" of freezing. Such information should aid in the control of icing on airplanes, and also perhaps in the casting of metals and alloys, where the change from the liquid to the solid state is important. As far as the present research is concerned, these applications, however, lie in the future, and must be left to the attention of the development engineer. The particular phase discussed here is one of several investigations being pursued currently.

J. B. Hawkes, Professor of Physics at Stevens Institute of Technology, received his M. E. degree in 1923 and Ph. D. in 1938 from Columbia University. During the war he was physicist at the Naval Ordnance Laboratory. The research on the optical properties of liquids is being done jointly with R. W. Astheimer under an ONR-sponsored contract.

Our work on the index of refraction of water in the neighborhood of 0°C is for the purpose of finding small significant anomalies. For this purpose two methods are available, (1) measuring the index of refraction at various temperatures, (Fig. 7), or (2) measuring the thermal coefficient of the index of refraction at various temperatures (Fig. 8). The thermal coefficient of index (2) is the "slope" of the index-temperature curve (1). In case (1) we obtain a curve of n (index) versus T. The latter curve (2) shows irregularities in the behavior of the index much more clearly than does the former. A similar situation exists in thermal expansion measurements where a curve of length-of-specimen (l) versus temperature is so nearly a horizontal straight line as to show little about the behavior of the specimen. On the other hand, the coefficient of thermal expansion $\left(\frac{1}{l}\frac{dl}{dT}\right)$ gives a much clearer picture of the properties of the specimen.

We are using for our measurements a Jamin interferometer, shown in Fig. 5. Light from a source (a sodium arc) falls on mirror M. Some light is reflected from the front surface of M, as ray A. The rest of the

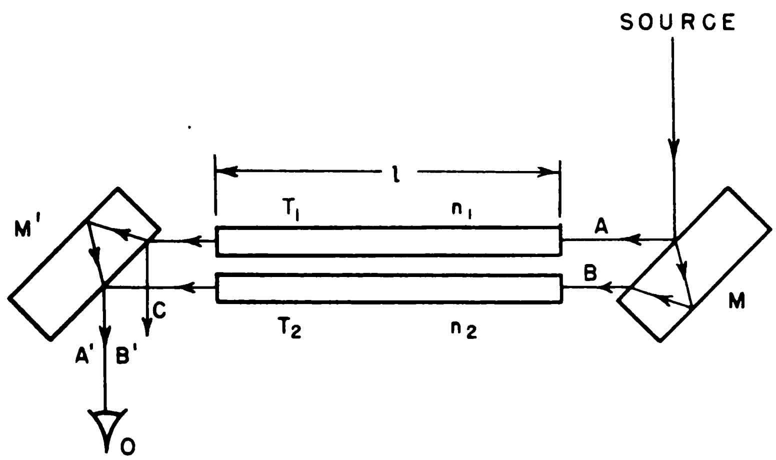

Fig. 5. Schematic diagram of the Jamin interferometer.

light goes into the glass of the mirror, which is about an inch thick, is reflected from the silvered back surface, and emerges as ray B. Rays A and B pass through two identical cells containing water, and fall on mirror M´. Here ray A is partly front-reflected as ray C which is of no use to us, and partly back-reflected as ray A´. Ray B is partly front-reflected as ray B´. Other reflections exist but are of no use. By proper adjustment of cells (1) and (2) and of mirrors M and M´, we can make ray A´ coincide with ray B´. If mirrors M and M´ and cell (1), comparison cell, and cell (2), test cell, are exactly alike, the light waves in A´ and B´ will be precisely in step and will reinforce each other so that observer O will see a bright spot in the mirror M´. If the water in cell (2) has an index n_2 slightly different from n_1, then the waves in A´ and

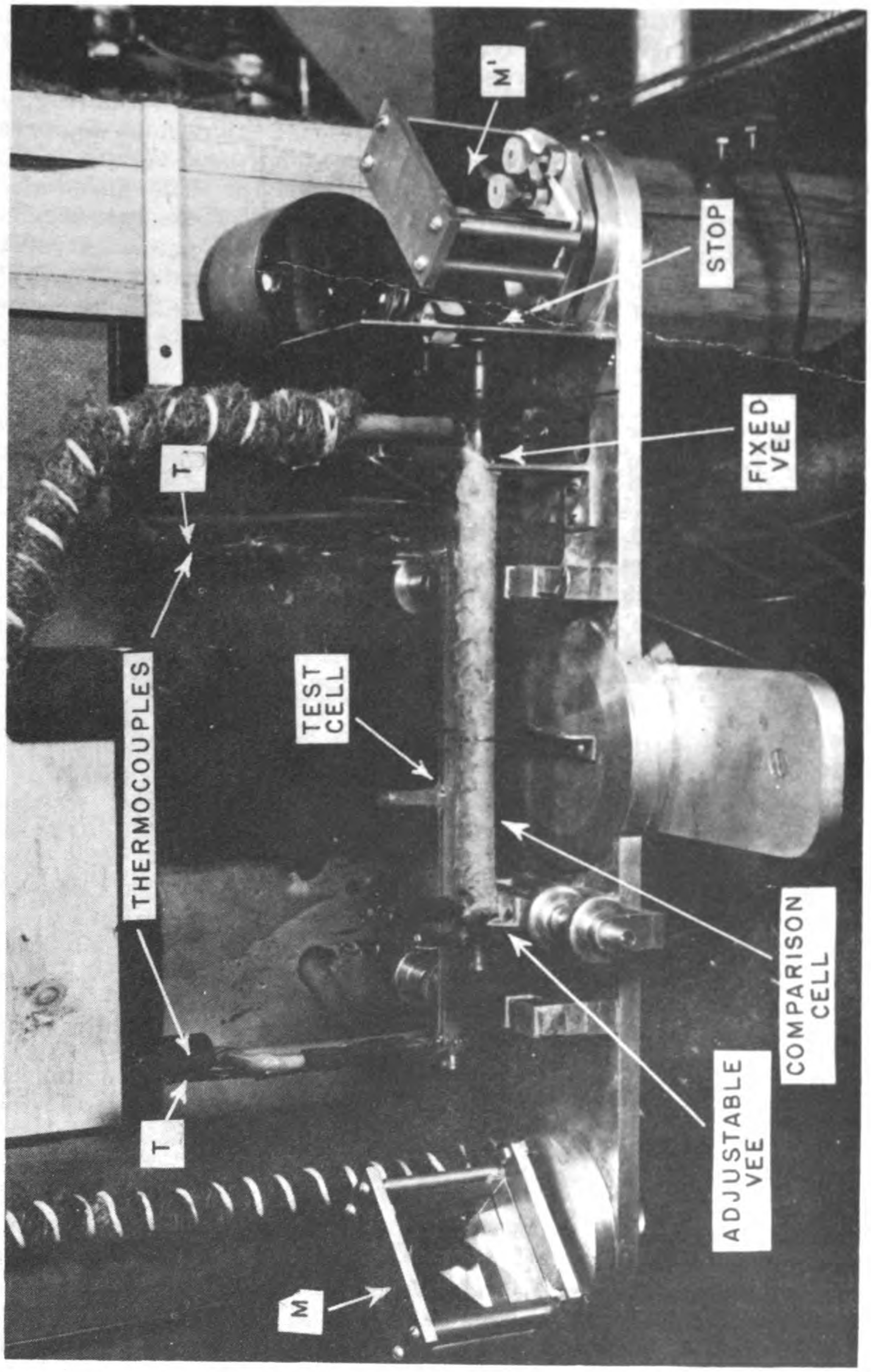

Fig. 6. General view of interferometer showing cells and mirrors.

B′ may be exactly out of step (180° out of phase), so that trough will fall on crest, and ray A′ will cancel ray B′. The observer will then "see" darkness. As n_2 differs progressively more and more from n_1, which is held constant, the observer will see successive alternations of light and dark. These alternations of light and dark he may count, and by simple calculations find the change in n_2 which produced the alternations. The changes in n_2 (denoted Δn_2) are produced by slowly changing temperature T_2 (by an amount ΔT_2). The ratio $\Delta n_2/\Delta T_2$ is the thermal coefficient of the index of refraction, as mentioned previously. In making these measurements the temperature, T_2, is varied at a fixed known rate - so many degrees per hour - which is selected in advance; the corresponding rate of change of n_2 is observed. The apparatus is shown in Fig. 6, with the various parts labelled for identification.

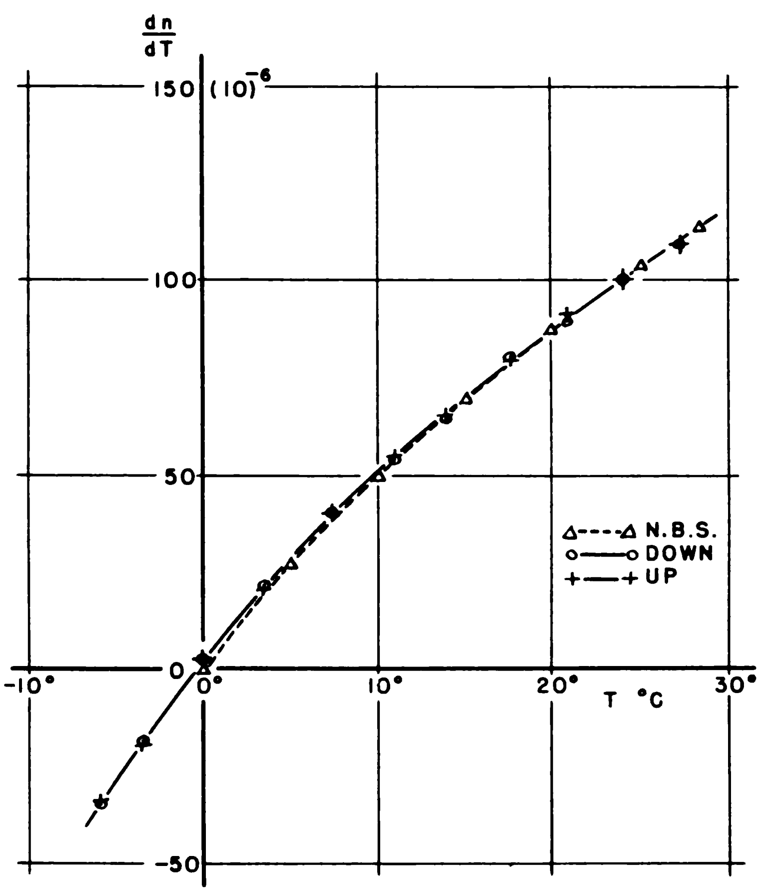

Fig. 7. Index of refraction of water. Thermal coefficient versus temperature.

The measurements have a precision of about one part in a million, although refinements are being made which are expected to raise this to one part in ten million. The results obtained to date are shown in

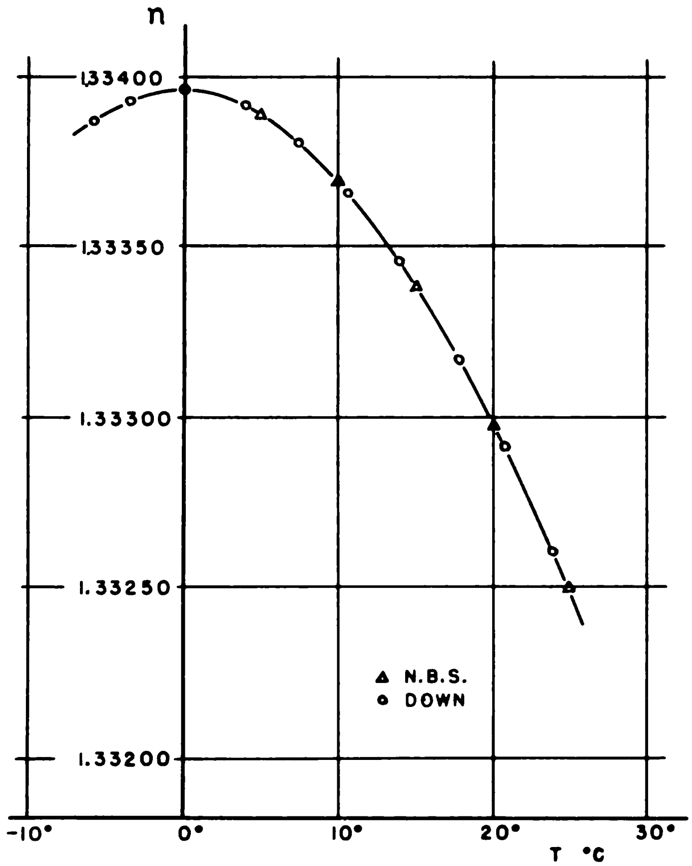

Fig. 8. Index of refraction of water versus temperature.

Fig. 7 (dn/dt versus T). The dashed curve shows results obtained by the National Bureau of Standards. The agreement is good but not quite perfect. By integrating dn/dT graphically, Fig. 8 is obtained for the index-versus-temperature relations. Here the agreement with the Bureau of Standards appears perfect and well within the experimental error.

One fact the reader will observe: the maximum index of refraction does not occur at the same temperature, (4°), as the maximum density of water. This is one anomaly. There are also indications that on changing the cell temperature the index of refraction does not come to a final value quite as rapidly as does the temperature. This is particularly true in the undercooled region (-5° to 0°C). Thus, if we change T_2 from, say 0°C to -5°C rapidly, and then hold T_2 at -5°C, there is an appreciable time required for n_2 to reach the value characteristic of -5°C. This is the crux of our problem at the moment, but much further research is required before our findings can be conclusive.

THE TRAVELING WAVE TUBE--
ANOTHER FRONTIER IN ELECTRONICS--

Lester M. Field
Stanford University

From the first vacuum tube produced by DeForest, through the introduction of screen grid tubes and pentodes, even through the klystron and magnetron used during World War II, all vacuum tubes had the following common feature. They all used the principle of shooting a stream of electrons across a small fixed region in which was placed the signal to be amplified. As a result no tube, whether operated at low frequencies or microwaves, could give a larger value than about 100 for the product of its voltage amplification times the width (in megacycles) of the band it would amplify.

This meant that no matter how much we might dream about relaying by radio or co-axial line many television programs or thousands of telephone channels on one line, no amplifier capable of handling the job could be made using the tubes known at the end of the war. In addition, the use of even klystrons or magnetrons to produce easily tunable oscillators for wavelengths shorter than two centimeters proved to be a difficult and costly job.

The traveling wave tube, which uses a completely new principle of amplification, has broken through the limits imposed on all previous tubes, not by a small amount, but by a factor of 1000 times in measured results of the product of amplification times bandwidth. This tube makes it feasible to amplify simultaneously without any scrambling, as many as 100 television programs occupying 10 megacycles each or as many as a quarter million voice channels occupying 4000 cycles each. Of course, such unprecedented bandwidth might also be used for fewer channels and would allow very high index frequency modulation or complicated pulse modulation with its attendant possible secrecy and almost complete freedom from interference.

At Stanford University, our group under sponsorship of the Office of Naval Research aims to produce tubes of this new type for all frequency ranges of interest from about 200 megacycles to 25,000 megacycles

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Lester M. Field, associate professor of electrical engineering, Stanford University, is engaged in ONR-sponsored research in the field of electronics. He took his B. S. degree from Purdue University (1939), Ph. D. from Stanford (1944), and has been associated with the latter institution since 1941 except for the years 1944-46 when he joined the Bell Telephone Laboratories as a member of the magnetron development group, and later the electron dynamics group, of the physical research department.

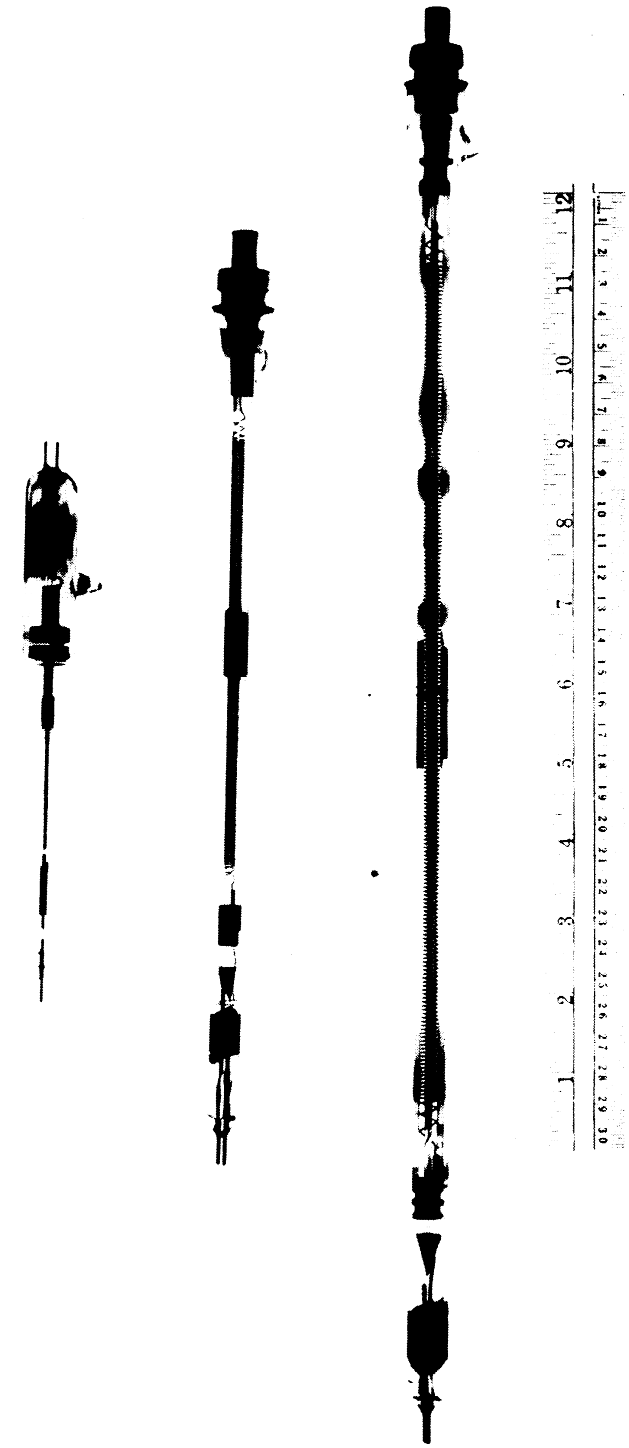

Fig. 9. Three typical traveling wave tubes of the helix type built at Stanford University under ONR-sponsored contract.

and will attempt to extend the range of operation even further. This new principle turns our attention to two other major problems, the development of amplifiers for microwaves with much less noise than any now existing, and the development of high-power wide-band traveling wave tubes.

Fig. 9 illustrates three typical traveling-wave tubes of the helix type, built at Stanford. The largest tube is for use near 3000 megacycles, the middle tube is for use near 10,000 megacycles, and the smallest one is for 25,000 megacycles operation.

The principles of operation may be visualized from these tubes. The signal to be amplified is applied at the left end of the helical wire seen inside of each of these tubes. Unlike a signal applied to a grid or a cavity resonator for which the field produced by the signal stays in one place, the signal field runs along the helix from left to right toward the output. Since the signal travels along the wire at the speed of light, but the wire is coiled, the signal progresses toward the output at about one-tenth the speed of light for the tubes shown, since it must follow a long path to move forward a short distance. Of course helix size and wavelength must have about the right relative size for this to happen.

If now, when a signal is traveling down the tube as previously described, a stream of electrons is shot from a cathode down the center axis of the helical coil at nearly the same speed as the signal is traveling, a given part of the signal and some of the electrons are exposed to each other for a very long time, actually dozens of cycles. This long exposure results in a large exchange of energy, and turns out to be of such a type that the signal gains energy from the electron stream in every part of the helix. The result is that the signal increases as it travels along the helix according to the same kind of variation as it follows in decreasing along a lossy transmission line. In a sense this tube amounts to a concentrated length of transmission line, with positive gain instead of loss, which can be inserted at intervals along a normal transmission line to make a relay system.

Fortunately, the only kind of resonance used in this tube is velocity resonance, that is electrons and wave must have nearly the same speed. Since the wave speed varies very little even with large changes in frequency, widely differing frequencies are amplified equally well, for example, a band 25 percent wide at microwaves, or even the entire region, 350 to 1000 megacycles, in a lower frequency tube. In comparison, other tubes use resonant circuits which are frequency sensitive and give only a few percent bandwidth at microwaves.

The smallest tube of Fig. 9 is being studied as a possible local oscillator for wide tuned microwave receivers. When used in the circuit shown in Fig. 10 this tube has proved to be capable of oscillating over a 1.6 to 1 frequency range giving fundamental output power from

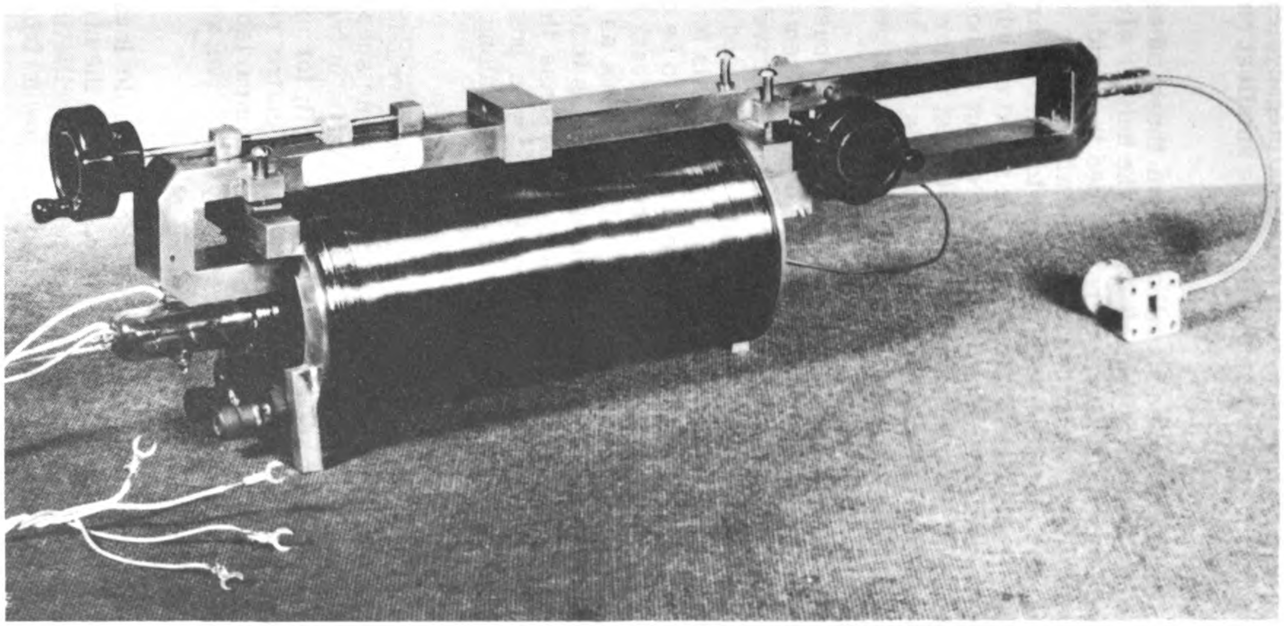

Fig. 10. Traveling wave tube oscillator having fundamental output power of 7500 to 11,750 mc and second harmonic power of 15,000 to 23,500 mc.

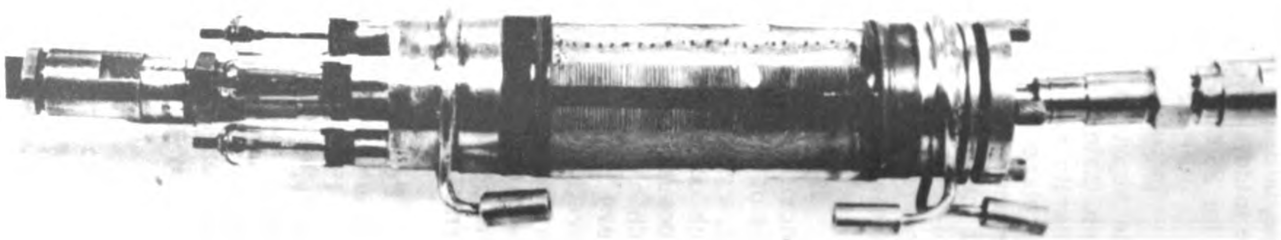

Fig. 11. One new type of traveling wave tube being studied at Stanford. In the disc-on-rod tube a series of discs propagates a wave slowly, and a hollow cylindrical electron beam skims over the edge of the discs.

7,500 to 11,750 megacycles and second harmonic power from 15,000 to 23,500 megacycles. The tube may be compared with the much more complicated and expensive local oscillator tubes now available for these frequencies which tune about 10 percent at most.

In Fig. 11 may be seen one of a variety of completely new types of traveling wave tube being investigated at Stanford. Shown is a disc-on-rod tube in which a series of discs substituted for the helix of previous tubes propagate a wave slowly, and a hollow cylindrical electron beam skims over the edge of the discs. This tube is a relatively narrow band amplifier but goes to appreciably higher power as a linear amplifier than does the helix tube. The tube shown is designed for linearity up to a power output of 8 watts at 10,000 megacycles and to date it has operated successfully up to somewhat lower levels. Another type of tube receiving much attention uses an electron stream shot across the wave instead of along with it. By an appropriate warping of the wave structure, the wave has a component of velocity in the electron flow direction so that traveling wave interaction occurs. Much larger currents can be shot across a wave than along with it because of the short length for the electron beam and great width available for high current in such a device. Such high currents are necessary for a truly high power traveling wave tube.

Studies of noise reduction possibilities in the use of these tubes occupy a major portion of the work. Schemes for getting low noise include grid modulation of the beam before entering the helix (see the two larger tubes of Fig. 9), a very low beam current, low velocity, small helix diameter tube (known to be capable of giving the lowest noise at 3000 megacycles of any tube or crystal now known), and finally the excellent possibilities now predicted theoretically for a transverse field tube.

This newly discovered principle of amplifying by traveling waves is a powerful new tool capable of extending performance figures of previously available devices by large factors, and capable in some cases of permitting totally new devices, the operation of which would be impossible without this tube. As an extreme example, traveling wave tubes have been produced with greater capabilities than anyone has yet found need for. The principle is so new, however, that very probably its most important forms and applications remain to be invented or discovered.

BUILDING BIG MAGNETS WITH LITTLE MODELS

Edward C. Creutz
Carnegie Institute of Technology

A major portion of the cost of a cyclotron is a large direct current electromagnet. The purpose of this magnet is to cause the charged nuclear particles which are being accelerated to travel in arcs of circles. Thus, although the magnetic field does not contribute directly to the acceleration, it confines the particles to a small region of space where they may be conveniently worked with. Also, since it causes them to pass through the same electrodes many times, it makes it possible to use a relatively small applied voltage over and over again, to build up a very high total effective voltage. The purpose of this article is not to discuss the operation of a cyclotron itself, but rather to describe some of the features of magnet design which make it possible to produce the desired result with a minimum amount of material, and thereby at a smaller cost.

The three costs to be considered in the magnet problem are those for steel, electrical conductors, and power. Let us suppose that a magnet is desired for a cyclotron to produce protons of a given energy. It is easily shown that the highest energy $\underline{E}$ that can be produced by a given cyclotron is proportional to the square of the magnetic field $\underline{H}$ and also proportional to the square of the radius $\underline{r}$ of the pole piece. Thus, we may write the proportionality $\underline{E}$ is proportional to H^2r^2. On the other hand, steel is useful to carry only a certain number of lines of force per unit area. When this limit is reached, it is said to be saturated. There is, therefore, a practical upper limit to the value of $\underline{H}$. By definition, the field $\underline{H}$ is equal to the number of lines of force per unit area

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E. Creutz, Associate professor of physics, Carnegie Institute of Technology, describes his main job since the war as "the design and construction of a 400 million electron volt proton synchro-cyclotron. He looks forward to "research in this wide open high-energy field in which we hope to understand some of the complex observations now being made with cosmic rays and to tie this information together with our meager present knowledge of the atomic nucleus." After receiving his Ph. D. from the University of Wisconsin in 1939, he went to Princeton University to study the nuclear properties of uranium by means of the Princeton cyclotron. By 1942 he had joined the World War II atomic bomb project, first working under the University of Chicago's contract with OSRD and later under the Manhattan project with the Los Alamos bomb physics division. Dr. Creutz describes his earlier days of study in nuclear physics in his undergraduate and graduate days as "somewhat of a toy but becoming exciting, particularly by the time I went to Princeton in 1939 when Neils Bohr came to this country with news about fission of uranium."

in the space between the pole pieces. The total number of lines of force that must be carried around the magnetic circuit by the steel poles and the yoke of the magnet is proportional to the number of lines of force per unit area and also proportional to the area of the pole piece. This total number of lines of force is called the flux, and the proportionality may be written as flux is proportional to Hr^2, since the area of the pole is r^2. Now it is really the total flux that one pays for in building and operating a magnet, since to increase this quantity one must either buy more steel or put more current through the coil. The latter could be accomplished by buying higher power or by using the same power but decreasing the resistance of the coil by buying more electrical conductor. We see, therefore, that the ratio of the proton energy, which can be produced, to the cost of the magnet to produce it is, within these approximations, proportional to H^2r^2/Hr^2 or proportional to $\underline{H}$ itself.

It is customary to operate cyclotron magnets with a field between the pole pieces of $\underline{H}$ equal to 14,000 to 18,000 gauss. On the other hand, good steel does not saturate until it is carrying a flux density equal to about 21,000 gauss. The reason for the discrepancy in these two figures is that not all of the flux produced by the coil in the pole pieces passes through the useful region of space directly between them. In fact, in

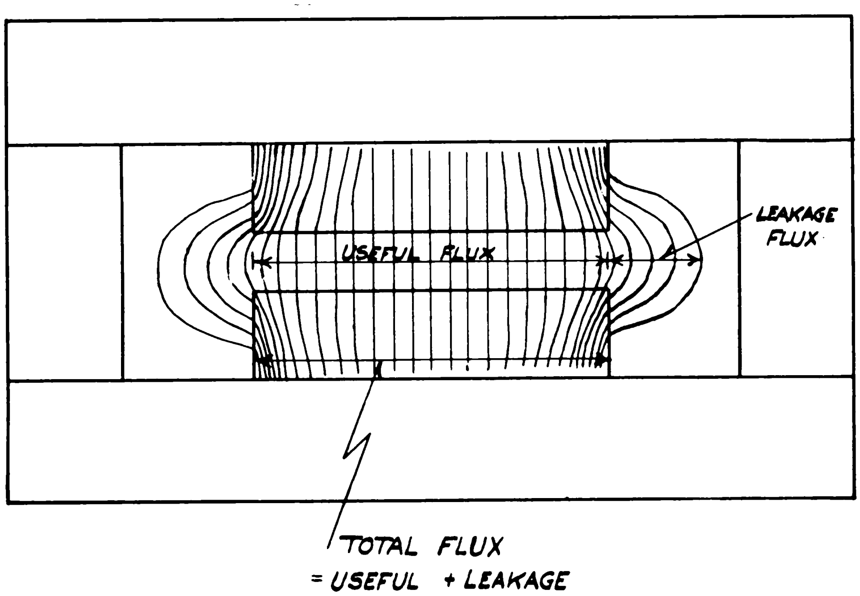

Fig. 12. In magnets now in use about one half the flux is useful while the remainder, which is called leakage flux, passes from pole to pole outside the useful area of the pole faces.

many magnets now in use, only about 1/2 the flux is useful while the remainder, which is called leakage flux, passes from pole to pole outside the useful area of the pole faces. This effect is shown in Fig. 12. Thus, the flux which contributes to the useful field has a lower density

H than the total which exists in the pole piece. The pole piece will therefore saturate with 21,000 gauss even though the useful field may be as little as 15,000 gauss. To remedy this, the pole piece must be tapered so that it is bigger at the base where a large amount of flux must be carried than it is at the tip where only the useful flux is being handled. On the other hand, if it is tapered too much, leakage from the tapered surface of one pole to the tapered surface of the other will be increased simply because these surfaces are brought closer together by the tapered condition than they would be in the case of cylindrical poles. There is, therefore, some optimum shape to the pole which depends on the magnetic field desired, the length of the pole, and the relative dimensions of the gap and the pole. Although good clues to the proper shape can be obtained by calculation, the final determination must be done experimentally. Studies at Carnegie Institute of Technology have shown that it is possible to shape the pole so that an efficient magnet can be made working with fields as high as 20,000 gauss in the gap.

The field between the pole pieces of a magnet is not uniform but falls off at large radii. To be useful for a cyclotron, the field should be kept to a large fraction of its maximum value up to the greatest possible radius, and then should fall to small values in a short distance. This makes it easier to remove the proton beam from the cyclotron once it has been accelerated to the high energy which brings the orbit to this radius. The problem then becomes one of "working against" the field so as to deflect electrically the beam against the magnetic field which tends to keep it circling around. This shaping of the field is usually accomplished by making the face of the pole deviate from a plane surface by machining it with a contour so that the gap is smaller at a large radii than it is at the center of the pole face. In fact, it would be theoretically possible to keep the field constant up to the full radius of the pole by making a steel ring to bridge the gap at the periphery of the pole. However, such a device as this would, of course, prevent access to the working region of the magnet and would therefore be impractical.

There is another requirement of the magnetic field, namely, that it should decrease slightly from center to the edge of the pole in order to keep the proton beam focused and to prevent its wandering from the median plane of the gap. The attempt is made therefore to satisfy these two conditions, namely, that the field falls off a few percent from the center to a large fraction of the full radius of the pole and then decreases as rapidly as possible at larger radii. A good theoretical approach to the problem of shaping the steel to produce this field is the following: one can calculate the exact shape of the steel required to give the desired field, assuming that steel has infinite permeability; that is, it acts as a perfect conductor of the magnetic lines of force. This is an inaccurate assumption because as the flux density of the steel approaches closer and closer to saturation, the permeability of the steel becomes smaller and smaller. However, this assumption does lead to an approximate shape for the steel and strangely enough, indicates that for ideal steel of infinite permeability, the pole shape should be something like that shown in Fig. 13. Experiments must again be referred to, to determine the deviations from this ideal shape that are required due to the fact that the permeability of steel is less than infinite. These experiments are of the trial and error variety in which model magnets

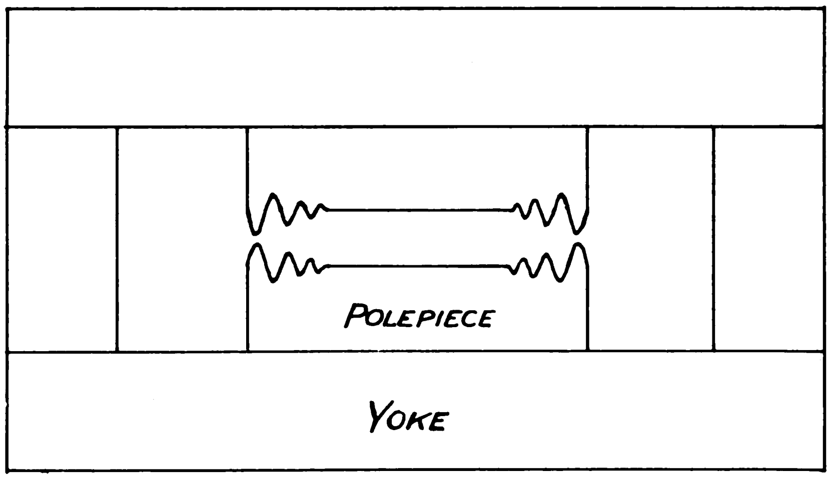

Fig. 13. For ideal steel of infinite permeability, the magnet's pole shape should be as shown above.

with poles a few inches in diameter are made, the field is measured, and corrections are made to the pole. This work requires extremely high precision in the machining of the steel since all deviations from the true shape would be scaled up on the actual magnet. For instance, if a cyclotron magnet with 150-in. diameter pole pieces is desired and a model is made with pole pieces 10-in. in diameter, a machining error 0.001 on the model would correspond to a machining error of almost 1/64-in. on a full-scale magnet. Since errors appreciably smaller than this are desired, attempts are made to keep the model accuracy down to a few ten-thousandths of an inch.

With a magnet of a certain size, that is, with a gap between pole pieces of a given dimension and a pole and yoke area of determined dimension, a definite number of ampere turns is required to produce a fixed magnetic field. By ampere turns is simply meant the number of amperes flowing in the coil times the number of turns of the coil. However, nothing is determined about each of these factors independently, that is, if 1 million ampere turns are required for a full-scale magnet with a gap of 15 in., this number could be obtained with a million turns of wire, each carrying 1 ampere, 100,000 turns carrying 10 amperes, 1,000 turns carrying 1,000 amperes, etc. However, there are certain conditions which limit the choice of currents. Motor generators to produce D.C. currents larger than a thousand amperes or so are uncommon and expensive. There is, however, some advantage in having currents of many thousand amperes. The reason is simply that the number of turns is thereby decreased and, since each turn must be insulated from its neighbors, the total amount of insulation required is decreased. This is a very important factor since the more insulation that is put into a coil of a fixed size, the less copper can be used. Having a given number of ampere turns on a specific magnet, the product of copper and power required is a constant, that is, if all the space in the coil could be filled with copper and no insulation were required, only 1/2 as much power would be required as if only 1/2 the space could be filled with copper and the remainder were required for insulation. There are other advantages of a few turns carrying large currents, namely, that the coil is easier to construct since the conductor is larger and mechanically more rigid, and cooling may be easily accomplished by means of oil in direct contact with the conductor or by means of water flowing through holes in the conductor. Neither of these cooling methods is practical with a coil of very many turns of small size, since the size of each cooling channel would be very small and the pressure drop experienced by a liquid going through the channel increases rapidly

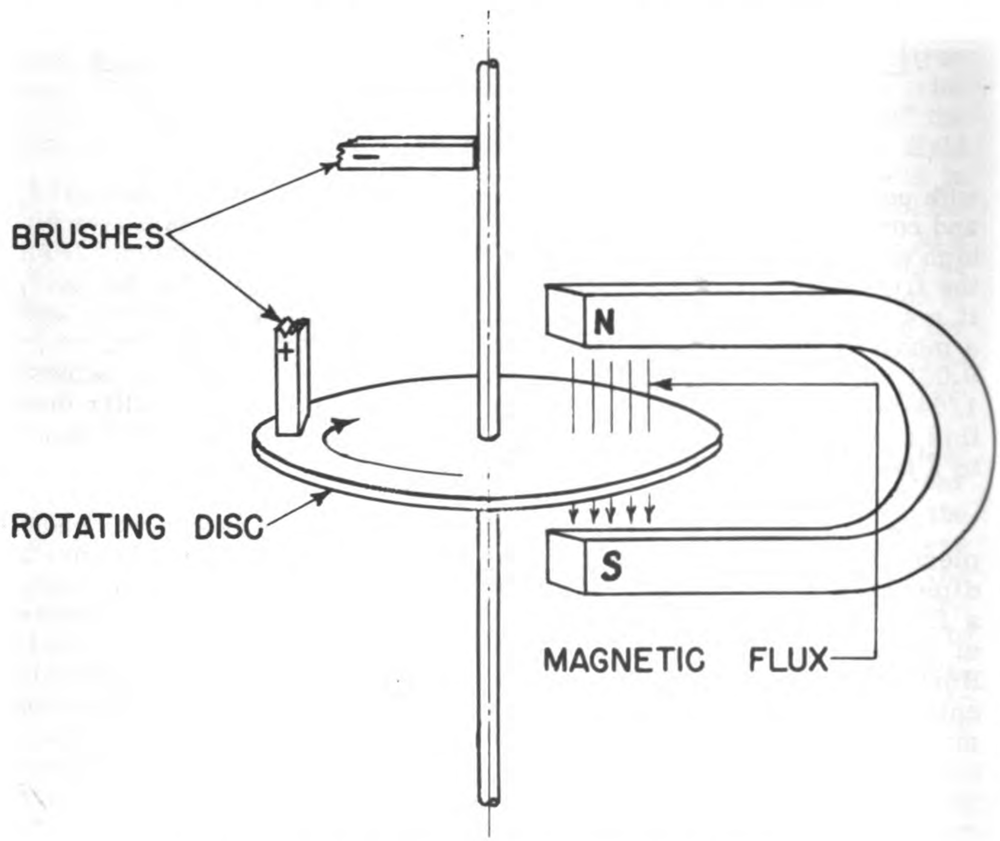

Fig. 14. Design of generator of homopolar type.

as the dimensions of the channel decrease. It has been found practical in our laboratory to use 20,000 amperes in the cyclotron coil. To do so, a generator of somewhat unconventional design must be used, known as the homopolar type. This generator makes simple use of the fundamental law of electromagnetic induction, namely that when a conductor moves through a magnetic field there is a difference of potential induced across its ends, at right angles to the field and in the direction of motion. A disc of copper is rotated in a magnetic field and brushes contact this disc in two places as shown in Fig. 14. In this design of generator, no reversal of the current at commutator segments is required as in the usual generator. There is, therefore, no tendency for a brush sometimes to be partly on each of two commutator segments at a difference of potential and therefore to cause a partial short. For this reason the efficiency of such a generator is high.

As a result of special studies on these magnets previously described, it has been possible to design a smaller and more compact machine than those which are based on previous experiments with smaller cyclotrons. Extrapolating the older designs leads to magnets weighing about 1,000 tons more than that based on the previous description, for the same energy output. The experience gained with the homopolar generator will be valuable for further generator design to produce compact high current machines. Possible uses of such machines include magnetic mine sweeping and degaussing of ships. Thus we see such apparently unrelated engineering enterprises as the construction of cyclotrons for nuclear physics research, and the development of high current generators with possible uses in naval activities, sometimes find common requirements.

TIP TO NAVAL RESEARCH RESERVE

The Naval Research Reserve has been organized in order to keep scientific personnel in the Naval Reserve informed of scientific work being done by the Navy and under Navy sponsorship. Since the Research Reserve is just getting organized, recent meetings have been mainly devoted to problems of organization, but it is hoped that the Research Reserve units can devote their full attention to Navy research as soon as possible. For this reason the question asked in the "Letters" section of Research Reviews this month is especially pertinent. How can Research Reserve units find out about Navy research?

There are two answers. First, Research Reviews is intended to give brief descriptions of Navy research in the fields of physical, medical, and naval science.

Second, commanding officers of Research Reserve units may obtain the latest technical information for members of the Research Reserve. General information on research in any given field may be requested from the Chief of Naval Research, Code 103R, Department of the Navy, Washington 25, D. C. Such general information is difficult to assemble, and whenever possible specific reports should be requested. Beginning next month all Research Reserve units will receive copies of the Technical Information Pilot (TIP), which contains abstracts and indexes of all unclassified technical reports under the National Military Establishment, other government agencies, and of some independent workers, and is the only abstracting service for these reports. Reports listed in TIP should be obtained by following the instructions given in the front of each issue.

The meetings of Research Reserve units are not required to follow any specific program laid down by the Navy; they are left to the discretion of the members. In groups containing large numbers of active scientists, there may be occasions when a member may be asked to report his own work, or a scientist doing Navy work may be asked to come in from outside to speak. Another possibility is opened by the editor's reply in the "Letters" column of this issue. A member of a Research Reserve unit may be asked to obtain the technical literature on a certain project or group of projects and report on it to the unit at one of the regular meetings. A perusal of Research Reviews may suggest projects on which a unit may want a more detailed account, and TIP will help to locate individual reports in any given field.

The Office of Naval Research sponsors research in many fields. New information is constantly coming into ONR in the form of technical reports from the various projects. It is hoped that the Research Reserve will take advantage of this information.

NOTE

The Chief of Naval Operations has recently authorized six additional billets for Naval Reserve Commanders who will serve as administrators of the Research Reserve program in the five branch offices of ONR and in Office of Naval Research, Washington, D. C. These six officers will assist the commanding officers of the branch offices in the administration and training of the Naval Research Reserve portion of the Naval Reserve program.

The Chief of Naval Research requested these billets in order to provide an officer in each branch office to organize, administer, and train Research Reserve units within the various territories. Branch offices are located in Boston, New York, Chicago, San Francisco, and Los Angeles. The Office of Naval Research in Washington has cognizance of the Southeastern area. Commanding Officers of the branch offices have been requested to nominate suitable officers prior to 1 February 1949. The Commanding Officer, ONR branch office, will make nominations by endorsing the letter from the officer requesting active duty.

Handling of the Research Reserve program by the commanding officers of the branch offices was necessary in order to get the units started, but the Chief of Naval Research and others connected with the Research Reserve program believed it advisable to authorize full-time officers in the various branch offices to assist in the implementation of this program. The commanding officers of the branch offices will continue to carry out the planning, supervision, and inspection functions essential to Research Reserve units. The newly authorized commanders will, however, carry out the details of organizing, activating, and training these units in their areas.

The Naval Research Reserve program has received enthusiastic response among qualified scientific personnel. As of the middle of December eight units have been officially activated, and at that time, at least as many more were in the process of organizing to request activation. The Research Reserve program is expected to expand at the same accelerated rate during the coming year, and the recruiting, training, and administration of Research Reserve units will be an important activity of ONR.

Naval Scientific Establishments--
Michelson Laboratory

Aerial view of the Navy's Michelson Laboratory at the Naval Ordnance Test Station at Inyokern, Calif. Completely air conditioned, it is the most complete science research facility of its type in the world. Structure was dedicated on May 8, 1948. Named after Albert A. Michelson, the physicist who established the speed of light as constant (186,000 miles per second).

When Professor Albert Einstein announced his revolutionary Theory of Relativity ($E=MC^2$), he acknowledged that his assumption of the absolute velocity of light(c) was based on experiments of Professor Michelson, the only graduate of the United States Naval Academy to be awarded a Nobel Prize for scientific attainment. Michelson was instructor at the Naval Academy from 1875 to 1878, following his graduation in 1873. He resigned from the Navy in 1883 to become professor of physics at the Case School of Applied Science. While in the Navy, he conducted investigations which determined with great precision the velocity of light, and had performed his most famous experiment for the detection of absolute motion. Michelson's invention of the interferometer, capable of measuring a light wave-length with an accuracy of one part in 10,000,000 made it possible to use the wave-lengths of light as a measuring unit. Application of the interferometer to astronomical problems enabled Michelson to measure the angular diameters of Jupiter's four Galilean satellites, and, in 1920, to make the first measurement of the diameter of a star. Only less notable than the interferometer was Michelson's echelon spectroscope, which he devised for separating the components of a spectral line. In 1903 Michelson embodied in his book, Light Waves and Their Uses, all that he had learned about light during the previous quarter of a century. Four years later his eminence was given world-wide recognition when he received the Nobel Prize for Physics. Until two years before his death in 1931, Michelson served for thirty-seven years as head of the Department of Physics at the University of Chicago.

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Note: For the Southeastern area Research Reserve matters should be referred to the Director of Research Reserve, Office of Naval Research (Code 103R), Department of the Navy, Washington 25, D. C.

FIGURES

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