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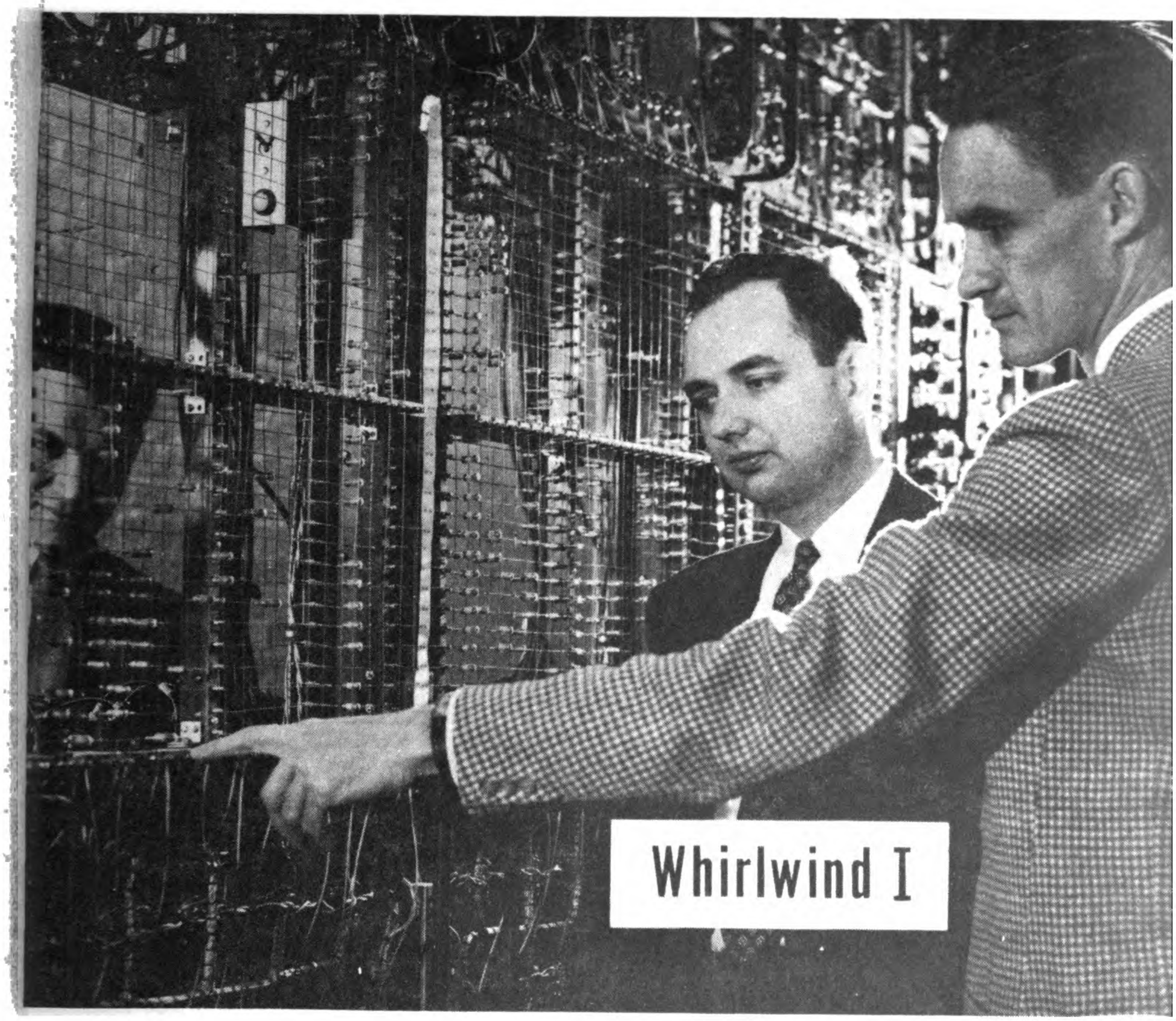
RESEARCH REVIEWS



NAVEXOS P-510

DEPARTMENT OF THE NAVY
WASHINGTON, D. C.

COVER PHOTO: Digital Computer Laboratory engineers Norman H. Taylor, Robert R. Everett, and John A. O'Brien inspect the electronic switching center of the MIT computer Whirlwind I. This apparatus can select the appropriate line to any section of the 5000-tube system in one ten-millionth of the time it takes to dial a telephone number. For more about the big computing machine, see pp. 1-3.

Approved by Bureau of the Budget, 13 April 1948.

In this issue--

Here is what Whirlwind I's "memory" looks like. Electrostatic storage tubes enable the machine to "remember" information in less than one twenty-five-millionth of a second. Shown testing a tube assembly are Jay W. Forrester, Director of the Digital Computer Laboratory, Patrick Youtz, Head of Storage Tube Development and Stephen H. Dodd, Jr., in charge of systems engineering.

Whirlwind in Action

There are plenty of complex problems to which scientists and technologists need the answers "immediately if not sooner." In the past automatic computers could help little in many such applications because even their high speed operations could not provide solutions in time to be applied to the problem effectively. For example, there was no machine in operation capable of supplying the instantaneous instructions necessary for controlling traffic over a modern airport. Now with Whirlwind I, an ultra-high-speed digital computing machine in operation at MIT, the answers to such problems and countless others in industrial process control, insurance handling, inventory, economic analysis and scientific and engineering computations can be obtained within effective time limits.

Whirlwind I, the only large-scale computer of its kind in full operation in this country, can remember, act upon, and deliver information at a rate of 20,000 times a second. It was developed under ONR sponsorship at MIT's Digital Computer Laboratory under the direction of Jay W. Forrester.

How does the big, complicated machine actually work? Once a problem has been inserted, it operates automatically. High-frequency electrical pulses travel along transmission lines from one element of the computer to another, causing electronic circuits to be turned on and off. The resulting electronic states of these circuits represent the numbers in the problem. Since Whirlwind I selects, remembers and operates on all the digits of the number simultaneously, it can complete thousands of arithmetic operations per second, solving in 15 minutes some problems which would require years of manual work.

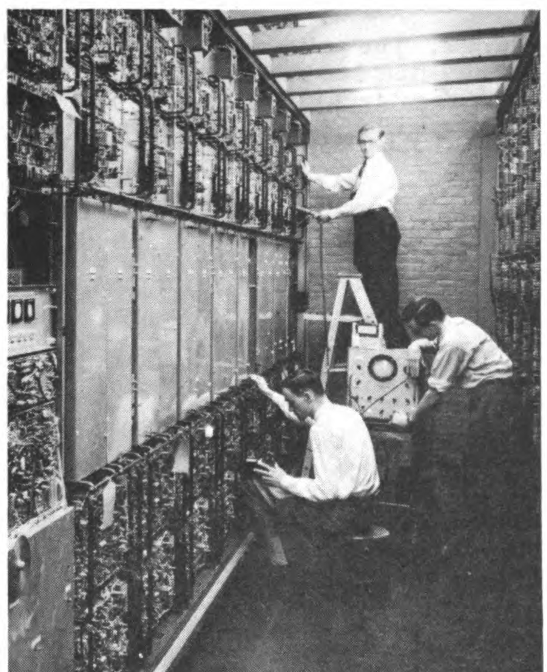


Figure 1. Others at MIT who took an important part in the successful development of Whirlwind I perform further testing. Engineers John A. O'Brien, Charles L. Cordermann and Norman L. Daggett are shown.

Whirlwind I, like every other computing system, has certain basic elements. In a typical manual system, these elements might be the familiar desk calculator, an operator, a notebook for entering incoming data and reading results, and messengers to bring in the problem and carry away the answers. In Whirlwind I, the arithmetic element corresponds to the desk calculator, the control may be likened to the

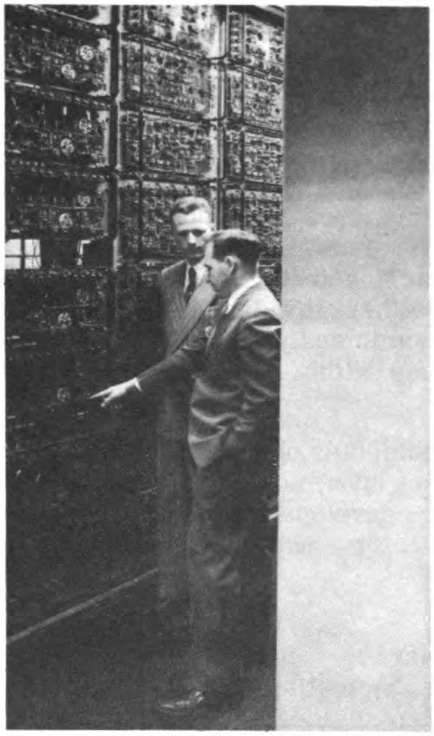


Figure 2. The arithmetic element of Whirlwind I is examined by Jay W. Forrester and Norman H. Taylor, who heads Electronic Development.

operator, the storage or memory is the notebook, and the input and output are the messengers.

Perhaps the most interesting part of the big machine is its "memory". By means of specially designed electrostatic storage tubes, a 16-digit number can be read into or out of the machine in twenty-five millionths of a second. Each storage tube uses a movable electron beam to distribute information over a surface (your television works the same way!). A digit in the form of a charged spot on the storage surface is written by a high-velocity, sharply focussed electron beam, which is also used to "read" the stored information. Still another guardian beam keeps digits "in storage" for as long a period as desired.

During its tests Whirlwind I was used to compute how proposed ultra-high-frequency television channels could best be assigned to the various cities of the Nation. Another use made of it was in the production of instructions for automatic control of large machine tools. An even more important application is now being made to the problems of the petroleum industry. One long-range study under way involves figuring out the most efficient and economical techniques for pumping oil from subterranean reservoirs.

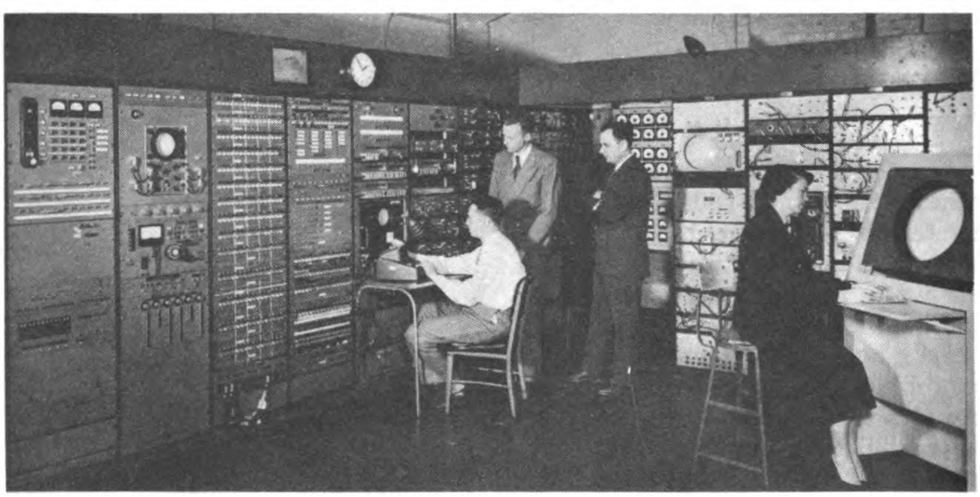


Figure 3. Here is the Operations Center for Whirlwind I. Stephen H. Dodd, Jr., Jay W. Forrester, Robert R. Everett (Associate Director of Digital Computer Laboratory) and Ramona D. Ferenz watch the solution of a problem.

The potential importance of this investigation lies in the fact that an economy of one percent in production could amount to an eventual saving of millions of dollars.

What is the future of Whirlwind I? Certainly there will be plenty of work to keep the big machine busy for a long time. During the next year Whirlwind I will be devoted to a variety of engineering, scientific and industrial uses, as well as to military projects. The important studies to be made involve problems where the machines, devices or systems to be controlled will operate at their own actual speeds. In such applications the computer receives a continuous flow of data to be processed instantaneously into instructions for operating the control system. For example, the computer might be part of an air traffic control center, regulating the flight pattern of hundreds of planes of varying types and speeds approaching the airport from several directions and leaving it for various destinations.

Actually there is still plenty of work being done on Whirlwind I. MIT's Digital Computer Laboratory is looking into the possibilities of extending the capacities and terminal facilities of the machine. Magnetic-tape and magnetic-drum units are now being added and research on the MIT storage tube is being continued with the aim of obtaining tubes of higher speeds and greater storage densities. In addition there will be broader research into applications of digital computers.

NRL Plays Important Part in Developing Synthetic Gas Turbine Engine Lubricant

Combined efforts of ONR, BuAer, the Air Forces and industry have resulted in the first joint military specification for a synthetic lubricating oil for gas turbine aircraft engines.

Initial research for the new synthetic lubricant was done by the Naval Research Laboratory of ONR. An aggressive joint development and testing program by the Navy Bureau of Aeronautics, the Air Force and industry established its suitability and assured production for peacetime and possible wartime use.

The new oil is applicable to both turbo-jet and turbo-prop engines. It will withstand operating temperatures from minus 65 to plus 500 degrees Fahrenheit. At the lower temperature it is about one-third as sirupy, or viscous, as the best petroleum-base product. At the upper temperatures it is one-twentieth as volatile as petroleum-base products and therefore will not boil off. These characteristics are "musts" for lubricants used in gas turbine engines.

The oil is not intended for reciprocating engines and is not expected to replace petroleum products except where military application requires its lubricating characteristics. Its high cost and relatively short supply are expected to prevent widespread commercial use.

The base of the new lubricant is one of a class of chemicals known as aliphatic diesters. To the base is added phenothiazine, to prevent oxidation at high temperatures. A third chemical, tricresyl phosphate, helps to prevent gear wear.

Ultrasonics-

A Tool For Biological Research

by
William J. Thaler
Physicist, Acoustics Branch, ONR

In the past decade, the improved techniques and constant accumulation of data in the realm of ultrasonic waves and their reaction with matter has led biologists to begin experimenting with this new tool. Many interesting results have been obtained, ranging from the therapeutic use of the heating effects of ultrasonics to the destruction of red blood corpuscles by irradiation. It would be difficult even to catalogue the myriad experiments made and results obtained.

Actually, it is a rather exacting task to perform experiments of this nature because of the many factors which must be considered in carrying out the experiment and in interpreting the results. Often the experimenter is either a physicist with a smattering of biology or a biologist with a smattering of physics trying an experiment out of pure scientific curiosity (guided perhaps by intuition). This sort of approach is, in some ways, typical of a new and growing field in science.

In the past three years, there has been a steadily growing trend toward the formation of research teams which combine the talents of physicists, biologists and medical men. This greatly increases the probability of obtaining useful information by carrying out experiments in the fields of biology and medicine.

One such group[1] was formed in the Physics Department of the Catholic University of America at the instigation of Dr. Oscar Lavine of St. Elizabeth's Hospital, Washington, D. C. The problem chosen was the study of the effects of ultrasonic waves on the refractive (i.e., light-bending) media of the eye. The ultimate goal was to study the production of cataracts (opacities) in the refractive media of the eye and to investigate the possibility of clearing them by means of ultrasonic irradiation.

The ultrasonic range includes sound waves having a frequency above the limit of audibility of the human ear (i.e., greater than 30,000 cycles per second). The propagation characteristics of ultrasonic waves depend on the density, elasticity, viscosity and structure of the medium. High-energy ultrasonic beams may bring about thermal, chemical, and mechanical changes in the medium.

William J. Thaler (B. S. Loyola College, M.S. and Ph. D. Catholic University) has been working in the field of ultrasonics for several years and has published a number of papers in the Physical Review and the Journal of Applied Physics.

[1]The group combined the talents of Dr. Lavine, an ophthalmologist; Dr. K. H. Langenstrass, a pathologist at St. Elizabeth's Hospital; Dr. C. M. Bowyer, a radiologist at the National Institute of Public Health; and Drs. F. E. Fox, V. Griffing, and the author, physicists at the Catholic University.

The physical makeup of the calf's eye, which was used in the experiments has the same general characteristics as the human eye. Figure 1 shows the construction of the eye.

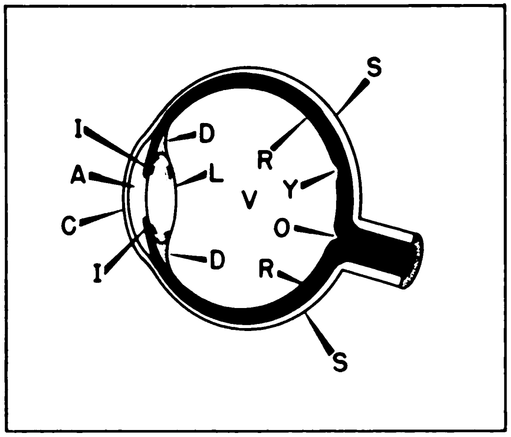


Figure 1. The construction of the eye

The lens L is known as the crystalline lens. It is doubly convex with its outer surface less curved than the inner one. Its composition is largely protein material held in a thin, semi-permeable membrane called the lens sac. It is in the interior of the lens and in the cornea that natural cataracts occur. The lens lies between A, the aqueous humor and V, the vitreous humor, both of which are more or less fluid and have different refractive indices. The iris, I, is a diaphragm having a circular opening of variable diameter, which controls the amount of light admitted to the retina, R, where the image is formed. The outer coatings of the eye are C, the transparent and tough cornea, which protects the lens, and S, the opaque, horny sclerotic. Between the sclerotic and the retina is a thin black membrane called the choroid which, like the black interior of a camera, prevents internal reflections. On the axis of the lens is a yellowish area of the retina, Y, known as the yellow spot, which is somewhat thicker there than elsewhere. The place where the optic nerve, O, enters the eye is called the blind spot because it is not adapted to receive visual impressions directly.

Very little experimental work has been done to determine the effects of ultrasonics on the eye. The first work was reported by Erich Zeiss[2] in 1938. Zeiss studied the effects of ultrasonic waves of high intensity with a frequency around 250 kilocycles per second on the vitreous and lenses of eyes taken from recently slaughtered two- to three-year-old cattle. He used both plane waves and focussed beams of ultrasonic waves. Most of the significant results were obtained with the focussed beam. Zeiss distinguishes three different phenomena:

(a) irreversible liquefaction of the vitreous with two- to four-second exposure to the ultrasonic beam

(b) an opaque zone composed of very fine bubbles in the periphery of the embryonic nucleus of the lens with two- to eight-minute irradiation

(c) leucoma-like white spots in the outer cortical layers of the lens, where it had evidently been in contact with the supporting test tube.

The zone-like type of opacity disappeared in from five to thirty minutes after removal of the lens from the sound beam and Zeiss ascribed its

[2] Zeiss, Erich; Über Linsenveränderungen an herausgenommenen pinderlinsen durch Ultraschalleinwinkung, Archiv für Ophthalmologie 139, 301-322 (Sept. 1938)

formation to cavitation. The leucoma-like white spots were irreversible and he did not offer an explanation as to their cause.

More recently, Kawamoto[3] has reported some results of irradiating excised lenses and vitreous bodies of adult white rabbits and guinea pigs with high-intensity plane ultrasonic waves of 547 kilocycles per second frequency. In all cases the vitreous body was liquefied after short exposure. In irradiation of the lens, the deep layers of the cortex surrounding the embryonic nucleus become turbid, the same effect as that described by Zeiss. In addition, a longer exposure to the ultrasonic beam developed a spotted, dense turbidity around the nucleus and a small, thin, cloudy turbidity within the cortex under the capsule. These latter two effects were irreversible.

As is often the case, the acoustic conditions in the experiments of Zeiss and Kawamoto were not accurately known and the interpretation of the results was not well defined by acoustic measurements.

In the work at the Catholic University, every effort has been made to specify the precise acoustic conditions under which the experiments were made. The acoustic intensity and frequency, the temperature reached by the absorbing medium, and other factors were determined and recorded. Excised eyes were used exclusively. These eyes were obtained from freshly slaughtered calves, 4 to 6 weeks old, and were kept in a water-ice mixture at 0°C until immediately before use.

Let us now consider the physical effects of ultrasonic irradiation in the case of plane waves and focussed waves. If a plane parallel beam

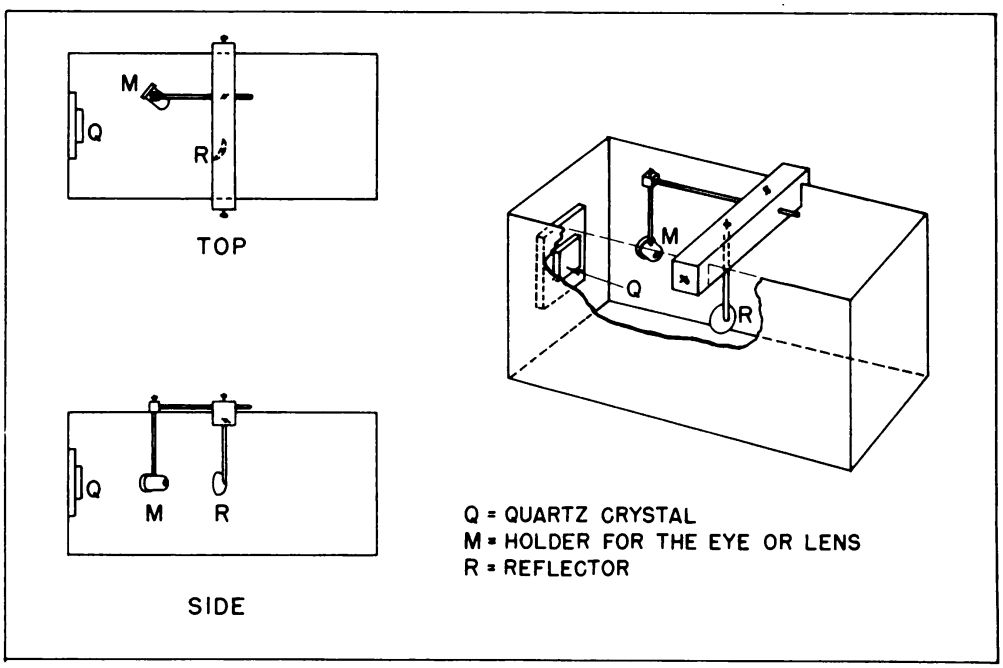


Figure 2. Experimental arrangement: Q, quartz crystal; M, holder for the eye or lens; R, reflector.

[3]Kawamoto, Ikuo: Experimental Studies on the Effect of Ultrasonic Waves on the Eyeball. Nippon Garka Gakkai Zassi Vol. 51, No. 1-2, 12-16 (Feb. 1947)

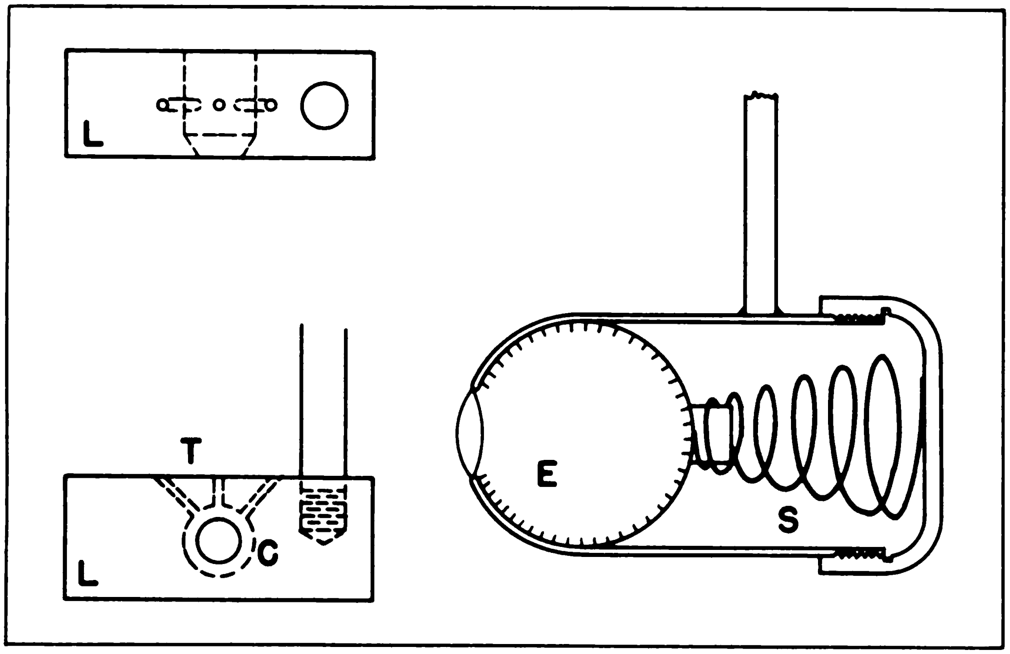


Figure 3. Details of (a) holders for lens and (b) holders for whole eyes: L, lucite block; C, cavity for holding lens; T, channels for thermocouple; S, spring for holding whole eye, E, in position.

of ultrasonic waves is applied to the eye, there will be fairly uniform concussion of all structures in the path of the beam. As a result, the cornea, lens, vitreous and aqueous humor, retina, choroid and sclera are uniformly irradiated. No selective irradiation of the lens is possible. However, when the ultrasonic beam falls first upon a concave reflector, and is thus focussed, the situation becomes quite different. Nearly all the energy in the ultrasonic beam is concentrated in a very small area, much as the parallel light rays from the sun can be focussed with a magnifying glass. Moreover, it is possible to determine precisely the focal region of the ultrasound by knowing the geometry of the reflector system. If such a convergent ultrasonic beam is focussed on the substance of the crystalline lens of the eye, an almost completely selective effect upon the lens fibres is obtained. The effects on the cornea, retina, and other structures of the eye are negligible.

The experimental arrangement is shown in Figure 2. The reflector used was a watch glass 7.5-cm in diameter with a 6.4-cm radius of curvature. The holder for the lens and that for the whole eye can be moved in three dimensions so that any part of the eye or lens can be brought to the point of focus of the ultrasonic beam. Figures 3a and 3b show the holders in detail. Provision is made in the lens holder for the insertion of a thermocouple. The entire system can be easily removed from the tank for insertion of lens, thermocouples, etc., without changing the relative positions of the reflector and holders. It is then easily replaced at a marked position across the top of the tank. This provides for accurate reproduction of the experimental conditions for the irradiation of any chosen part of the eye or lens in successive exposures.

Several methods were used to measure the intensity of the applied ultrasonic beam. The most direct was the measurement of the gain

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of the ultrasonic source-reflector system at a given frequency[4]. The gain is defined as the ratio of the maximum (or average) intensity in the focal region to the intensity in the plane ultrasonic beam. The pressure exerted on a very small glass bead in the focal region was measured. This enables the energy density and intensity in the focal region to be calculated. The energy density in the plane wave as it leaves the transducer was also calculated from the voltage on the crystal, its known sharpness of resonance and resonant frequency.

Measurements of the local temperatures in various irradiated regions were made by means of a very small thermocouple (copper-constantan wire, B. and S. No. 30). Preliminary tests indicated that the effect of the ultrasonic waves impinging directly on the thermocouple was less than 0.5°C. The cold junction was kept at 0°C in a water-ice mixture. Calibration was accomplished by comparison with a mercury-in-glass thermometer and a microammeter was used for observation of the temperature changes.

During the first experiments, made with whole calves' eyes, it was possible to observe the lens within the eye during irradiation. The focus of the ultrasonic beam was within the lens. With 1000 volts (rms) on the quartz crystal transducer, a white opacity (Lavine cataract) developed at the focus in one second. After continuous irradiation for 30 seconds, this cataract had grown so that the whole lens was a dense, firm, white mass. The greater the voltage applied to the crystal, the less time it took for a cataract to form. Below a certain minimum voltage no opacity formed, even though the irradiation was continued for as long as 30 minutes.

These Lavine opacities showed no tendency to change after irradiation; moreover they were irreversible. No changes could be observed in any part of the eye other than that in the focal region of the ultrasonic beam. A corneal opacity could be produced by fixing the focus of the ultrasonic beam in that region but the minimum voltage required was much higher. Many measurements were made on the lens only.

In interpreting experimental observations, two possible explanations presented themselves. First, the Lavine opacity could represent the direct result of the ultrasonic irradiation itself. This would mean it was dependent directly on the alternating pressure, temperature, and density changes in the ultrasonic wave. Secondly, the opacity could be the result of a secondary effect of the ultrasonic beam. The most probable effect of this kind would be local heating of the medium due to absorption of the ultrasonic energy concentrated in the focal region of the beam. Thus coagulation of the protein of the eye lens would result in much the same way as heating a chicken egg causes the albumin, which is protein, to coagulate. If the effect were direct, then one would expect that irreversible changes in the lens would occur before the cataract became visible. The time of irradiation necessary to produce a just visible opacity would also be more or less independent of the fact that the irradiation was continuous or intermittent. If the effect were

[4]Fox, F. E. and Griffing, V., Experimental Investigation of Ultrasonic Intensity Gain in Water due to Concave Reflectors, J. Acous. Soc. Am. 21, 352-354 (1949)

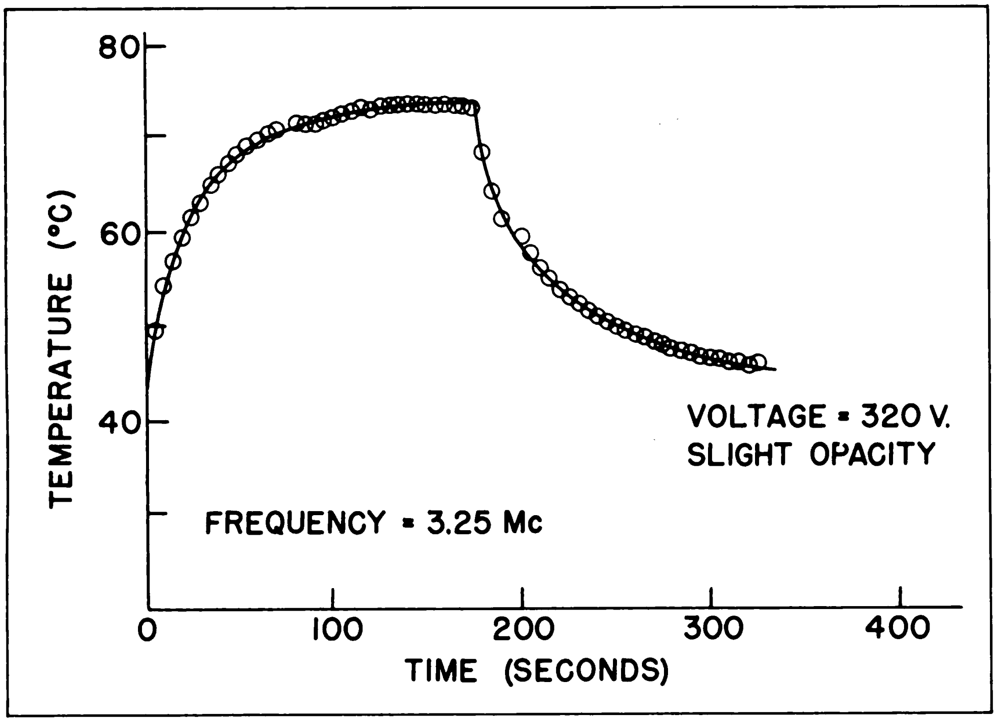


Figure 4. Temperature rise vs. time at constant frequency

secondary, however, and due to local heating then interruption of the irradiation before coagulation starts would result in a certain amount of cooling. Therefore, a longer total irradiation time would be needed at a given intensity and the threshold intensity would depend strongly on the length of the on-off periods of irradiation.

Experiments with intermittent irradiation were performed to test for the secondary effect. The results strongly suggested that local heating was indeed the probable cause of the cataract formations.

In order to obtain direct confirmation of this, a tiny thermocouple was inserted into the lens at the exact focal region of the ultrasonic beam and the temperature was recorded. A typical curve obtained from the thermocouple measurements is shown in Figure 4. The temperature as ordinate is plotted against the continuous exposure time at constant voltage on the crystal and constant frequency. It was found that the opacity became visible only when the local temperature in the lens was higher than 70°C. It was, in fact, possible for an observer reading only the thermocouple to determine the time of appearance of an opacity by noting the time at which the thermocouple indicated that the local temperature had reached that level necessary for coagulation to occur.

Another experimental technique was developed as a further test of the rate of local temperature rise in the formation of the Lavine opacity. The intensity was increased in small steps, with continuous irradiation, allowing two minutes for the local temperatures to reach steady state at any one intensity. A corresponding rise in the steady-state temperature was observed until the temperature reached the threshold value. At this temperature the opacity developed.

The Lavine cataract assumes a variety of geometrical shapes. Figure 5a shows the general appearance of the cataracts produced by focussed ultrasonic beams. If the focal point lies within the lens, it is always spindle-shaped (fusiform) in its initial stage. The poles of the spindle are slightly rounded with the long axis along the axial ray of the focussing system. The intensity, frequency, and time of irradiation determine the denseness and size of the opacity. Continued irradiation tends to round off the poles of the spindle and the entire lens becomes opaque and hard.

Examination with usual ophthalmological techniques, such as the slit lamp microscope, shows an uneven, fuzzy surface everywhere along the interface between fusiform opacity and the surrounding clear lens. The opaque area appears uniformly dense.

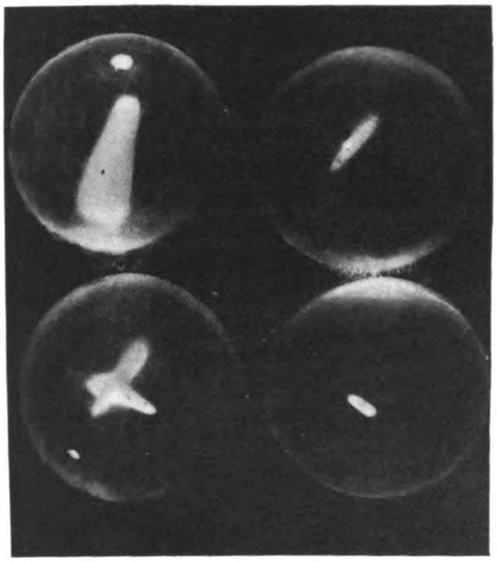
A freezing microtome was used to cut equatorial frozen sections at ten microns thickness. These were studied in their unstained conditions with a microscope having magnifications of 110X and 440X. A kind of granular disintegration seems to have taken place in the opaque region. Outlines of a few lens-fibres are seen, but the finer architecture of the individual fibres is completely invisible and seems to have been almost completely destroyed.

A narrow concentric ring of brown discoloration surrounds this central area of destruction. Structural changes are only slight, here. A second zone surrounds this narrow ring. No trace of structural damage is visible in this second zone but a pale brown color characterizes its appearance. Further outward even the brown color disappears and the lens fibres appear healthy, transparent and clear.

If the focus of the ultrasonic beam was so placed that the posterior or anterior poles of the fusiform opacity came in contact with the lens capsule, a local rupture of the capsule occurred. This rupture could actually be heard as a clear-cut "puff". The slit lamp shows this rupture as an irregular elevation of the polar region of the dense opacity and a small area of capsular laceration.

As long as the lens capsule remained intact, there was no evidence of any cavitation such as produced by Zeiss and Kawamoto. This is explained simply by the fact that at higher frequencies, the intensity must be increased before cavitation occurs.

A series of experiments was performed to determine whether temperature elevation alone could cause opacities to develop in the refractive media of the eye. A heater, stirrer, thermometer and thermostat were arranged in a one-gallon thermos flask. The lens, cornea, and capsule were placed in the bath and the temperature raised in equilibrium steps of one degree centigrade. In all cases, there was a temperature threshold above which an opacity appeared: For the capsule about 55°C, for the lens in the capsule 63°C, and for the cornea 50°C. But in this situation the lens opacity developed from the outside of the lens and grew inward. The rate of coagulation increased with the temperature of the bath, as did the density of the final opacity. The minimal temperature for the ultrasonic production of the Lavine cataract lies above that obtained in the temperature bath. This is to be expected, since the formation is much more rapid in the ultrasonic production with conse-



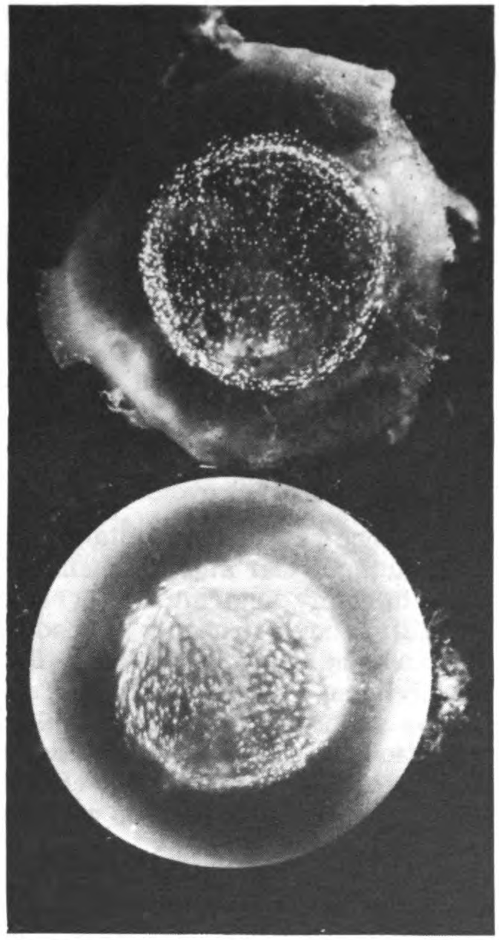


Figure 5a. Lavine cataract produced with focussed ultrasonic irradiation; f = 3.25 mc; time of irradiation for the lenses shown ranged from less than one second for the smallest opacity to ten seconds for the largest opacity. All voltages were 800 volts rms. The lens with the three cataracts (two crossed) indicates how a cataract can be placed in almost any desired area within the lens. Figure 5b. Zeiss cataracts: opacities produced by irradiation for two minutes with 500-kc plane wave; rms voltage 2000. The capsule has been removed from one lens, after irradiation, in order to show the detailed structure of the Zeiss cataract.

quent error in correlating temperature reading with first visible appearance of the cataract.

Plane waves were then used to form opacities. The voltage used was of the order of 1200 volts and several minutes irradiation was required for both the lens in the whole eye and the lens alone. Standing wave systems and progressive plane waves were used, and the variations in location of the opacity and time for formation were dependent on the geometry of the system and the applied intensity.

All these experiments confirmed the conclusion that the Lavine cataract is related to the equilibrium temperature distribution during irradiation and therefore to the viscosity and thermal conductivity of the medium and the geometry of the system.

The cavitation phenomena of Zeiss and Kawamoto were also reproduced using a plane standing wave system at 500 kilocycles per second and 2000 volts. Figure 5b shows a lens treated in this fashion. The bubbles disappear entirely a few hours after irradiation ceases.

This whole series of experiments was undertaken with the hope that ultrasonics would provide a means for treating cataracts. It was hoped that the disruption and ultimate liquefaction of the opaque lens-protein and lens-fibre system of clinical cataracts could be obtained. This hypothesis is based upon many reports that molecular rearrangement can be effected by ultrasonics, that aerosols can be dispersed and coagulated by ultrasonics, and by cases where the opaqueness in traumatic cataracts of youth and in certain other types has disappeared by natural processes.

We have succeeded in producing a new type of ultrasonic cataract which is similar to clinical cataracts. These ultrasonic cataracts can be produced at specified areas, within a few seconds, without any observable effect on the rest of the eye. Thus we have a readily available material and technique for medical as well as experimental cataract research.

Since reversible cavitation effects offer some promise for clearing cataracts, further study of such effects should be made. High-frequency, high-intensity, intermittent irradiation should be investigated since cavitation could probably be produced in this fashion and the advantages of focussing could be utilized. In addition the effects of ultrasonics on the living eye should be studied, since it is believed that certain types of cataracts occur because of faulty nutritional processes. In the lens, nutrition takes place by a process of diffusion through the semipermeable lens capsule. One might expect that ultrasonic irradiation may influence the permeability of the lens capsule with subsequent improvement in the nutrition of the lens.

Obviously much work remains to be done. This report only serves to illustrate what can be accomplished through teamwork in applying to biological research the new and fascinating tool of modern physics which is ultrasonics.

Conference on Scientific Manpower Held at Recent AAAS Meeting

The 118th meeting of the American Association for the Advancement of Science, held in Philadelphia December 26th-30th, included for the first time a conference on Scientific Manpower.

The Program Committee was composed of: Chairman, Dr. Ralph M. Hogan, Manpower Branch, Human Resources Division, Office of Naval Research; Dr. T. A. Marshall, Engineering Manpower Commission, Engineers' Joint Council; Dr. M. H. Trytten, Office of Scientific Personnel, National Research Council; Secretary, Mr. John A. Nagay, Manpower Branch, Human Resources Division, Office of Naval Research.

This conference, in three sessions, December 28, 29, and 30, was organized to bring before the Association some of the crucial problems involving scientific manpower in the fields of physical, biological, engineering, and social sciences. That there is an increasing public awareness of personnel problems related to scientific manpower is evidenced by the nationwide interest stimulated by the recent decision to base military service deferments of college-age men upon test results. It is hoped that conferences on this subject can eventually be integrated into the program of the Association as a permanent feature.

Crystal Electron Valves - Diode and Triode

by

Emerick Toth
Naval Research Laboratory

It has been rumored that Arthur Godfrey (a well-known alumnus of the NRL Radio Materiel School) upon being confronted with news of the development of the first Transistor, remarked, "Radio sure has progressed. For thirty-five years crystal detectors had one cat whisker. Now they have two". Like many another statement made in jest, this one is not only funny but is also an essentially sound appraisal of the

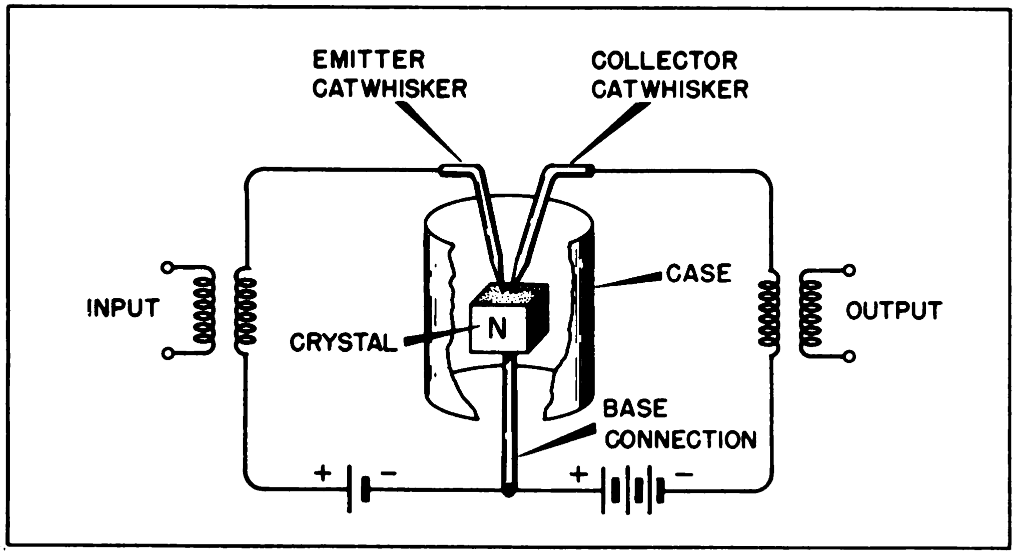


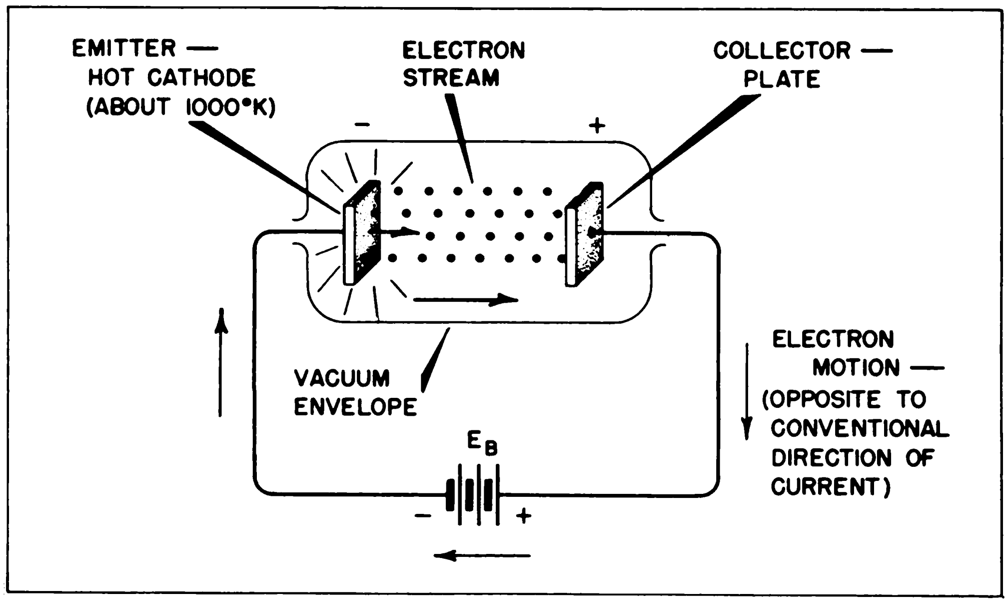
Figure 1. Basic elements of a crystal triode (contact-type Transistor).

situation. The second cat whisker touching the surface of the crystal forms another rectifier or detector. When the proper spacing between cat whisker points is provided (about 0.002 to 0.030 inch) and the rectifiers are connected in circuit back-to-back, the device is capable of operating as an electron valve in a fashion resembling the operation of a vacuum tube of the triode type.

Emerick Toth, an electronic scientist at the Naval Research Laboratory, has been engaged for many years in research and development work in circuitry and receiving equipment, particularly military types. He received his B. S. at the Newark College of Engineering and then took a position as Associate Research Physicist at the Physics Laboratory of the Bakelite Corporation. Later he was a radio receiver engineer at Bell Telephone Laboratories, Wired Radio, Inc., Hygrade-Sylvania Corporation, Pilot Radio Corporation and Bendix Radio Corporation. He has been at NRL since 1938.

The continuously regulating electron valve has made modern electronics possible. The appearance of a new form of such a device is therefore a matter of outstanding importance. The new valve may be thought of as an attempt to produce a sort of atomic assembly in triode form. This necessarily involves new techniques and concepts, of which some understanding is essential if the valve is to be used effectively and within its limitations. The atomic type of valve structure is both simpler in design and much more difficult to produce and reproduce than the assembly of small metallic and ceramic parts constituting the usual vacuum tube. Development of the crystal triode has also produced a new form of crystal diode (the pn junction type) but tetrode and higher order structures have not, as yet, been developed with any considerable degree of successful performance.

By a fortunate combination of circumstances, the thermionic vacuum form of electron valve was invented and developed to its present high degree of refinement prior to the invention of a successful crystal triode. Despite some fundamental shortcomings, the vacuum tube is basically a true unidirectional regulating valve. The vacuum between cathode and plate electrodes forms a gap in the external copper circuit; this gap is spanned by electrons boiled off from the cathode emitter



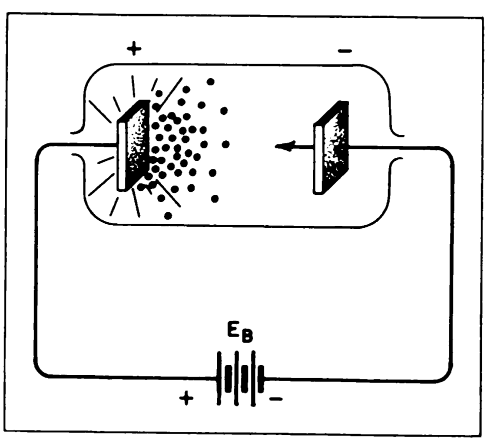


Figure 2. Thermionic vacuum diode: above, plate positive; diode circuit closed. Increase of E_B increases flow of electrons. At left, plate negative; diode circuit open.

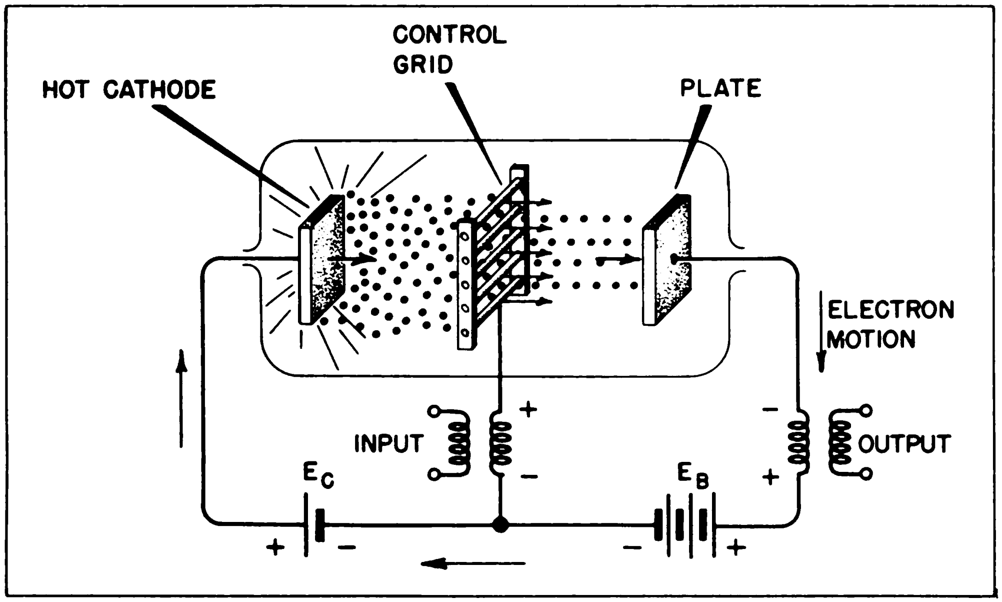


Figure 3. Thermionic vacuum triode with bar-type control grid.

surface. Application of an electromotive force in series with the plate circuit will increase or decrease the rate of flow of the electrons through the circuit (including the gap) as the emf makes the plate more or less positive with respect to the cathode. This flow is one-way, because the plate is not normally an emitter. Therefore, if the plate circuit emf is alternating, plate current will flow only on the half cycles during which the plate is the positive electrode. (Actually total plate current cutoff will occur when the plate is negative with respect to cathode by a voltage corresponding to the thermionic emf or "contact" potential.) The electrons in the cathode-plate space will be repelled by the negative plate on the reverse half-cycles.

If the plate circuit emf is supplied by a battery or other suitable fixed potential dc source which is poled to make the plate positive, it is possible to interpose a suitable obstacle or barrier in the electron stream between cathode and plate so as to provide accurate control of the flow of current. The obstacle most often used for the control electrode is a wire mesh grid or screen, but it may also be a deflector or any other barrier which can interfere with the normal course or flow of electrons. Any desired reasonable number or arrangement of control obstacles may be interposed between emitter (cathode) and collector (plate) electrodes; this is what makes possible the almost endless variety of thermionic vacuum tubes.

These vacuum valves (triode and higher order) are remarkably effective devices because of one outstanding feature. They are essentially voltage or potential controlled, corresponding to <u>force</u>-controlled mechanical valves. This means that the control or driving circuit need provide very little power or current to the control electrode, if the designer so desires. Ideal electron valves should have infinitely high input impedance, requiring no control current at all, and output resistance which can be chosen as desired. Additionally, they should be capable of relatively easy design and construction in sizes proportional to the power output capability required for various applications, with power

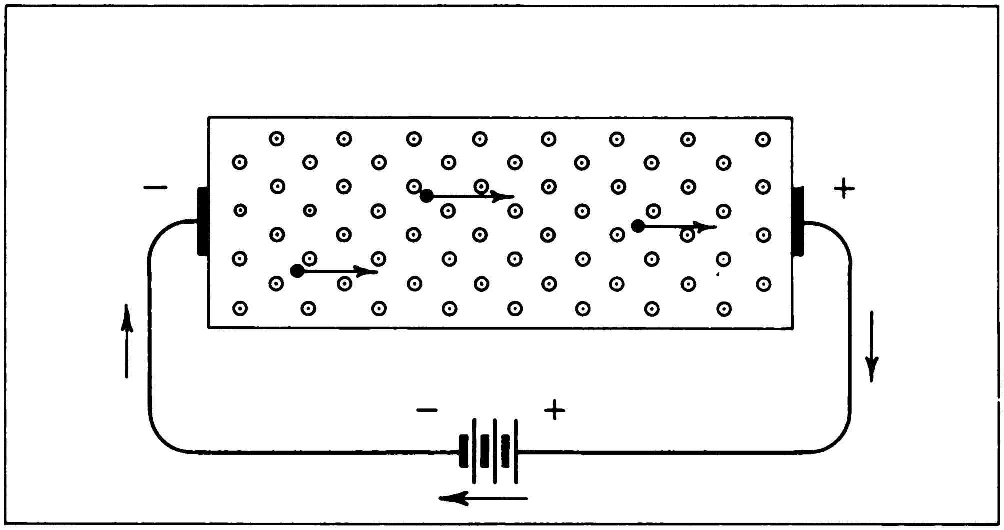


Figure 4. N-type crystal; conduction by excess electrons. ● = electrons. ⊙ = normal bonded atom in lattice (no missing electrons).

conversion efficiency comparable to other electrical machines. The thermionic vacuum valve approaches most of these goals to a high degree. Its present major deficiency is inability to operate efficiently at low power-output levels (a few milliwatts or less). To a large extent, this is the result of the power wasted in heating the cathode. It is present general design practice to employ tubes with fractional-watt output capability in micropower-level circuits (for example the first r-f amplifier is a receiver). This is in part due to lack of tubes designed for micropower use, in part due to the economics of design (limitation on number of tube types, number of voltage values, etc.) and in part due to contingency factors (the first r-f tube may at times have to accommodate several volts of input signal instead of microvolts, etc.)

The crystal detector is a device similar to the diode thermionic vacuum valve. However, it has a number of complications which the thermionic diode avoids by the simple expedient of interposing nothing (in the form of a vacuum) in the path of the electrons, the vacuum being housed in a glass or metal "bottle." The equivalent of the vacuum of the thermionic valve is provided by the interatomic spaces in the crystal. Since long, relatively straight corridors are desired so that an electron need change course very little as it scoots along between atoms, elements such as silicon or germanium are chosen from Group IV of the Periodic Table of the Elements. These crystallize in a cubic or tetrahedral structure. In this form of crystal, the basic lattice has eight shared atoms per cell, located as though they were at the corners of a small cube of space relative to each other, with four atoms wholly within the cube. The desired straight corridors appear between the atoms of successive cubes. These are relatively spacious paths, since the clear inter-atom cross-section area seems to be on the order of about 5 to 20 times the cross-section area occupied by an individual atom.

That eminent sea-going scientist, Mr. Colin Glencannon, once observed while investigating the Yogi system of breath control, "The very next thing to do is to acquire a good strong breath to control." Similarly, the basic crystal "bottle" needs some good strong electrons

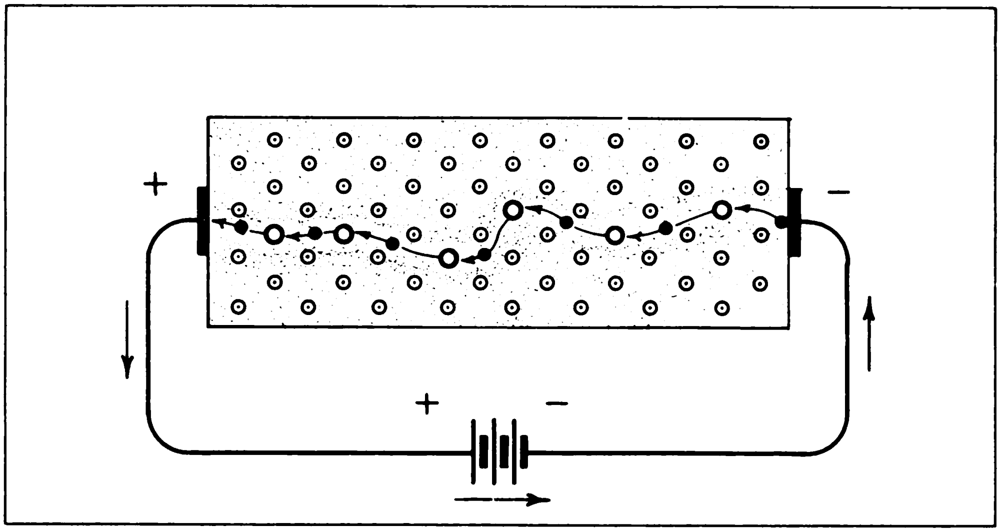


Figure 5. P-type crystal; conduction by electron deficiency or holes (only one path shown). ● = electron. ⊙ = normal bonded atom in lattice. O = bonded atom with one electron temporarily missing (i.e., hole).

to control. These are supplied in thermionic diodes by the hot cathode. In the crystal case, they are "salted" in by the addition of so-called impurity atoms. These are not impurities in the usual chemical sense. They are elements chosen from Group V of the Periodic Table, such as arsenic or antimony. The members of Group V are valence-5 atoms, which have five electrons available to form bonds in chemical combination. Only the merest trace of the "impurity" is added to the germanium or silicon, for instance, about one part in ten million to germanium (typically, 1×10^{-6} to 1×10^{-8}). The added valence-5 atoms attempt to combine with the valence-4 atoms, which leaves one electron free for every ten million or so germanium atoms. This lonesome fellow[1] drifts along more or less aimlessly in the atomic corridors until a substantial external electrical potential is applied across opposite faces of the crystal, whereupon the electron acquires purpose and direction.

The germanium or silicon plus the deliberately added Group V impurity is designated n-type material (n for negative) because it contains excess or free electrons. Actually, both these elements in the "pure" state are known as semi-conductors, because their electrical conductances fall between the values for good conductors and good insulators. For instance, the resistance of nominally pure silicon is about 60 ohms per centimeter cube. With the addition of one part in ten million of "impurity," the resistivity of silicon falls from about sixty to about one ohm per centimeter cube because of the free electrons. Similar changes in conductivity occur with the addition of impurity elements from Group III of the Periodic Table, with one important difference in

[1]Lonesome in the sense of some early Western pioneers, who felt crowded when neighbors got as close as fifty miles. There are about 4×10^{22} atoms in a cubic centimeter of germanium. Even with only one ten-millionth as many free electrons, this electron population is 4×10^{15}, which is enough to provide the respectable current of 1000 amperes per square centimeter with comparatively little electrical persuasion.

the mechanism of the conductive effect. These elements have only three electrons available to form bonds (valence-3). Incorporation of valence-3 atoms into a valence-4 atomic lattice structure will produce a structural deficiency at the location of each valence-3 atom, which can be corrected only by addition of an electron from some source. These deficiency points are known as "holes," and the crystalline elements in which they exist are designated p-type material (p for positive) because they are electron-deficient.

Application of an emf across a p-type crystal causes electrons to move through in much greater numbers than for the same conditions with pure germanium or silicon. This is because of the phenomenon called hole conduction. The electrical potential impressed across the crystal urges electrons to move away from the negative end toward the

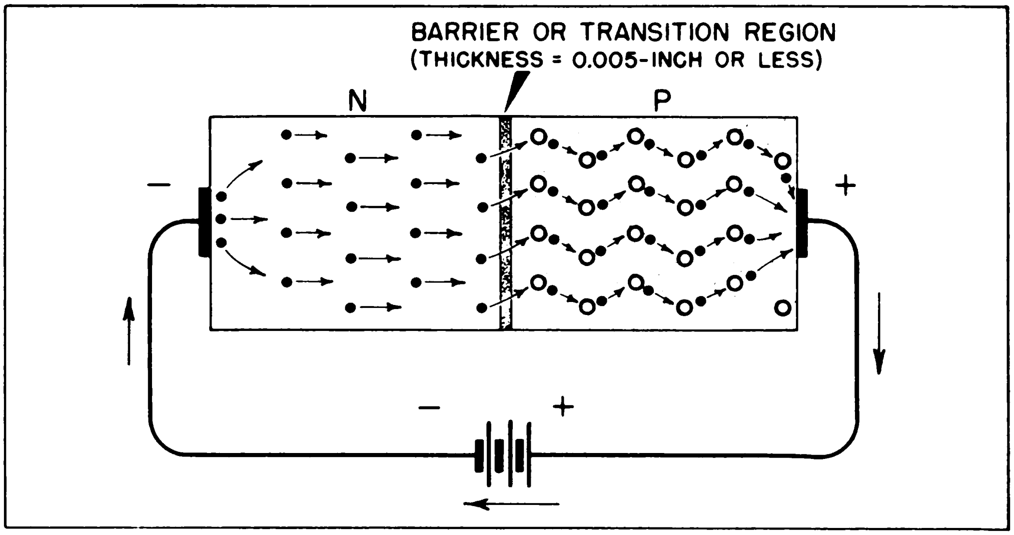


Figure 6. Forward conduction in PN junction diode. Only electrons and holes are shown.

positive potential end. Since there are practically no free electrons in the material, some of those not too tightly bonded in the lattice are constrained to move so as to fill nearby holes in the positive potential direction. Thus the imperfect points in the lattice are corrected toward the positive end, resulting in an increasing concentration of holes or electron-deficient points toward the negative end. This produces an apparent movement of holes from the positive to the negative terminal, where they can pick up electrons from the external copper circuit. This progression is, however, illusory; only the electrons actually move.

The junction, or "pn," type of crystal diode consists of a block of n material in intimate contact with a block of p material. This form of diode, although not yet widely available, will be discussed first, since the cat-whisker type may be considered as essentially another version of the junction type. In practice, it is difficult to insure that the separate p and n surfaces are joined properly without intervening oxide films and with true flat contact rather than a large number of point contacts. For this reason, it is generally better to start with a block or bar of pure germanium or silicon of appropriate dimensions, one end of which is then converted to n-type material and the other to p-type by some process such as diffusion of the appropriate impurities into the ends of the bar. Other methods of fabrication may alternatively be used. Whatever the process, the desired result is a homogeneous bar with no physical breaks, but with a sharp transverse transition from p to n type material about midway between ends.

Separately, the p and n portions of the combination are each capable of passing current freely in any direction. Together, however, they form a unidirectional conductor. If an emf poled as in Figure 6 is applied across the opposite ends of the bar, the electrons in the n portion will move away from the negative pole toward the pn junction, and the "holes"

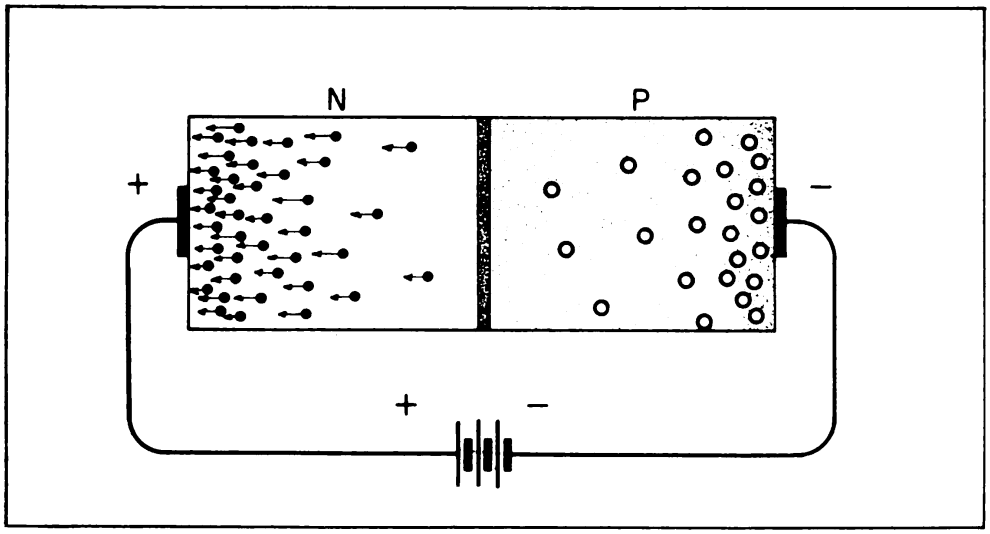


Figure 7. Effect of reverse voltage in PN junction diode.

will likewise (appear to) move away from the positive pole toward the junction. The holes thus become available at the junction to aid the electrons' escape from the repelling polarity being applied to the n section. If the supply of holes and electrons in the two sections of the block is sufficiently large, with enough holes to transport the electrons seeking escape, a relatively heavy "forward" current can flow. As previously mentioned, this can be as high as 1000 amperes for a square centimeter cross-section. The holes may be thought of as a sort of bucket brigade, which itself does not move about but which can pass onward a good many "buckets" in the form of electrons. When the emf is reversed and the p end becomes negative while the n end becomes positive, the electrons and holes concentrate away from the junction. The free hands in the bucket brigade and the buckets thus move away from each other and essentially no current will then flow through the valve.

All this presents a relatively nice, simple picture, despite some resemblance to the old two-fluid theory of electricity. But there are inconsistencies hidden in it. Electrons can be salted-in the crystal

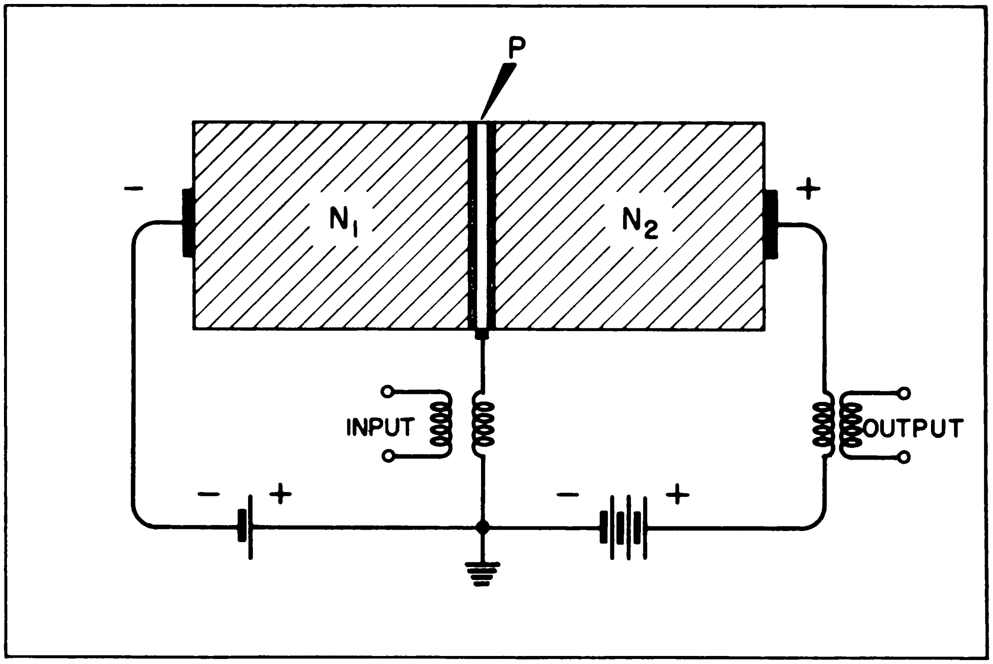


Figure 8. NPN junction triode in grounded emitter circuit (equivalent to grounded cathode vacuum triode circuit).

structure to make n material by adding the proper impurities but, disconcertingly, application of a pressure of 100 tons per square inch or more to n germanium changes it over to p-type. Heating n-type germanium[2] to somewhat over 500 degrees C and then quenching it produces p-type material; likewise, cooking p material for 15 minutes to 100 hours at a temperature somewhat over 500 degrees C makes it into n-type. Another element to consider is that the application of a field of 200,000 volts per centimeter disrupts the atomic bonds and makes either type of germanium into an excellent conductor until the field is removed. If the material is thin enough, this can occur at just a few volts, with no damage to the germanium.

Since the pressures encountered under cat whisker needle-points are often well over 100 tons per square inch, a contact-type crystal rectifier such as a block of n germanium and a suitable cat whisker will really be a pn junction device. The region immediately surrounding the point will apparently be converted to p material by the pressure; alternatively, such a p region, if not formed by pressure, may be produced by heating the point-contact area with a large pulse of current (welding). These effects shed a good deal of light on the peculiarities of the crystal detector of yesteryear, and also explain why the modern cat-whisker types may require retirement from active duty after overload. Heating of the cat whisker contact region by relatively large currents applied for sufficient time will convert the p material back again to n-type, destroying

[2]The melting point of germanium is about 950 degrees C.

the rectifier action. Reactivation may be possible with suitable techniques.[3]

Production of even an essentially simple form of crystal valve such as the two-electrode or diode version is laden with difficulties. Many serious "little" problems arise - for instance, the determination of impurity level in the crystal. Chemical or optical tests are of little value for impurities of one part in ten or a hundred million. Recourse is necessary to such uncommon means as Hall-effect measurements, in which an electrical potential is produced across the crystal at a right angle to the normal current flow by application of a transverse magnetic field. This is an indirect method at best and does not indicate that other than electrical conduction impurities are present. The germanium metal employed in making present-day crystal valves is of exceptionally high purity, probably the highest of any metal commercially used. However, the effect of the non-conducting impurities remaining may be very important.

Small cat whisker-type diodes are on the commercial market in several different categories of back voltage, forward current, resistance, etc., but they all appear to start as one design at the beginning of the production line. The several varieties are apparently obtained by sorting and selecting at the output end of the line. The junction-type diodes are more recent devices and production is still in its pilot stages; consequently production experience in their case is still meager.

The troubles experienced with crystal diodes can be expected in greater degree with the crystal triode or Transistor. This is essentially a two-whiskered crystal detector in its initial (Type-A) guise, as previously mentioned. The later form, the npn (or pnp) junction triode is, however, simpler to understand and is a better electron valve than the contact type in a number of ways. This device is basically an assembly of an np and pn junction in series. Actually,

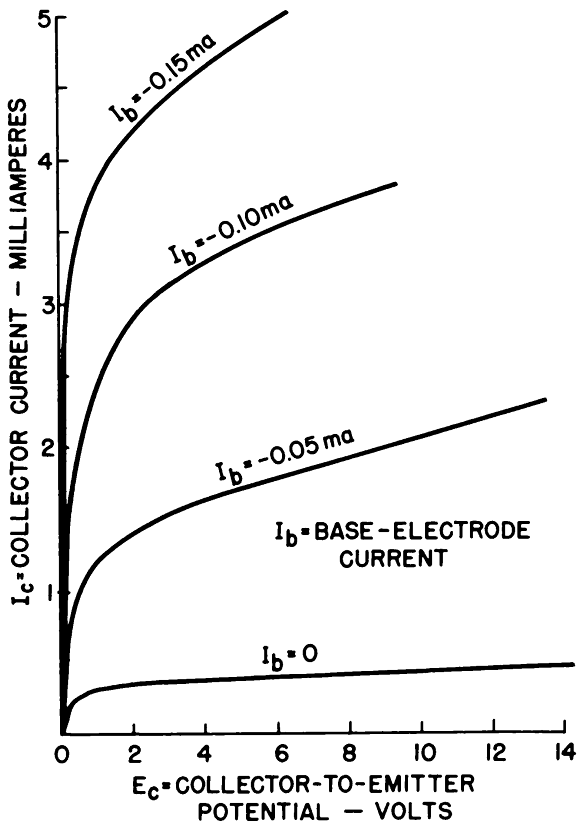


Figure 9. Collector characteristic curves.

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[3]A form of shock therapy sometimes favored in Naval circles for radar crystal detectors is quite satisfying and occasionally effective. The delinquent valve is hurled full force at a metal bulkhead or other suitably hard surface. After the operator and the crystal have both cooled off, the detector is checked for activity.

as so far produced, it consists of a homogeneous bar of p or n silicon or germanium, which is fabricated to have a thin sheet (0.005 inch or less) of the opposite type of material forming a transverse section in the bar. (A metallic control grid or obstacle such as used in vacuum tubes would be "shorted" in the crystal.) Current flows through the bar under the urging of an external dc emf connected across the two ends (n-material in the npn form). This current consists of the free electrons in the n material, which are moving away from the negative end of the bar and toward the positive end. At the N_1P junction next to the negative end, the electrons encounter a barrier—the transition to p material—where conduction is via holes. With no external emf appearing between electrodes N_1 and P, the few holes available tend to be concentrated at the N_1P junction, which is negative relative to the PN_2 junction. The output circuit or collector current under these conditions is quite low (see region of Ib = 0 in Figure 9) and is limited to almost a constant value, despite increase in collector-to-emitter voltage, by lack of sufficient holes to furnish transport from N_1 to N_2 for all the available electrons.

When an external emf makes P substantially positive relative to N_1, additional holes are "liberated" in the p section under the influence of the increased potential difference. This gives the waiting electrons in N_1 their opportunity to cross in greater number over to N_2 (a distance of only a few thousandths of an inch or less) via the larger number of holes. In so doing, a few, relatively, are diverted to the P terminal and provide the quite low values of base input current marked on the curves of Figure 9. Most of the electrons appear to prefer the higher positive potential of N_2. Since the rectifying junction N_1P must be biased in the forward or maximum conduction direction to allow increase of collector current, its resistance is very low, and the potential difference between N_1 and P needed to produce the values of base and emitter current shown is a few tenths of a volt or less as compared to volts at the collector. This low input resistance makes it essential that dc current regulation (in the form of a high dc resistance or some other simple means) be provided in the input circuit to prevent accidental burnout of the crystal. The low N_1P barrier resistance additionally requires that the circuit driving the base to emitter circuit of the triode be designed to work into a low value of impedance.

The family of curves in Figure 9 shows a rapid initial rise of output or collector current with increase in collector (-to-emitter) potential. Above about one-volt collector potential, the collector currents tend to level off at values determined by the base or control-element current. Further increase of collector potential causes relatively minor change of collector current. Apparently, the bucket brigade (the holes) is passing nearly its full quota of buckets (electrons) from N_1 to N_2 for any given value base current when the collector potential reaches one volt or more. Increasing that potential places greater pressure on the brigade to speed up its handling of the greater number of buckets piling up at the N_1P junction. However, 1000 percent increase of that pressure produces only about 100 percent more delivery of buckets to N_2.

Any valve, mechanical or electrical, is an amplifying device if a power level change appearing in its output or controlled circuit is greater than the associated power level change required in the control circuit. The junction Transistor is an amplifier when proper input (control) circuit and output load impedances are provided for it. As

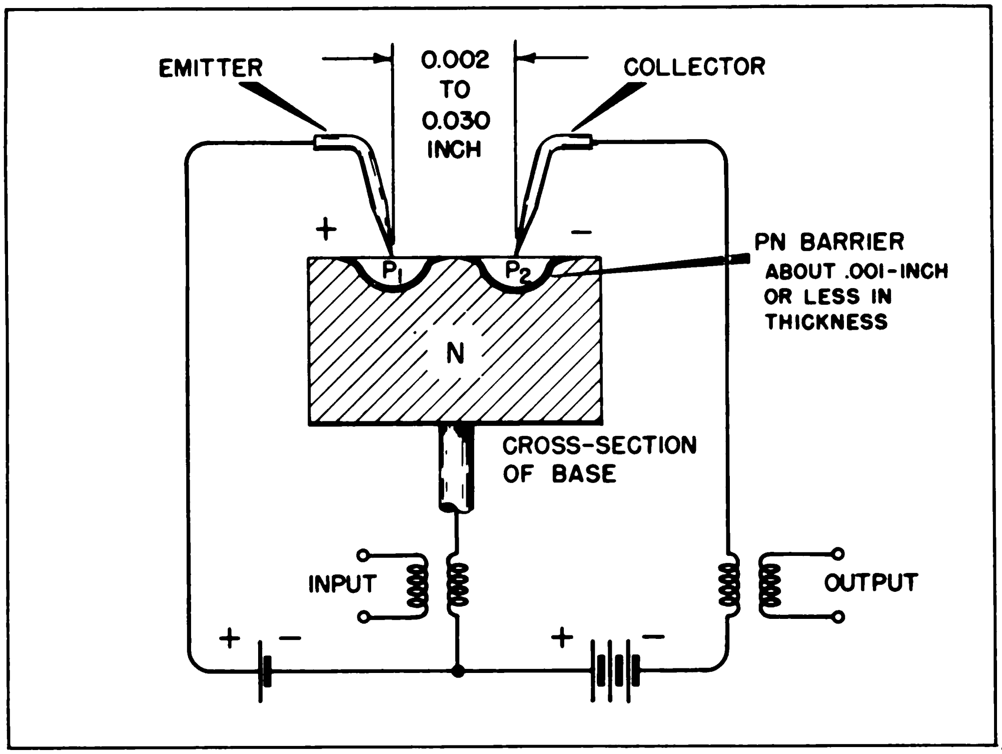

Figure 10. PNP junction structure produced by heat or pressure in a contact type triode.

mentioned, its input impedance is that of a "closed" diode, of higher than normal forward resistance, about one hundred to a few thousand ohms when inverse feedback is not provided in the triode system. Its output impedance, however, is that of an "open" diode, with a back resistance value of a few hundred-thousand ohms to ten or more megohms. With the necessary impedance matching means provided (transformers, etc.), the junction crystal diode is capable of producing a change in output power level of as much as 50,000 to 1 for a unity change of power in the control circuit, or about 45 decibels of amplification for one valve. This is power amplification; the voltage amplification (more properly, voltage multiplication) realized in any individual circuit design will, of course, depend on the particular impedance conditions.

The upper-frequency cutoff of the crystal triode is generally limited to a figure less than that obtained with an equivalent thermionic vacuum valve. With vacuum tubes, electron-group transit time is usually the final limitation. In the crystal valve, however, it is variation of individual electron transit which is important. The sudden appearance of a bunch of new members (liberated holes) in the bucket brigade resulting from an abrupt change of control element (base) current appears to cause confusion in the system. Instead of all the larger batch of buckets which can then be accommodated traveling by the shortest chain of handlers from N_1 to N_2, some appear to be fumbled around so that they arrive by longer paths and later than they should. A signal which appears as a square-wave current in the control circuit will emerge from the output circuit with rounded corners if the keying rate is in the tens or hundreds of kilocycles,[4] the frequency limit depending on load

[4] With present junction Transistor designs.

impedance. Also, because of high valve output resistance, a good output impedance match is usually possible only at the lower frequencies. Amplifiers required to work above a few kilocycles must increasingly trade gain for higher frequency response by using less than the optimum load impedance.

The junction crystal triode is truly remarkable for its ability to function at very low collector potentials, as evident in Figure 9. Within its various limitations, it is an almost ideal micropower amplifier of extraordinary efficiency. "Plate" efficiency figures for Class A, B, and C operation can approach the theoretical maximum values quite closely, and no filament or heater power is required. When available with uniform characteristics and in production-line quantities, it will undoubtedly appear in many commercial low-power audio applications, such as telephone and hearing-aid amplifiers. It will provide a nearly perfect replacement for triode vacuum tubes in computer circuitry and similar applications where low power-level operation generally prevails. The military applications, however, are less obvious, because of basic limitations such as temperature vulnerability, which will be touched on later.

The contact or cat whisker-type crystal triode using n material may be thought of as a pnp junction device. The contact pressure or the heating of the cat whisker points by forming or welding currents will tend to produce tiny islands of p material under the microscopic whisker tips. With voltage polarities as shown in Figure 10, holes will tend to concentrate at the P_1N junction under the influence of the emf applied. Since the two islands about the cat whisker points are almost touching (the cat whiskers being usually only about 0.002 to 0.005 inch apart at the points), a small emf that causes diode P_1N to conduct will apparently free some holes to transport electrons through the barrier at NP_2. Most of the collector electrons which traverse P_2N will prefer the more direct path back to the battery through N, avoiding passage through a second barrier at NP_1. This is indicated by the relative values of emitter and base-electrode current shown in Figure 11. With this type of triode, as with the junction type, one volt of collector-to-emitter potential difference is sufficient to produce operation for the particular unit measured.

As in the case of the true junction triode, the base-to-emitter potentials which produce the current values shown in Figure 11 are only a few tenths of a volt or less, since P_1N is "closed" and is consequently very low in resistance. Current regulation is again needed in the input circuit to prevent accidental burnout. The contact-type triode, like the junction type, is characterized by low input or control circuit resistance and high output resistance. Output diode NP_2, although its conductivity can be forced by action of the P_1N circuit, is nevertheless biased "open-circuit" and has a relatively high resistance. In general, the contact-type triodes have lower input and output resistances than the junction types so far produced.

Either type of crystal triode may be connected with any one of the three electrodes as the common input-output circuit terminal or "grounded" electrode. The family of "plate" curves for the junction type (Figure 9) indicates that no peculiarities other then those normal to a current-controlled valve are likely to appear. The three basic circuit configurations (grounded emitter, grounded base, grounded collector) should therefore be stable under normal conditions. However, the family for the contact type (Figure 11) shows a reverse slope for base current control at collector potentials over one volt. Base current control is obtained when the emitter or collector is grounded and the ungrounded side of the input source is connected to the base of the triode. The contact-type valve's input resistance is negative (several thousand ohms) when the emitter is the grounded terminal. With the collector grounded, both the input and output resistances are negative, for example, on the order of ten thousand and fifty thousand ohms respectively. Such negative resistances will cause circuit oscillation unless special measures are taken. Control by base current does not seem practical in the contact triode case, except for oscillator applications, even though the linearity of collector current change with base current variation is quite good. Emitter current control, on the other hand, is also quite linear and the curves have a positive slope, indicating satisfactory amplifier operation. The power amplification in that case is about 20 decibels maximum in the audio-frequency region. Normally, only the grounded-base type of circuit is useful with contact-type units for the usual amplifier applications.

There are many factors in the crystal valve picture which cannot be covered in the space available. For instance, noise figures for the contact-type triodes are about 45 to 70 db above equivalent resistor thermal noise at 1000 cps. The junction type appears much better in this regard, about 8 to 25 db above thermal. A good vacuum tube will have a noise figure of about 0 to perhaps 10 db, depending on circuitry. Transistor noise decreases at a rate of about 11 db per decade of increase in frequency, while vacuum-tube noise is quite evenly distributed over the spectrum, except at extremely low audio frequencies. Dc amplification with crystal triodes is a special problem.

The life expectancy of the crystal valves is very good, provided that particular care is taken to respect their inherent limitations. Overload or any other condition which produces localized heating is much more dangerous to the Transistor than it is to the vacuum triode. Ambient temperature in excess of about 60 degrees C is unsafe for the germanium crystal valve, and any considerable operation above 70 or 80 degrees C will terminate its usefulness. Silicon crystals, although not as good in some other ways, are superior to germanium in capability of high-temperature operation. When conservatively operated and properly protected against surges or transient overload,

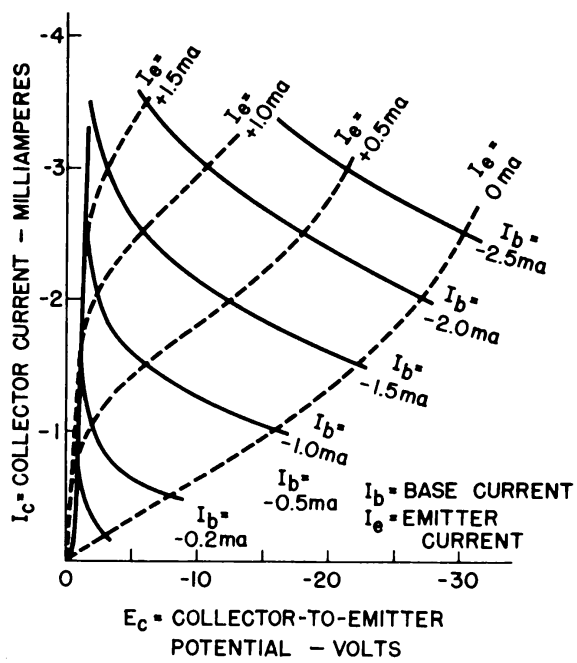

Figure 11. Collector characterization curves; contact-type Transistor, N-material base.

the germanium Transistor has a half-life[5] period estimated at about 70,000 hours.

Only the most rudimentary form of crystal valve - the cat whisker diode - is available in significant quantity at the time this is written. This has been the case for many years, but the most modern version, the germanium detector, is capable of operation which makes it competitive with small receiver-type thermionic vacuum diodes. One form of pn junction-type germanium rectifier designed for receiver power supply applications is now becoming commercially available. A major manufacturer of telephone equipment has indicated that quantity production of contact-type triodes will probably be under way at a rate of about 20,000 units per month by early 1952. The junction type may possibly be in small quantity experimental production at about the same time.

The crystal-triode designer has control of a different and much more limited set of elements than does the designer of vacuum tubes. Intangibles such as hole life and excess electron population, thickness of the p to n transition region and the nature of the transition curve determine crystal valve performance. A dash of the optimism which is essential for good aviators would seem to be a useful ingredient in the makeup of the Transistor engineer. Barring exceptional good luck, it will take much patience and hard work to make good crystal triodes available in the neighborhood radio-parts store in anything like the quantities and prices which apply to vacuum triodes. As for tetrodes, pentodes, heptodes, etc., etc., they may presently be gleams in some designers' eyes but, in the practical sense, probably not much more. However, in radio and electronics, as in other human activities, anything may happen and often does.

One of the basic difficulties in the crystal valve field seems to be that of a really sound understanding of the device. This is reflected in the "discovery" by scientists working in that field of a group of mythical elements, which might perhaps be allocated to the Comical Group (if such existed) in the Periodic Table. There is pressurium, which makes n material turn into p-type when pressure is sufficiently high, thermium, which enters into the temperature conversion of n to p reverse, and deathmium (or lifemium) which is involved in the life expectancy of the lattice imperfections known as holes. Perhaps a fundamental limitation in the mechanistic way of reasoning about physical processes is showing up, perhaps something beyond quantum mechanics is needed before the picture can be seen unobscured. It is desirable to keep this in mind when considering expositions of crystal-valve materials and action such as given in this paper. All the explanations presented are helpful; all of them seem to break down if pressed hard enough in detail.

In Summary:

1. Crystal diodes and triodes are relatively small and lightweight devices inherently capable of extraordinarily efficient performance as compared to vacuum tubes, particularly in micropower applications.

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[5] When amplification drops to 3 decibels below the preceding average level, due to aging.

2. They are inherently highly reliable and long-lived, and at the same time much more vulnerable to electrical or thermal damage than are vacuum tubes.

3. The Transistor crystal triode is at present:

a. A low-frequency device, relatively. (Amplification possible at frequencies up to about 20 Mc if mismatched loads are used.)

b. A low-power device. (Class A audio output about 100 milliwatts maximum.[6])

c. A low input-impedance, high output-impedance device. (Input: about 100 to 10,000 ohms; output: about 20,000 ohms to 10 megohms, for most useful circuit applications.)

d. A low-voltage device. (About 1 to 300 volts collector potential, so far.)

e. A low-temperature device, relatively. (Safe upper limit about 60 degrees C, with output resistance showing considerable decrease above 20 degrees C.)

4. The Transistor, for some time to come, will probably be a supplement rather than a competitor to thermionic vacuum valves and will initially appear mainly in computer and low-power audio applications.

ACKNOWLEDGEMENT

A good deal of the information in this paper was derived from material in published papers, lectures, and discussions by scientists and engineers of the Bell Telephone Laboratories and the General Electric Company, as well as from work done in the Radio Techniques Branch of Radio Division II. The writer does, however, assume responsibility for various interpretations and viewpoints which are his own and in which other workers in the field may not entirely concur.

[6] Pnp-junction models have been built with 50 watts dissipation capability but with severe distortion of output.

Picture of Dr. Fish

In last month's issue the frontispiece photograph which accompanied the article "Have Mental Ills a Physical Basis?" by Dr. Hudson Hoagland, bore a caption identifying the scientist pictured as Dr. Hoagland. This was incorrect, since the picture actually showed Dr. Charles Fish, a colleague of Dr. Hoagland's at the Worcester Foundation for Experimental Biology. The editors of Research Reviews regret the error.

The Navy's First Investment in Basic Research

In 1905 a pipe-smoking, violin-playing physicist, Albert Einstein, concluded that mass and energy were equivalent. At the time, this theory seemed of no practical value to scientists and engineers. Nor did Einstein's famous equation, $E = mc^2$, make a much more immediate impression, though it first revealed the stupendous amount of energy obtainable from a given quantity of matter. Yet that seemingly simple equation later helped to make possible the atomic bomb, with all its portent for mankind.

The most important element of $E = mc^2$ is c, the velocity of light, which no other velocity can equal, and which is constant under all conditions. Without exact measurements of this speed it would have been impossible for Einstein to reach his momentous conclusion. For this essential knowledge Einstein was indebted to one of the greatest of the Naval Academy's graduates, Albert Abraham Michelson, and to the United States Navy, which encouraged Michelson in his early experiments and provided facilities for conducting them.

Michelson, born in Germany in 1852, was brought to the United States in 1856, and graduated from the Naval Academy in 1873. After serving there as instructor of physics and chemistry from 1875 through 1879, he studied at the University of Berlin, the University of Heidelberg, the Collège de France, and the École Polytechnique. Returning to America in 1882, he became a professor of physics at the Case School of Applied Science, where he remained until 1889, when he assumed a similar position at Clark University. In 1892 he accepted the invitation to become Head of the Department of Physics at the newly-created University of Chicago, where he stayed until his retirement as Professor Emeritus in 1931, shortly before his death. The sole interruption to his academic career was during World War I, when he rejoined the Navy and devoted his entire time to work on new devices for naval use. While engaged in this wartime activity Michelson invented a range finder that was adopted by the Navy as an item of equipment for combat ships.

Almost all of Michelson's professional life was devoted to research in connection with light. His investigations were mainly concerned with two aspects of his subject - the accurate measurement of the velocity of light, and the study of optical interference. Of the 79 scientific papers that he published, all but twelve were on various problems relating to the phenomena of light.

His first experiments were carried out at the Naval Academy, where, in 1878, he conceived the idea of modifying slightly the optical path of an apparatus originally used by Leon Foucault for measuring the velocity of light in different media. At a cost of less than ten dollars, Michelson developed equipment with which he achieved a precision equal or superior to that of the elaborate and expensive instrumentation with which Foucault's unmodified experiment had been conducted at the Academy.

A more ambitious attempt to measure the velocity of light was made by Michelson in 1879. This experiment was possible because of the cooperation of the Navy Department, which not only made physical facilities available to him, but took the unprecedented step of granting him two appropriations, one of which was for $2,000. These were probably the first sums granted by the Navy for the support of basic research. For this experiment Michelson established a base at the Washington Monument and another in Arlington, Virginia, some three miles distant. The time that light took to pass from one base to the other was measured so precisely that the speed of light was determined with greater accuracy than had ever been possible previously. In 1882, while he was at the Case School of Applied Science, further refinements of his experiments enabled Michelson to obtain new and more exact figures for the velocity of light in a vacuum.

His interest in the possible effect of the earth's motion on the observed velocity of light led Michelson, in 1886-1887, to invent his interferometer, which permitted the wavelengths of light to be used as a measuring unit. He then proceeded with what is now called the Michelson-Morley experiment, which attempted to determine the existence of an ether by measuring the effects of the earth's motion on the time required for a light signal to traverse a fixed distance. The result of this experiment, which demonstrated that the earth's motion had no effect on the velocity of light, was confirmed by numerous later repetitions of the test. This conclusion obstinately refused to fit into the contemporary conceptions of the nature of the universe, but later formed the starting point of Einstein's theory of relativity.

On 24 September 1904, Henri Poincaré, President of France during World War I, addressed the International Congress of Arts and Sciences at St. Louis, Mo. The startling feature of his speech was his statement that for an understanding of the universe an entirely new type of dynamics was required which must be developed around the law - verified by Michelson - that no velocity could exceed that of light. A year later, this program indicated by Poincaré was carried out by Albert Einstein, then professor of theoretical physics at the University of Berne, who announced to the world his tradition-shattering theory of relativity.

Had Michelson's fame rested solely on his contributions to the work of Einstein he would still occupy an exalted place in the pantheon of science. Until the end of his life, however, he continued to increase his reputation by additional inventions, discoveries, and publications. Using his interferometer, he measured the meter in terms of the wavelength of calcium light; this meant that the standard meter bar preserved in Paris could be replaced at any time, since its length was now known in terms of an absolute unit. In 1891 he had used the interferometer for finding the angular diameter of the four Galilean satellites of Jupiter, and in 1920 he made the first measurement of the diameter of a star when he demonstrated by light interference that the diameter of Betelgeuse was 240,000,000 miles. He was also active in developing use of the interferometer at the Mt. Wilson Observatory in California.

Michelson's invention, in 1898, of the echelon spectroscope, especially adapted to the separation of the components of a spectral line, opened for him a new area of research. By 1903 he had accumulated enough knowledge and experience to communicate what he had learned about the properties of light waves in a book entitled Light Waves and Their Uses. Four years later he was awarded the Nobel Prize in Physics for his spectroscopic and metrologic investigations.

Oddly enough, Michelson, who was showered with honorary degrees by universities and colleges in the United States and Europe, never received a graduate degree following completion of a recognized course of study. But among the distinguished graduates of the Naval Academy, none left behind them more brilliant and enduring accomplishments than Michelson.

Radio "Telescope" to Provide Eclipse Data

This weird looking apparatus, called a radio telescope, will help Naval Research Laboratory scientists determine the temperature of the sun's atmosphere during a solar eclipse expedition they will make to the Sudan next month. Dr. John Hagen, Head of the R-F Research Branch, is shown making final adjustments on the apparatus. The Sudan expedition will be headed by Dr. E. O. Hulburt, NRL's Research Director, who will take color distribution photographs of the sun's outer edge. The information obtained is expected to be useful in improving long-range radio communication.

On the Naval Research Reserve

PRNC Training Director Praises VNRR Oak Ridge Seminar

CDR Leo M. Jacobson

A man who is in a position to know a good seminar when he sees one is CDR Leo M. Jacobson, PRNC Training Director, who has attended many such meetings. Reservists will be interested in his comments on the Nuclear Physics Seminar held last month at Oak Ridge, Tenn., under the auspices of the VNRR. The following letter was written by Mr. Jacobson to the Commandant, Potomac River Naval Command:

1. From 27 November to 3 December 1951, the Director of Training attended the third annual Nuclear Physics Seminar at Oak Ridge, Tennessee. This seminar was sponsored by the Naval Research Reserve in conjunction with the Atomic Energy Commission and the Oak Ridge National Laboratory, who together presented a symposium on nuclear reactors. As a Naval officer in the field of education and training and a former administrator and instructor in public school work, I have attended many seminars. This was one of the best seminars it has been my pleasure to attend.

2. The following comments are in order: Although there is no regular Naval establishment at Oak Ridge, the local Volunteer Naval Research Unit, together with the Inspector-Instructor at Knoxville, were fully prepared at the local premises of the seminar to receive the officers reporting and handle promptly and efficiently all matters of transportation, billeting, pay accounts, health records, etc., normally carried on by a regular Naval establishment. The speakers at the seminar were leading authorities on reactor technology. They succeeded in presenting a very clear picture during their various lectures. This was very difficult when you consider the fundamentals involved, the scope of the regulations and the amount of time during which this had to be done. It was further noted that audience interest was maintained at all times at a high level. One thing that made this possible was that the speakers themselves encouraged questions from the group whenever one member felt a need for clarification before proceeding to the next item of consideration. Ample time was reserved at the end of each lecture for a question-and-answer period and participation by all members attending the seminar.. Another point worth commenting on was the high level of orderliness maintained. The selection of the speakers was excellent. The program was very well balanced. Items of general interest were

injected, with the resultant effect that everyone was on hand when talks were scheduled to start. Another factor which made the seminar very interesting was the introduction of the speaker by the Program Chairman who gave the background of the speaker giving the next lecture. In this way those attending the seminar felt they were acquainted with the speaker giving the lecture. Also, many of the speakers came back during recess periods to further implement by questions and answers further discussion on their part of the seminar.

3. For the off-hour periods there was a very well planned program of entertainment which went a long way toward making the seminar very outstanding. Also, there were times provided in which the various officers attending the seminar could get together for general discussions and other informal type meetings.

4. It should be further added in summarizing these remarks that the officers of The Office of Naval Research are certainly to be complimented on the high level of training being conducted. Particular commendation should be given to all the facilities which cooperated in making this seminar outstanding. It should also be stated that, in the opinion of the writer and those attending, this seminar attained a high degree of success. If all of our units in the Volunteer Program could be as well handled no concern need be felt concerning their further contribution to our country's preparedness and readiness for action.

CDR Ralph A. Jack is New San Francisco Program Officer

CDR Ralph A. Jack

CDR Ralph A. Jack is the possessor of an unusual combination of Navy and scientific experience that makes him well suited to his new post as Program Officer for the San Francisco area. A physicist in civilian life, CDR Jack was in on some of the most significant technological developments that took place during World War II.

When CDR Jack went on active duty in July 1940 radar was still a "mystery weapon," though insiders already realized it would play a decisive role in the outcome of the war. After teaching physics and electrical engineering at the Naval Academy, CDR Jack became active in developing fighter director techniques, altitude determination by radar and the use of radar in advance areas. Later he was commanding officer of Argus Unit No. 1 in the New Guinea area and eventually became Executive Officer of the Pacific Fleet Radar Center as well as Director of Pacific Fleet Schools. With all this valuable experience behind him it was only natural that CDR Jack should then be assigned to duty in the Office of Research and

Inventions and later to the Radar Desk in the Office of the Chief of Naval Operations.

Back in civilian life, CDR Jack took the position of Professor of Physics at Fresno State College, but he did not forget the Navy and the Navy's interest in research. As Commanding Officer of Unit 12-4, he directed the activities of that group until he returned to active duty recently.

ATTITUDE FILMS IN THE NAVY

LT R. F. Schenkkan, USNR
Commanding Officer, VNRRU 6-6
Communication Center, Chapel Hill, N. C.

Films have long been accepted as an integral part of the Navy's training program. Hundreds of movies have been made which apply to nearly every possible phase of the program, and no question of their value has been raised since the conclusive demonstrations of the efficacy of films in the Navy's mass teaching efforts during World War II.

Training films fall naturally into two classifications: How-To-Do-It movies and Attitude movies. The problems involved in production of successful "How-To-Do-Its" have been largely solved, if one thinks in practical terms. Although considerable research in such films is being carried on and more is contemplated in order to increase their effectiveness, the fact is that we can now, without further research, produce adequate movies of this type. But attitude films are another matter and the reasons are not hard to find. If you want to teach a sailor, for example, the principles of automotive transmission, you have a simple problem in physical demonstration. On the other hand, if you want to teach a sailor that he has the responsibility of representing the U. S. Navy in a favorable light at home and abroad, you have a complex problem in human motivations, prejudices, and preconceptions, with all that these may entail in demonstration difficulties. There is the added burden that while a failure in a film on the principles of automotive transmission will do no more harm than to slow down the learning process, the failure of a film on human motivation may actually lead to impairment of morale -- for films which deal with attitudes in the Navy ultimately deal with morale. The film, in other words, may "boomerang," and in an important area.

At this juncture in world affairs the success of the Services in the areas of political orientation and morale -- and all attitude films in the Navy have a bearing on the vital question of morale -- will undoubtedly be of great importance. The importance of the war of the minds has recently been underlined on the very highest level of the national defense effort by the creation of the Psychological Strategy Board. Is this importance being similarly emphasized on the level of officer and enlisted training programs in the medium of films? If so, how successful is the effort? What weaknesses are there? What do we need to know in order to make better motivation and attitude films?

Such questions have been under consideration by members of VNRRU 6-6 in Chapel Hill for over a year. In that time, approximately 40 films have been reviewed by a group whose civilian interests are widely disparate. Faculty and graduate students in sociology, education, psychology, and communications have sparked the study, but participants have included engineers, physicists, chemists, and University administrators, and the contributions of the "non-expert" have been as valuable as those of the "expert." It will be obvious to those familiar both with the activities of the Research Reserve and with the exigencies of social science experimentation that it would not have been possible to examine this entire question under the conditions of Research Reserve activities. The group has worked merely to discuss the problem, to open up the whole area to question, and where weaknesses have been uncovered, to attempt to frame some conclusions as to how the problem may be attacked. What work has been done has been work preliminary to creating experimental designs. Some interesting possibilities for research -- a highly practical kind of research -- have been unfolded. Some of these are suggested here:

1. A study of political orientation and morale factors in the field. What do our men know about Communism, for example? In what morale areas might they be open to enemy pressures? Which films now available deal with these specific problems? How effectively? Film by film, are we doing the job?

   This is the first big task; a survey of the whole problem on a thoroughly scientific basis is needed.

2. What can the training officer now do to cope with morale problems? How can he be guided toward better solutions? (A problem in catalogue and training guide organization).

3. In ideological films for enlisted men, is it better to portray the truth, the whole truth, and nothing but the truth so far as the medium permits, or is it better to be frankly propagandistic? This question is prompted by wide divergence of approach in existing films, and by the feeling that some propagandistic devices "boomerang."

4. What factors motivate enlisted men to adopt certain attitudes? Certain films seem, on the surface at least, to motivate adoption of a desired attitude. Others appear to ignore obvious possibilities. Do they, in fact, do so?

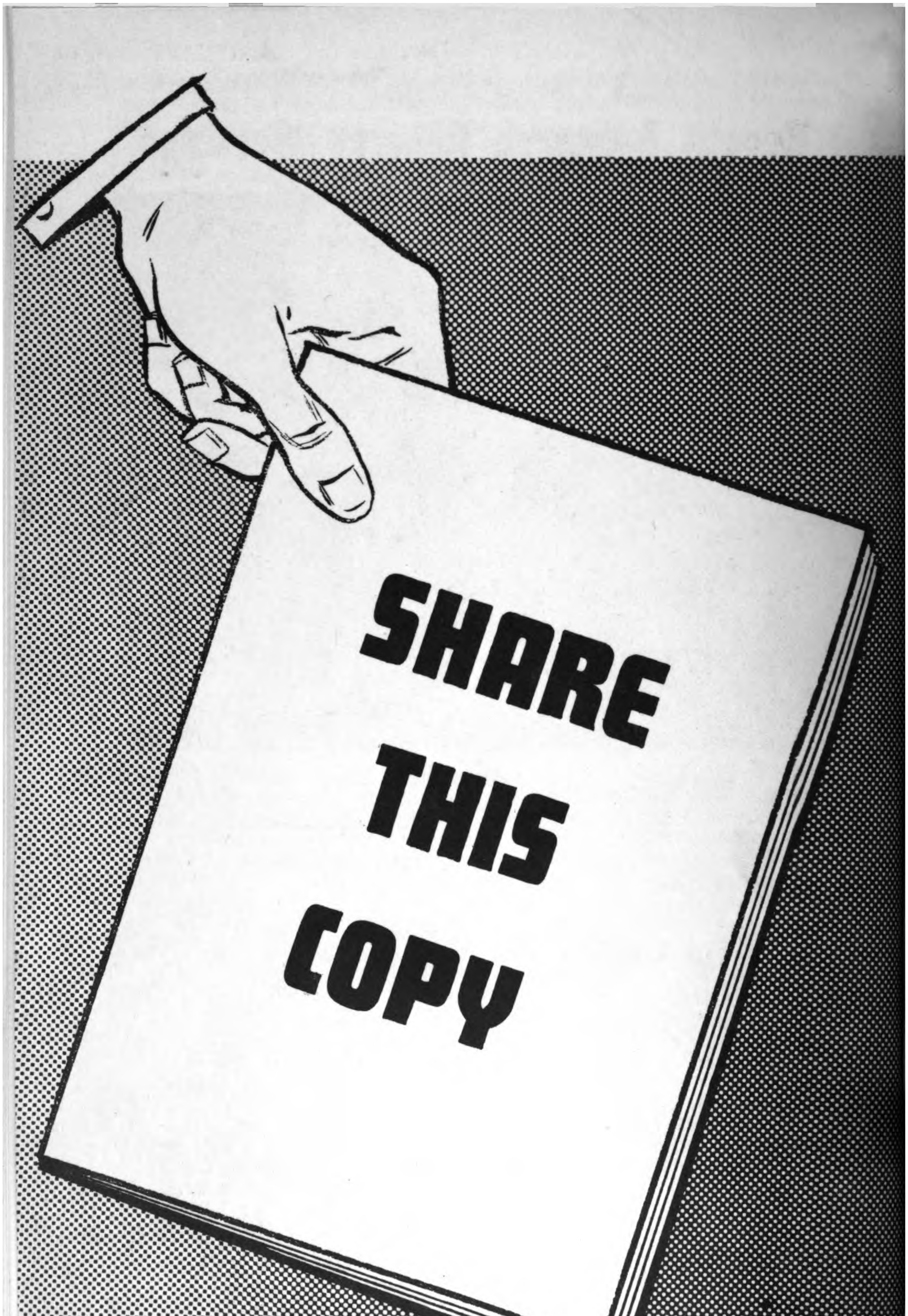
5. Is a story line essential to viewer acceptance in a film of ideas? Our observations tend to indicate that the better films do use a story line in selling ideas. Largely stock-shot films, of course, do not.

These are but a few of the many problems which have been opened for discussion in the study. A complete list would be pages long. Members of the study group have, of course, formed some very definite opinions on many of these questions, but opinion is not enough. Here is a research job that needs doing. Broken down into its proper small experimental segments, it can be done by Research Reserve groups. VNRRU 6-6 is continuing its study and would welcome the cooperation of other groups.

Recent Research Reserve Meetings

CAPT V. R. Sinclair, CO of the Naval Reserve Center at Fort Omaha and CDR F. L. Edmondson, director of the Research Reserve program are shown with LT B. J. Jaskoski (seated) at a recent meeting held in Omaha, Neb. for the purpose of getting a VNRR unit started in that city. LT Jaskoski, a professor of biology at the Creighton University Dental School, is promoting formation of the unit.

At a meeting of VNRRU 1-1 in Boston, Professor Warren M. Rohsenow of the Mechanical Engineering Department of MIT discussed his ONR contract on heat transfer at high-density flux. Members of the group are, left to right: LCDR A. Healy, CAPT L. Smith, LTJG Rohsenow and CDR C. Muckenhoupt.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