III. MODERN ELECTRONIC TECHNIQUES APPLIED TO PHYSICS AND ENGINEERING

A. Studies Leading to the Design of a Microwave Accelerator.

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Problems which require study before one can apply microwaves to the acceleration of electrons and protons are:

1. The problem of coupling energy from a magnetron into a high Q circuit.

2. The operation of many magnetrons into a cavity system such that the proper r-f phase relationships are maintained between the several magnetrons.

3. The coupling of many cavities together so that the coupled cavity system will be excited in one desired mode.

4. The problem of space and phase focusing of charged particles accelerated in a system of coupled cavities.

A systematic study has been begun of these problems separately with the goal in mind of a linear type accelerator in the hundred million volt region. It would be hoped that such a device would have advantages over cyclotrons, betatrons, and synchrotrons in cost of construction and ease of utilizing the final accelerated beam of charged particles. The following will indicate the manner in which these problems are being attacked, and the results so far obtained.

1. A tunable high power magnetron operating at a wave length of 10.7 cm. and pulsed at two microseconds has been coupled to a cavity with unloaded Q of 16,000. To prevent moding difficulties in the system, loss was introduced in series with the cavity such that 30% of the total available power from the magnetron was fed into this loss. The magnetron then locked to the cavity, and with about a megawatt of peak power produced, the electric field generated in the cavity was such as to produce a peak voltage of 2.2 million volts between top and bottom of cavity. The height of cavity was 5 cm. It seems reasonable to assume, then, that when a final assembly of cavities is made, it will be possible to couple energy from a magnetron into this system.

2. To study the locking of several magnetrons in phase, two magnetrons have been coupled in parallel by joining their coaxial outputs into a common T-section connected to a load. Phase locking has been accomplished, and with proper matching irises in the T-section the power output of this system is the sum of what can be obtained from each tube individually.

In line with what might be more useful in a final accelerator, a system has been designed which will permit magnetrons to feed at equal intervals along a waveguide. By the proper spacing of magnetrons into this guide and loads issuing from it, the system should develop power in these loads which is synchronized at r-f with predetermined phase relationship from one load to the next. Two magnetrons have operated successfully in this array, and it is hoped to add more soon. These loads would then be replaced by a continuous accelerating tube of coupled cavities.

3. A study is being made of frequency and shunt resistance of reentrant cavities of such dimensions as to be suitable for proton as well as electron acceleration. Mode separation in a long system of coupled cavities is being studied as well as methods of shifting modes in frequency. A tube consisting of 20 coupled reentrant cavities, all designed for a particle travelling with ½ the velocity of light, has been built for mode studies, and it appears possible to eliminate all but the desired mode of operation by proper use of mode-damping screws.

Another tube consisting of twenty coupled cavities (formed with irises in a circular pipe) has been built. It is possible to excite this tube in a mode appropriate for the acceleration of particles travelling at near the velocity of light. Other modes are sufficiently removed in frequency to cause no concern at present.

A systematic study is in progress to determine frequencies and shunt resistances of reentrant cavities for all values of particle velocity.

4. An electron gun capable of producing electrons with energies up to 300 kv is being assembled, and an analyzer for studying electron energy spectra has been built. A focused beam of electrons has been produced in this gun, and it is hoped to use this beam soon in connection with the accelerator tubes described above.

Preparations are being made for a thorough theoretical study of phase stability and space focusing of accelerated particles. This study will be backed by experiments using the gun and short accelerators as described.

III. B. Ultrasonics Research Program

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The purpose of the ultrasonics research program is to develop the applications of radar techniques to the study of the mechanical properties of solids, liquids, and gases at high frequencies. The two principal technical developments in radar are connected with pulse techniques and microwave power supplies. Pulse technique applied to ultrasonic work enables the convenient and accurate measurement of the velocity and absorption of sound waves in different media, and to the possibility of detecting inhomogeneities in materials. Microwave power opens up for scientific exploration the whole region in the acoustic spectrum between the frequency limit of pre-war studies at about 100 megacycles and the lower limit of thermal vibrations at 100,000 megacycles. This work is associated in part with the work of the Acoustics Laboratory under Profs. Morse and Bolt.

1. Application of Pulse Techniques to Ultrasonic Measurements

The idea in the determination of acoustic properties by pulse measurements is to measure with a radar range scope the elapsed time between the application of an electrical pulse to a quartz crystal and the time the signal is returned to the transmitter from a reflecting plate. The signal strength is also measured. From the elapsed time and the round-trip distance the velocity of sound is computed. From the variation in signal strength with distance the attenuation is computed.

At present two technical reports are being written up:

(a) Ultrasonic Propagation in Liquids: I. Application of Pulse Technique to Velocity and Absorption Measurements in Organic Liquids at 15 mc/sec.

(b) Ultrasonic Propagation in Liquids: II. Theoretical Study of the Free Volume Model of the Liquid State.

Short talks on the first subject were given at the April meeting of the American Physical Society and at the May meeting of the Acoustical Society of America.

The velocity and absorption of sound waves at 15 mc/sec were measured in about 25 organic liquids; in a number of cases measurements of the temperature coefficient of velocity and absorption were made. The accuracy of the velocity measurements is comparable with the better previous methods; the absorption measurements are believed to be very considerably better than any previous published work.

Considerable progress has been made in the theoretical analysis of velocity and absorption data. The consequences of the Tonks equation of state for an assembly of hard elastic spheres have been derived in terms of a free volume theory of liquids. It has been found to be possible to calculate the velocity of sound in an organic liquid from thermal expansion data, with fair accuracy. Theoretical predictions regarding the temperature and pressure coefficients of sound velocity are checked quite well by the measurements. The theory also gives a good account of the thermal expansion of a liquid and the ratio of the specific heats C_p/C_v. Regarding absorption, the Herzfeld-Rice theory has been applied to the free volume equation of state, and the resulting equation for the absorption is useful in interpreting data on the frequency and temperature dependence of absorption. In the near future an attempt will be made to derive the quantum theory analog of the Tonks equation.

Precision equipment has just been completed for the purpose of studying the acoustical properties of liquefied gases. Trials with liquid nitrogen are now underway. This is of particular interest as concerns the rare gases, since at present Mercury is the only monatomic liquid for which absorption measurements are available. It is of fundamental importance to check the hydrodynamical equations for sound absorption in the simplest possible cases - the monatomic liquids.

Some work has been done on the possible application of acoustic echo-ranging to the plotting of brain tumors. This has been carried on with the advice of the Harvard Medical School.

A student of Professor P. W. Bridgman of Harvard was trained for three months in the laboratory as a preliminary to a measurement program on the acoustic properties of matter under high pressures. This program, to be carried out at Harvard, will utilize pulse methods at pressures up to 100,000 atmospheres.

Pulse techniques at 10 mc/sec have also been used to study the effect of tube size and surface on the attenuation of a supersonic beam transmitted through a tube filled with mercury. The experiments have been conducted with glass tubes and steel tubes with clean-reamed bore. The inner diameters varied from 1/8" to 1/2". The measurement of attenuation for unit length is made by observing the decreasing intensity of successive echoes. The effect of tubular attenuation was particularly marked for the reamed tubes of smaller bore amounting to more than 4 db per ft for the tubes with 1/8" bore. The effect is less for the glass tubes and varies about as the reciprocal of the tube diameter.

Such theory as already exists in the literature agrees well with the results obtained with glass tubes. A solution of the viscous equations inside a tube checks the earlier theory and gives additional information, particularly on the influence of wall material. It was expected that the effect would be very sensitive to surface roughness since mercury does not wet the containing wall but will instead trap air in any irregularities which exist. At such bubbles the boundary conditions are perturbed and the ultrasonic wave is scattered. Most of the measurements for this project are complete. It remains to observe the effect with smooth lapped tubes and with rough ground tubes.

An attempt is being made to account for the elastic and piezo-electric properties of quartz on a simple model, using only two or three force constants. One would expect that, in a valence lattice such as quartz, only nearest and next nearest neighbors would be important. So far only indifferent agreement with experimentally observed quantities has been obtained.

Pulsed techniques can be useful in tracing phase changes in a solid medium. At present measurements are being taken of the elastic moduli of Rochelle Salt, which has a transition point in the region of room temperature. The procedure is to affix a quartz crystal to the fact of a Rochelle Salt block and observe the time intervals between return echoes from the opposite sides. Opposite faces of the block must be flat and parallel. An organic substance which melts at 42° C is used as a binding film between Rochelle Salt and quartz and allows for the transmission of even transverse waves. The shear wave whose velocity is determined by C_{44} is most difficult to propagate since this constant varies rapidly with temperature. Qualitatively all the results check well with the predictions of Mueller's phenomenological theory, but actual values of the moduli agree closely with values calculated by Mason (from his measurements of elastic constants) in only two instances, C_{55} and C_{66}. It is difficult to understand the source of the discrepancies in the other cases.

A long-term program is underway to study the causes of internal friction in solids in the megacycle range. For this purpose single crystal specimens are best suited for an initial investigation. A group of alkali-halide crystals have been measured and shown to have very small attenuation. Incidentally some precise measurements have been made on the elastic constants of these substances. Fair agreement with values existing in the literature have been obtained, except in the case of lithium fluoride where our values for C_{11} and C_{44} are about 80% of values quoted from optical measurements. A press is being built and it is planned to study attenuation as a function of plastic deformation and annealing treatment. There is likelihood that some metal single crystals can be obtained for study. In particular a single crystal of copper will be supplied by Dr. Gold of M.I.T. in the near future. Some work will also be done in correlating observed attenuation figures with magnitude of anharmonic forces as indicated by coefficients of thermal expansion and thermal conductivity.

It is planned to begin two new projects immediately. One is the development of L band transducers in the 500-1000 mc/sec range to bridge the gap between the low frequency and the microwave work. The other project is really a continuation of the present work on absorption in solids with a view to comparing absorption in single crystals of metals with microcrystalline specimens; and further, to investigate the possibilities of detecting magnetic domain structure.

2. Ultrasonics at Microwave Frequencies

It is planned to try to drive quartz crystal transducers at both S- and X-band frequencies. The S-band work is somewhat further along. Here a 750 kilowatt pulsed power system is used, employing a rotary gap modulator with a one microsecond pulse at a repetition rate of 400 per second.

Several schemes have been tried for the detection or transduction of sound at these microwave frequencies, but none have yet yielded positive results. This is believed due to the fact that it has not yet been possible to assemble equipment with the essentially "optical" tolerances necessary for this work (the wavelength of sound in quartz at $3 \times 10^{+9}$ cps. is about 20,000 Angstrom Units, and about one-fourth of this in liquids). The following experiments have been conducted to date.

Cold Tests - Tuned Cavities

1. Search for impedance change at S-band due to the electromechanical coupling of a quartz crystal in the cavity; the magnitude of the reflected signal was examined as a function of frequency.

2. Search at X-band for a change in the resonant frequency of a cavity due to effect of a vibrating crystal, using a modified form of the techniques developed by Drs. Roberts and Beers, and Prof. Hill for the study of caesium hyperfine structure.

Power Tests

1. Optical Methods - Several optical methods are being employed for detecting mechanical excitation of a quartz crystal placed in the thin portion of a horizontally mounted tapered S-band waveguide.

(a) Diffraction

The distances separating planes at varying density due to standing waves of sound at S-band are small enough so that Bragg reflections may be expected (in quartz about four optical wavelength separation and about one in liquids). Light is projected through a narrow, longitudinal slit cut in the center of the top of the guide and into the material under observation. Reflections of light of various wavelengths should occur at certain critical angles with respect to the horizontal planes of vibration.

Examinations are made both within the quartz crystal itself and within liquids contacting the crystal. For the former case it is planned to have the crystal optically treated to diminish surface reflections. In either case "background" reflections are reduced about 400-fold by using a light source which operates only during the duration of the pulse, thereby illuminating the crystal only when the reflecting planes of sound exist.

The usual Debye-Sears technique of passing light parallel to the planes of vibration is difficult at these frequencies since the first order diffraction angle is relatively large (for liquids the sine of this angle may exceed unity). However, solids such as quartz the longer acoustical wavelengths will make a modified form of the experiment possible and preparations for tests are underway.

(b) Polarization

Methods are being used similar to the "optical value" technique employed by Anderson in velocity of light determinations. The optical system is so adjusted before power is applied that light passing through the material under examination is extinguished by means of crossed polaroids. Then if vibrations are excited upon application of power, the resulting mechanical strains should upset the optical cancellation with resulting passage of light. Here again an intermittent light source should increase the sensitivity.

2. Pulsing Methods - A cartridge containing a piezo-electric crystal is inserted in the flat side of a waveguide. To one side of the crystal a fused quartz rod is soldered. When the cartridge is placed in the side of the tapered waveguide it may be possible to set up vibrations which will be transmitted through the fused quartz and then reflected back to the crystal, which in turn will send a radar wave down the guide to the receiver.

Transducers

A theoretical program on design considerations for transducers at microwave frequencies has made considerable progress. An analysis has been carried out on the problem of producing ultrasonic energy by coupling a piezoelectric crystal into a resonant cavity, and driving the crystal at a high overtone of its natural frequency of vibration.

It turns out that the calculated rate of production of sound energy for a voltage of one volt across a one cm. thick crystal is about 8.8×10^{-5} watts per sq. cm. per sec., assuming that the piezo-electric mechanism of quartz is maintained at microwave frequencies. A study of equivalent circuits shows that the maximum power output occurs for critical conditions of mechanical loading of the crystal. For example, if the crystal fills the entire gap between the condenser plates of a resonant circuit it will impart energy most efficiently if the specific acoustic impedance of the test specimen is 0.07 of that of quartz. By leaving a gap between the crystal and the condenser plates the value of the critical loading may be varied at will.

III. C. High Speed Oscilloscope and High Voltage Pulse Measuring Techniques

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1. High Speed Oscilloscope

This project was initiated at M.I.T. Radiation Laboratory in October, 1944. The need for an instrument to measure times of the order of millimicroseconds became evident during an investigation of the abnormal behavior of magnetron oscillators in pulsed radar systems. In particular, there seemed to be some correlation between the occurrence of cathode sparking (and r-f moding) in pulsed magnetrons and the rates of rise of the plate current and the applied voltage pulse. Frequently the magnetron plate current pulses were observed to have rise-times of the order of 3×10^{-9} seconds.

The accurate measurement of current and voltage build-up and other "leading-edge" effects was hindered by the oscilloscopes then available in to major ways: (1) sweep speed and (2) writing speed. The first limitation was removed by employing specially designed sweep circuits, the second by using a cathode ray tube built by A. B. DuMont Laboratories in collaboration with the Radiation Laboratory. In an experimental test set-up sweep speeds of greater than 100 inches per microsecond and writing speeds upwards of 300 inches per microsecond have been obtained. This oscilloscope is described in Radiation Laboratory Report No. 1001.

At present one cabinet model has been completed and operated. Minor difficulties in the trigger-sweep phasing circuit remain to be worked out. A second unit is approximately one-third completed.

2. Pulse Measuring Techniques

The high-speed oscilloscope offers the possibility of measuring high voltage and high current pulses with durations of the order of a few hundreths microsecond and rise-times of the order of millimicroseconds. However, for these fast rising pulses it is necessary to develop improved voltage dividers (see R.L. Technical Series, Book 32, Appendix A) which will cause minimum disturbance of the pulse generator circuit, to devise improved methods of matching the dividers to cable and oscilloscope, and to obtain a quantitative evaluation of the fidelity of pulse response of the overall viewing system.

To survey the limitations of conventional pulse viewing techniques, including the use of coaxial current viewing resistors, capacitance voltage dividers, and differentiating R-C circuits for voltage rate-of-change measurements, preliminary tests were made with a Stromberg Mark II pulser adapted to give 10 kv, 0.1 µsec pulses rising in approximately 0.05 µsec on a 1000 ohm resistance load. After trying several arrangements of the load and attenuators, a set-up was determined in which shielding was satisfactory and ground circuits were balanced sufficiently to give an excellent cross-check of the I, V and dV/dt signals presented on a Model 5 synchroscope. A series compensated R-C voltage divider was also tried with moderate success. This divider causes less disturbance of the pulser circuit than the conventional capacitance divider but complicates the problem of matching to the cable and oscilloscope.

To provide a more severe test of the pulse viewing system it appeared desirable to build a special pulser designed to give 12 kv pulses rising in less than 0.005 μsec. The basic problem in the design of a pulser with a fast rising voltage pulse is to obtain high current immediately after closing the pulser switch, in order to charge the output capacitance to full value within the desired time of rise. For example, with output capacitance (including that of the load) reduced to a minimum of say 30 μμf, the current required for a rise time of 0.005 μsec and maximum voltage of 10 kv is approximately

$$I \approx \frac{CV}{t} + \frac{V}{2R} \quad \text{where } R = \text{load resistance}$$

$$\approx \frac{30 \times 10^{-12} \times 10^{4}}{5 \times 10^{-9}} + \frac{10^{4}}{2 \times 10^{3}}$$

$$\approx 65 \text{ amps.}$$

Because of this high current requirement and other considerations it was decided to construct a hard-tube pulser, using several (probably six or more) 5D21 tubes in parallel for the pulser switch. Line type pulsers were ruled out because of the inherent limitations imposed by pulse transformers and the ionization time of gas tube switches. However, it seemed expedient to use a line type pulser as a driver. With the 5D21's biased considerably beyond cutoff only a small fraction of the driver pulse amplitude is effective in producing positive grid swing, and hence the total time of rise of the driver pulse can be considerably greater than the rise-time required for the output pulse to the load.

Before building a six or eight tube pulser it seemed advisable to perform further tests with a "bread-board" pilot model using first one 5D21, then two 5D21's in parallel, with a driver employing a section of 50 ohm cable instead of the usual pulse forming network, and a 3C45 hydrogen thyratron. To avoid the use of a pulse transformer, the driver was capacity-coupled to the 5D21 grids. Measurements on this pulser have progressed far enough to verify design predictions and to justify beginning construction of an eight tube pulser. With one 5D21 a respectable 12 kv pulse with a rise-time less than 0.025 μsec was obtained on a 1000 ohm resistance load (output capacitance ≈ 30 μμf). With two 5D21's the rise-time was reduced to less than 0.014 μsec. This rise-time could be reduced appreciably by overdriving the 5D21 grids but the pulse shape became somewhat distorted from its trapezoidal form. Chief difficulties are (1) shielding the pulser from the viewing system, and (2) obtaining optimum arrangement of components to minimize spurious oscillations caused by improper ground connections. If these difficulties can be alleviated the eight tube pulser may be expected to give a time of rise less than .005 μsec. with the same load. It should be suitable for generating short pulses, say less than .02 μsec., if a proper length of cable is used in the driver, and it should operate satisfactorily into any load impedance down to 200 ohms (but with some increase in rise-time).

While this pulser is under construction testing of the two-tube pulser will be continued to determine the optimum operating voltages on the 5D21 control grids and screen grids and to improve shielding and grounding schemes.

When this pulse generator circuit and the viewing system have reached a satisfactory degree of improvement the application of these techniques to specific problems in engineering and physics will be reviewed. From those problems which have been suggested, the following three are representative.

(a) The correlation of magnetron starting behavior and pulser-magnetron instantaneous impedance relationships with mode selection and cathode sparking.

(b) The measurement of ionization time in high voltage breakdown of gas tubes.

(c) The measurement of cathode emission with pulses of sufficiently short duration to minimize the I^2R heating effect during the pulse.

III. D. High Pressure Ionization Chamber

Staff: Mr. L. Davis

The amount of ionization produced in an ionization chamber by the passage of a charged particle through it is directly proportional to the pressure used, providing the particle has sufficient energy to pass through the sensitive volume of the chamber. At lower energies heavy charged particles may be stopped completely within the chamber and the total ionization created by the particle measured directly (total ionization is directly proportional to energy). It is, of course, impossible to pass low energy charged particles through the walls required by such pressures, but cosmic rays or neutrons may readily be studied with such a chamber.

A high pressure (200 atm.) parallel plate chamber has been constructed. It will be used to determine the feasibility of using gas at these pressures in an ionization chamber. It is expected that drift velocities (of electrons) will be high enough to permit a short collection time (one-half microsecond) with a usable supply voltage. As the drift velocity has not yet been checked experimentally at these pressures, this must be done before further work with this chamber is carried on. In addition the probability of electrons to attach to neutral atoms to form immobile negative ions must be measured to determine if the chamber will be usable in this respect.

The chamber, as built, can be readily adapted to neutron studies. By allowing neutrons of one to fifteen million electron volts energy to pass through the walls and impinge upon hydrogen nuclei on the inside of the chamber plates, protons of equal energy can be projected into the gas and thus the total number of neutrons and their spectral distribution can be determined.

In order to conduct this work, a system for purifying the filling gas has been constructed. In addition, an x-ray tube for pulsed operation has been built and the associated power supply, modulator, and pulse transformer placed in operation. The pulsed x-rays will be used as a source of synchronized ionization bursts of known amplitude in the ionization chamber for determining the previously mentioned properties of the high pressure gas.

III. E. Cyclotron Project

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It is the purpose of this project to modify the cyclotron and develop the necessary instrumentation for use with it to conduct scattering experiments and allied types of nuclear research. To date the M.I.T. cyclotron has been used exclusively for the production of radioactive materials for medical use and research, so that considerable modification is necessary before the machine can be used for such experiments. The high radiation background existing around the machine at this time due to inadequate shielding makes the instrumentation problem a difficult one.

The cyclotron beam must be piped away from the machine and focused to as small a point as possible in an external chamber which can be shielded from background radiation. The approximate path of the emergent beam has been located and the mechanical layout completed. Work on the various mechanical parts is either under way or completed. This includes such items as a focusing magnet, water cooled defining slits, vacuum plumbing for the beam, etc.

Provision is being made to pulse modulate the beam in case it becomes necessary to reduce background by this means or it is desired to conduct experiments which require pulsing.

The instrumentation problem is one of detecting and identifying protons, deuterons and alpha particles, measuring the angular distribution of such particles scattered from a target and determining their energy. Such detectors must be capable of working in the presence of high backgrounds.

It was decided to use either ionization chambers or proportional counters as the basic detectors, and amplify their output by wide-band amplifiers equippped with high pass filters. This permits operation by electron collection and eliminates the microphonic noise troubles of linear amplifiers. Such detectors have been built and operated, and it has been found possible to distinguish two alpha particles separated by a microsecond in time.

To reduce background interference and increase the accuracy of energy measurements a triple coincidence detector was devised. This detector consists of three ionization chambers placed in line, the outputs amplified separately and fed into a circuit which registers a count when it receives a pulse of the correct amplitude from each of the three chambers simultaneously. It operates on the principle that the ionization produced in a chamber is a function of the charge and velocity of a particle passing through the chamber. This device has been made to operate but no measurements of its selectivity or its sensitivity to background interference have been completed.

III. F. Liquid Filled Chamber to be Used in the Photographing of Very High Energy Ionizing Particles

Staff: Dr. W. H. Bostick

The preeminent utility of a high pressure Wilson cloud chamber in studying the creation and decay of mesons and associated processes is common knowledge to physicists acquainted with cosmic rays and nuclear phenomena. The building of a high pressure cloud chamber is a difficult, expensive and time-consuming engineering feat.

The aim of this particular project is to create in a liquid bubbles of gas or vapor along the path of an ionizing particle, thereby rendering the path of the particle visible. A liquid filled chamber designed to accomplish this process will be called, for lack of a better name and because of the aptness of the colloquialism, a "fizz chamber."

The various proposed schemes for creating the bubbles have been described in a hectographed note entitled Fizz Chamber, W. H. Bostick, December 16, 1945. The apparatus which is now being built is designed to reduce suddenly the pressure on a liquid by opening a valve which permits the air (at atmospheric pressure) above the liquid to flow into an evacuated chamber. It is hoped that the bubbles may be formed of the liquid's vapor rather than by gas coming out of the solution, because the former process obviates the necessity of redissolving gas in the chamber before each successive release of pressure. The chamber and valve mechanism have been completed and the first experiments are about to be performed.

Obviously, if the number of ions formed in the liquid by ionizing particles are to be a large percentage of the total number of ions in the liquid, the amount of dissociation in the liquid must be vanishingly small. The conductivity of normal hexane given by the International Critical Tables is $\sigma < 1 \times 10^{-18} ohm^{-1} cm^{-1}$ and it is stated that the conductivity is reduced when the chamber is covered by a "lead mantle." In fact, Bialobzeski reports the successful use of a hexane-filled ionization chamber to detect cosmic-ray bursts. At 760 mm Hg pressure normal hexane boils at 68° C, and at 186 mm pressure, it boils at 20° C. The chamber which has been designed in this project will provide a sudden change in pressure from 760 mm to about 75 mm. It is hoped that the liquid hexane will vaporize along the path of ionizing cosmic ray particles which penetrate the chamber approximately coincident with the release of pressure.

A clearing field will, of course, be used to clear the chamber of unwanted ions which are formed during the time between pressure releases.

III. G. Measurement and Control of Deionization Time in Thyratrons

Staff: Mr. F. Verzuh

The deionization time of thyratrons is influenced by the applied grid voltage, the grid circuit parameters, the anode current, the anode voltage, the nature of the enclosed gas, the gas pressure, and the electrode dimensions and orientation. The purpose of this investigation is to obtain quantitative data for various thyratrons under dynamic conditions.

Since the number of parameters is large and many thyratrons are to be tested, a rapid measuring method is necessary. The circuit used in this work is a modification of a line-type modulator circuit and is shown in Figure 1. In addition the anode voltage and current waveforms for the test thyratron VI are shown. The deionization time is defined as the time interval between the cessation of anode current at t_1 and the minimum time t_2 at which the anode voltage may be reapplied to V1 without it going into continual conduction. The synchroscope permits a rapid and accurate measurement of time. The anode voltage may be maintained at any desired value determined by the match between the non-inductive load and the PFN.

In order to evaluate the individual effects of the various factors upon the deionization time, the parameters were assigned and the deionization time measured as a function of the applied grid voltage. Then the magnitude of one of the parameters, for example, the anode current, was altered by a desired amount and the process repeated. In this way a family of curves was obtained with one of the variables as a parameter.

During the post-conduction period there may be further ionization in progress. However, if the electrode separation is less than the electron mean free path, the probability of ionization occurring is small - particularly when sweep-out fields are applied. Pure hydrogren has a high electron mobility and a low ionization number, and as a result, the deionization time of the hydrogen thyratrons is less than that of any other thyratron.

Generally speaking, the deionization process is one of recombination at the bounding surfaces and the problem of recontrol is to provide a rapid means for transporting the ions to these surfaces. A large grid bias and a low grid impedance provide a large inverse grid current and a low deionization time. However, a compromise is necessary between the maximum allowable inverse grid current and the minimum deionization time. Furthermore, the grid circuit impedance must not be reduced to the extent that it causes instability of the trigger source. The deionization time of thyratrons used in pulsed circuits may be reduced by the use of a trigger voltage which forces the grid negative immediately after the pulse. The deionization time may be further reduced by decreasing the rate of reapplication of the anode voltage. An inverse anode voltage during the post-conduction period does not decrease the deionization time, but provides an additional period of time before the anode voltage reaches the reignition value.

In this investigation thyratrons with argon, hydrogen, mercury-vapor and xenon gas were tested. The effect of the gas pressure was observed with the aid of a constant temperature bath. A low gas pressure decreases the deionization time but increases the ionization time. This work was confined to commercially available thyratrons and therefore the influence of the electrode dimensions and orientation upon deionization time was not fully investigated. However, a summary of the available data relating the deionization time and the significant parameters is presented in the thesis: Measurement and Control of the Deionization Time in Grid-Controlled Thyratrons.

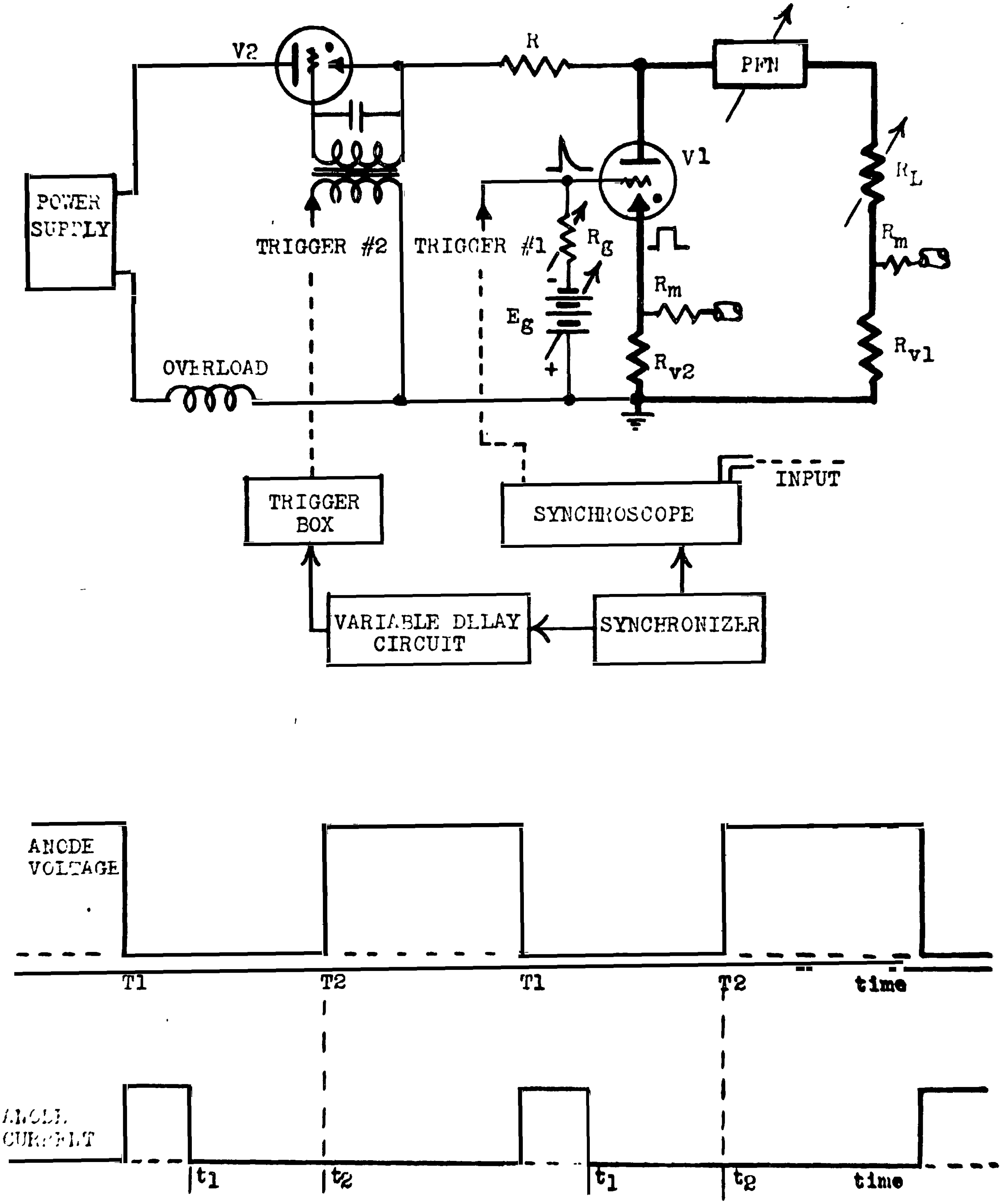


Fig. 1 CIRCUIT DIAGRAM OF CONNECTIONS USED IN MEASUREMENTS.

III. H. Experimentation in Photoelectric Spectrophotometry

Staff: Dr. B. Chance

Two important objectives have been achieved in the $4\frac{1}{2}$ months of this research project. The first is that the theoretical limit in the measurement of a small fluctuation of a given light intensity (photoelectric resolution) has been achieved with great stability, i.e., freedom from drift of either amplifier or lighthouse intensity. Second, some important applications of standardized plug-in amplifiers consisting of subminiature vacuum tubes have been indicated. The two phases of the problem will be discussed separately.

The use of a mechanical switch modulation-demodulation system for amplifying small photo-currents (.01 - 0.1 μa) with extremely high stability has been completely successful. These mechanical switch modulators, originally designed for use in circuits of a few ohms resistance, have been successfully adapted to circuits of resistance of at least 1/2 megohm. With suitable modification the pick-up of the carrier wave has been reduced to less than 1 microvolt. Furthermore, the stability with time is excellent, and drifts of less than 0.01 microvolts/minute over a 4-hour period are observed as indicated by the included Graph A. As contrasted to the usual practice in modulation-demodulation systems, relatively wide band a-c amplification has been used, followed by switch-type detection. The bandwidth of the system is then controlled after detection, and the design of networks for this purpose is therefore simplified, i.e., low-pass networks are used instead of band-pass networks. Since the operation of the switch detector is similar to that of the mixer, there is no loss of signal to noise ratio, and the noise level 0.2 μv of the overall modulator-demodulator system checks the theoretical figure to within the accuracy of measuring the bandwidth (~0.2 cps). A stable amplifier is useless for spectrophotometry unless the light source is similarly stabilized, and two types of light stabilization have been developed and both seem satisfactory. Both are degenerative stabilizers; the first employs a fixed-volt battery for a reference and the second, a pair of photocells which operate differentially to detect an increase in the short-wave radiation from the lamp upon increase of lamp current. In spite of the decrease in sensitivity, the differential method of detecting light intensity variations is preferred here, since photocell drifts cancel to a first approximation.

The Figure B indicates the overall performance of the system. With the lamp operating at maximum intensity, the drift of the output is recorded. The perfection of the instrument will be represented by the absence of noise and drift in the output and the sensitivity to small differential changes of light absorption. The principal fluctuation indicated by record B is the drift of the light intensity, and a value corresponding to 0.2 μv/min is obtained by averaging the data obtained over a longer period than indicated by Figure B. The signal sensitivity of the apparatus is measured directly by imposing an extremely small fluctuation of light upon the spectrophotometer. (This is not a fluctuation of total light but corresponds to a differential spectral shift which is measured directly on a calibrated micrometer screw.) The shift giving a deflection equal to noise and drift yields a resolution of roughly 4×10^{-6}. Thus the original objective of this research program (10×10^{-6}) has been not only achieved but slightly exceeded.

The theoretical performance of this apparatus is readily calculated. The total signal voltage, a photo-current of 0.06 μa, corresponding to 30 mv, results in combined shot and thermal agitation noise of roughly 0.2 μv p. to p. The ratio of noise and signal is 7×10^{-6} and checks satisfactorily the figure of 4×10^{-6} obtained above by direct measurement. The latter figure, of course, represents mainly the effect of light intensity fluctuations and not thermal agitation and shot noise.

Several associated instrumentation problems remain before the apparatus is suitable for experiments with biological preparations. At the present time, the oscillographic recording is incompletely testing, and the timing marker generator has not been built. In addition, a complete investigation of the limitation of this particular mechanical-switch modulator in high resistance circuits has not yet been made.

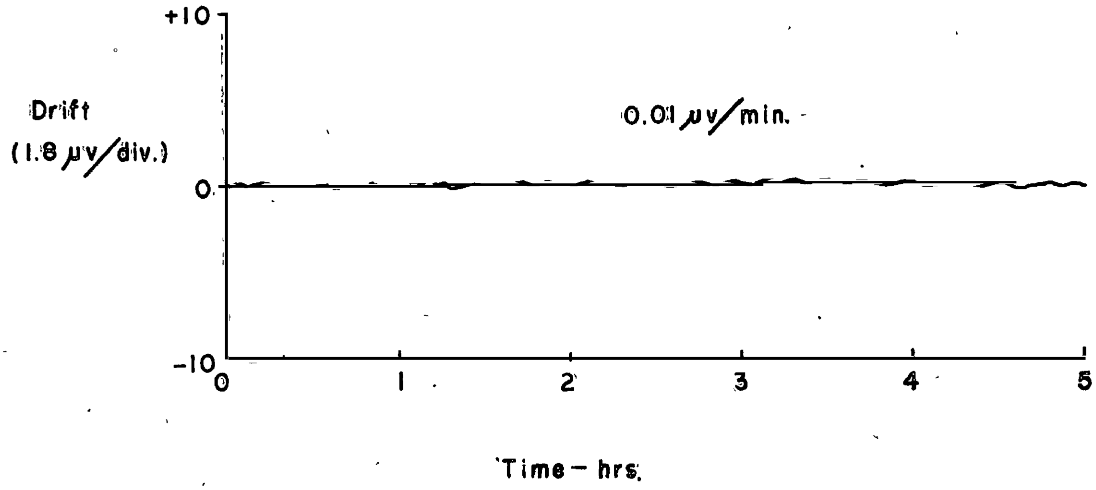
These principles of amplifier design have been applied to a double monochromator spectrophotometer. In this case, the light intensity available is much smaller, and a photomultiplier is required in order to obtain adequate signal-to-noise ratio. This has been supplied with a 1 kc. audio oscillator supply in which a degenerative d-c stabilizer is used to control the screen voltage of the oscillator and, hence, give constant output voltage. A mechanical-switch modulator and demodulator is used for precisely measuring the output of the photomultipliers. Although such elaboration might seem at first sight to be unnecessary since the output of the photomultiplier is at a relatively high level, the unquestioned stability of this system will permit more precise spectrophotometric measurements. The input to the modulator includes a slide-back potentiometer system which will permit a reading of the output of the photomultiplier to better than 0.1%. This unit includes necessary stabilization for the light source of the spectrophotometer.

The program of the use of subminiature tube assemblies has indicated by direct tests the utility of assemblies of subminiature tubes in rapid and effective circuit design. All the functions of the apparatus mentioned above are based upon two standardized amplifier designs - one, a-c coupled and the other direct coupled. (See Figure C). The a-c coupled amplifier has an open loop gain of roughly 20,000 and a closed loop gain of 1,000. The direct coupled amplifier has an open loop gain of roughly 1,200, and since it is nearly always used as a part of a negative feedback system having roughly unity gain, no internal feedback is provided. Each of these amplifiers is mounted on an octal base, and the units have been constructed and tested to the same standards of performance and are, therefore, completely interchangeable. The uses of the a-c amplifier are obvious; a carrier amplifier in the modulation system. The d-c amplifier is ubiquitous; it appears in all the stabilizer circuits, mirror oscillograph driver circuits, miscellaneous level shifting and amplifier circuits, etc.

It is believed that the simplicity of these units would suit them to wider applications. Considerable interest in these units has been expressed by a representative of the physics panel of the National Research Council Committee on

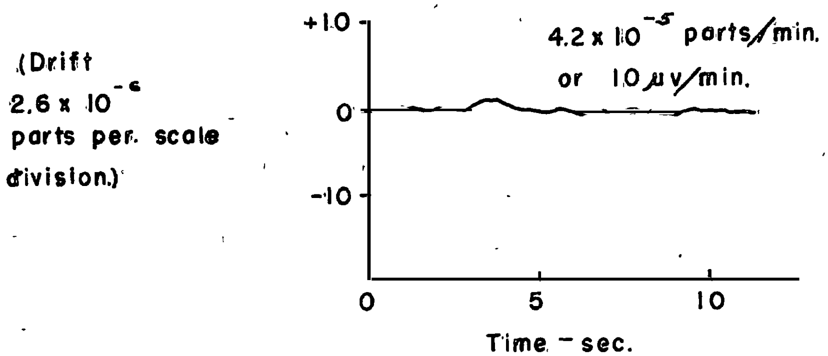
Growth, and it is believed that the application of this philosophy of circuit design is sufficiently useful that it may find application in several fields.

Fig. A



Drift at input with light off.

Fig. B



Drift at input with light on.

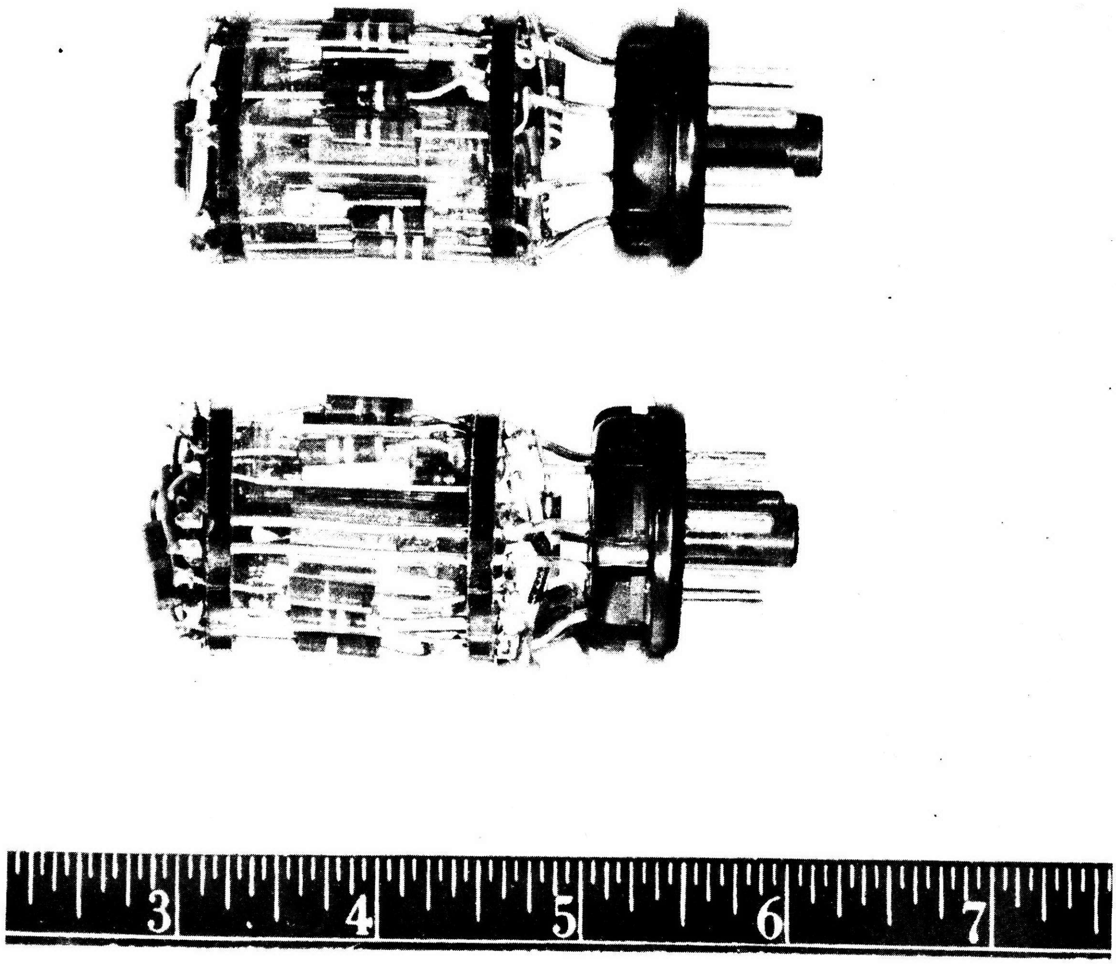


Fig. 6

III. I. Biophysics Project

Staff: Dr. S. Goldman

This project originated in the desire to show an instantaneous distribution of the electrical potential distribution on the surface of the skull as an aid in the diagnosis of brain tumors. The presentation technique is that of a radar P.P.I. The technical difficulties involved, however, are expected mostly in the pickup equipment because of the small values of the skull potentials (1-50 microvolts).

The project was started on May 1, 1946, and progress so far has been limited to the design of a preliminary pickup tube which is now under construction.

When once developed, the same technique should be applicable in other fields where it is desired to study two dimensional distributions of a variable. As a biophysics project, the technique will be used in studies of the brain and heart.