A DESIGN AND CONSTRUCTION OF A MICROWAVE ACCELERATOR

Since the last Progress Report experimental and theoretical work has continued on the 20-foot test model of a microwave electron accelerator. In addition, new and better laboratory space has been taken over and actual construction has begun on all of the major components of the accelerator. The following paragraphs will describe the work done since the last Progress Report was written.

The Accelerator Tube Three one-foot sections, each containing 6 irises, have been completed, fastened together, evacuated, and attached to three magnetrons. The unloaded Q of the resultant cavity is approximately 18,000 — in very good agreement with expectations. The future cavity sections will be constructed identically as the present sections final dimensions and coupling holes having been determined. Figures 1 and 2 show two views of one of the six iris cavities. Figure 1 shows the cavity with end plates attached and gives a view of the iris coupling from the waveguide to the cavity. A mica window is placed across the waveguide flange to allow evacuation. A three-wire grid is placed in the vacuum lead to make the waveguide electrically continuous.

Cold tests have been made showing the effects of varying various parameters in the magnetron-cavity line, such as line lengths and T construction.

The three magnetrons have been run simultaneously into the cavity and it has been observed that they lock in frequency and phase. With the use of a video amplifier it has been possible to observe the effect on phasing of pulsing one magnetron before the other two. This procedure has the effect of reducing the time elapsed before the second and third magnetrons lock together in phase.

If the three magnetrons are all tuned to the frequency of the mode adjacent to the desired mode, it is found that this adjacent mode is excited. Under the conditions set by this mode, the outer magnetrons are locked 180° out of phase, and the middle magnetron feeds essentially all of its power into the series load between it and the cavity. A possible interpretation of the data is that with the clustering together of adjacent modes which will occur in the 20-foot tube, there may be trouble due to the excitation of other than the desired mode. Further work is therefore proceeding on possible modifications of the magnetron-cavity coupling system to prevent the excitation of unwanted modes.

A special end coupling section has been designed and built which will allow measurement of the absolute power in the cavity.

A Rieke diagram is being taken to determine the conditions for maximum power output from the magnetron. This information will be used to suggest ways of improving...
Figure 1. Linear accelerator, front view.

Figure 2. Linear accelerator, side view.
the coupling system to obtain maximum fields in the cavity

**Beam Electronics** Experimental studies have been completed on the acceleration of electrons injected into a single microwave cavity. Results are found to be in complete agreement with theory as regards the maximum energy received and the shape of the energy spectrum.

Design data have been worked out for the construction of a cavity section to bring electron velocities up from low injection energies to the 2-Mev optimum value for injection into the uniform 30-foot section. In addition, a klystron-type cavity is being constructed to investigate the alternative possibility of producing some part of the necessary initial acceleration in a single cavity. Both of these accelerators are being considered as alternatives to the use of a 2-Mev Van de Graaff generator for developing the initial injection energy.

**Construction** Fabrication of additional one-foot sections of the cavity is continuing on a routine basis and the construction of the power supply and pulsing circuit has begun. Most of the electronic and mechanical parts for the final machine have been received.

Provision has been made in the newly required laboratory for the 30-foot tube and its associated equipment and also for the necessary testing and experimental work.

**Theoretical Studies** Along with the experimental work, several theoretical studies have been made which have greatly increased our understanding of the experimentally observed facts. These studies include:

1. A general analysis of the behavior of waveguide T's and "magic T's"
2. Theory of parallel operation of magnetrons transient and steady state
3. Theory of the iris-type accelerating tube
4. Dynamical study of electron propagation in a traveling wave

These studies will be made the subjects of separate technical reports.

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III 3 ULTRASONICS RESEARCH PROGRAM

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1 Scope and Purpose

The Ultrasonics Group was organized for the purpose of extending to the field of ultrasonics the special advantages and capabilities of pulse techniques, originally developed for radar. The effort has been in two directions:

a) To apply electronic gear already in existence to the measurement of fundamental ultrasonic properties of material. This has included determination of velocity, attenuation, and in some cases scattering, in a variety of liquids and solids. These measurements have been for the most part at 15 Mc/sec.

b) To develop new electronic gear for extending the frequency range both above and below this original frequency. A lower limit was set at 1 Mc/sec. No upper limit was imposed, and present measurements have been pushed to 300 Mc/sec, with no immediate barriers in evidence.

Echo-ranging techniques have many inherent advantages over c-w methods. The accuracy of basic measurements such as attenuation is increased, in some cases manyfold. The pulsing method is sufficiently straight-forward to allow absorption measurements in such heretofore difficult substances as liquid helium. Finally, the feature of discrete "sound packets" so simplifies the acoustic situation within highly scattering media that macroscopic detail such as grain structure in metals may be revealed.

2 Ultrasonics as a Tool

Ultrasonics provides several means for examining the mechanical properties of matter. In liquids, for example, the rate at which the pulsed energy attenuates is determined by three basic liquid properties: 1) the viscosity, 2) the heat conductivity, and 3) the tendency of molecular absorption of energy, i.e., relaxation phenomena due to inner vibrational states. The relative importance of these factors varies from liquid to liquid. Thus in the special case of monatomic liquids, no energy is lost to inner degrees of freedom. Measurements on these have given attenuations accounted for entirely by the viscosity and thermal conductivity (see Secs 5 2, 5 3 on liquefied gases). Conversely, for such low-viscosity, non-polar liquids as CC14 and CS2, the measurable absorption is many times greater (800 for CS2) than accountable on that basis. Such liquids owe their absorption primarily to excitation of molecular vibrations. A basic purpose in aiming towards higher frequencies (see Sec 6 2) is to observe "relaxation frequencies" associated with these internal, vibrations, the expected effect on absorption is discussed in Sec 4.

Ultrasonics can be put to an entirely different use in the case of single crystals. Attenuation with them is extremely low (see Sec 5 5) but the velocity is different along the various crystallographic axes. By employing both longitudinal and
transverse waves propagated along selected crystal axes, it is thus possible to obtain the complete elastic properties of crystals, i.e. the "stress tensors." The localization of the sound energy in discrete pulses make such measurements possible by enabling the observer to eliminate unwanted signals; i.e., the arrival-times of the signal pulses reveal the exact path traversed. Recently pulses have been sent down selected axes with sufficient intensity to produce permanent slippage effects between crystallographic planes. When a polycrystalline aggregate, such as a metal, is investigated, the ultrasonic attenuation is usually high, even though the loss inside individual crystals is slight. This is due to scattering by discontinuities at the crystal interfaces and it is expected that relationships between back-scattering and signal frequency will occur. For such investigations, equipment has been developed for complete coverage of the 1-Mc/sec to 100-Mc/sec frequency range.

3 Pulse Technique

Before examining more fully the mechanisms affecting the propagation of ultrasonic energy, the experimental method will be described. For directness, the least complicated procedure will be taken as exemplary; namely, propagation measurements in liquids at intermediate frequencies. Modifications for solids or liquids or for extremely high frequencies in liquids will be left to the appropriate sections.

3.1 Transducer-Reflector Arrangement. The scheme is essentially to use the liquid sample as a "storage medium" for short sound pulses and to measure the time delay and attenuation undergone by the sound in traversing a known path length. The acoustical pulses, after being generated from electrical pulses by the transducer, travel through the liquid to a plane reflector (Fig. 1) and back again to re-excite the crystal at a later time. The transducer-reflector distance is variable so that the increased delay produced by an increase in path length is a direct measure of wave velocity. The attenuation which must be removed from the electrical circuit to balance acoustical losses in the additional distance provides a measure of absorption.

3.2 Timing Sequence. The timing sequence is as follows (Fig. 2). A crystal-controlled circuit in the oscilloscope starts the scope sweep and simultaneously sends a trigger to the pulse generator. The pulse formed by the generator passes through an impedance-matching network to the transducer. When the resulting sound pulse returns to the transducer after its round-trip within the liquid, the delayed electrical pulse is formed and returns through the matching network. Since the transmitter is off when the echo signal arrives, very little leakage loss occurs and the main portion travels through the atten-
Both triggering and time measurements are accomplished by means of a crystal-controlled circuit in the oscilloscope (DuMont Type 2568 A/R Range Scope), so that automatic synchronization occurs. In addition to setting off the pulse generator and starting the sweep, this circuit also provides marker pips spaced every 2000 yards of radar range. For examination of the front edge of the echo signal, an expanded sweep with variable delay is used. Crystal control is necessary primarily for accurate timing of the marker pips, one pip is developed for each oscillation, and since the crystal frequency is accurate to better that 1 part in 10,000 the same holds for range marker positions.

3.3. Measurement Procedures. Velocity is obtained directly from the slope of distance traveled plotted vs pulse delay, and absorption is obtained from the slope of compensating electrical attenuation vs distance. Since the method depends only upon observing the effects of differences in acoustical path length, knowledge of exact distance traveled by the sound is unnecessary.

Velocity readings are taken for most liquids (liquid helium is the exception) at 2000-yard (radar) range intervals by placing the returned signal pip at definite positions with respect to successive scope range markers and recording the transducer-reflector distance. By adjusting the scope properly, these markers appear as very short (dark) breaks in the sweep, and if consistent criteria are adopted accurate range difference readings result. Since the echo signal is adjusted to a predetermined level on the scope for each range position (by means of attenuators without disturbing the gain of the remainder of the system), absorption data are obtained directly. Figure 3 gives sample data for three organic liquids. The round-trip attenuation is plotted against the transducer-reflector distance, and the slope of the straight lines is a measure of absorption.

3.4. Significance of Results. Results obtained in this manner may be regarded as physically equivalent to those obtained by continuous-wave methods, it may be shown that differences in behavior between pulsed sound and continuous sound in liquids should produce negligible effects. For example, no significant dispersion in liquids has been...
detected in the 15-Mc/sec range (nor pulse distortion) so that the group velocities measured by pulsing should not differ measurably from the phase velocities ordinarily obtained. Similarly, although attenuation within liquids varies as frequency squared, the bandwidth associated with the pulses is too narrow for a measurable effect to result.

![Figure 3: Sound attenuation vs distance](image)

The velocity of sound within most organic liquids is of the order of $1.5 \times 10^5$ cm/sec, or about 100 wavelengths per cm at 15 Mc/sec. Hence the crystal radiating surface is about 100 wavelengths across for a one-cm diameter. Accordingly, the pulses travel out within a very narrow beam (less than 1° to the first minimum). Therefore the pulses retain nearly their exact size and shape throughout their travel so that any geometrical attenuations due to spreading are completely overshadowed by true liquid attenuation. Therefore attenuation data may be converted directly to absorption coefficients without corrections, this may be seen from the linearity of the curves of Fig. 3.

4 Absorption Mechanisms in Liquids

4.1 Viscosity We return now to consider in greater detail the absorption mechanisms already mentioned in Sec. 2. We consider first the effects of fluid viscosity, being the simplest and yet illustrating many of the essential features common to all absorptions.
We can write the equation for longitudinal waves in the following form for liquids
\[ \frac{\partial^2 \xi}{\partial t^2} - \rho c^2 \frac{\partial^2 \xi}{\partial x^2} = \frac{4}{3} \rho \frac{\partial^3 \xi}{\partial x \partial t^2} \tag{1} \]

The first term represents acceleration of the fluid of density \( \rho \) and particle displacement from equilibrium \( \xi \). The second term is the restoring force due to the "stiffness" of the liquid against compression. The wave velocity is \( c \) (i.e., the value if no attenuation were present) and \( x \) is the coordinate along which the wave train travels. The last term introduces the effects of viscous friction, through the coefficient of shear viscosity.

That a purely longitudinal vibration of this nature should suffer losses due to shear viscosity may be at first confusing. However, since motion (i.e., compression and expansion) can occur only in one direction, the \( x \)-coordinate, it follows that any unit volume in the undisturbed medium undergoes a change of shape when participating in the motion. The change of shape involves shearing processes in addition to straight compression with the corresponding dissipation of energy into heat.

By following the usual procedure, a solution for Eq (1) can be assumed involving a wave velocity \( v \) and an attenuation factor \( \alpha \)
\[ \xi = \xi_0 e^{-2\pi f(t - \frac{x}{v})} - \alpha x \tag{2} \]

where \( f \) is the frequency.

Upon substitution in Eq (1) the true velocity \( v \) is found to be nearly equal to the unperturbed value \( c \) and an absorption coefficient \( \alpha \) given by
\[ \alpha_{\text{vis}} = \frac{8\pi^2 \frac{\eta}{\rho^3}}{3} f^2 \tag{3} \]

Thus \( \alpha_{\text{vis}} \) is seen to vary as the square of the frequency \( f \), and inversely as the quantity \( \rho c^3 \). The same tendencies are exhibited by sound absorption resulting from other processes, such as heat conduction or thermal relaxation.

4.2. Thermal Conductivity
In the case of heat conduction, the energy loss results from heat flowing out of the warm (compressed) portions of the cycle toward cooler regions. Thus more work is put into compressing a portion of liquid than is recovered during its expansion. The thermal absorption coefficient \( \alpha_{\text{th}} \) is given by
\[ \alpha_{\text{th}} = \frac{2\pi^2 (\gamma - 1)k}{c_p \rho c^3} f^2 \tag{4} \]

where \( k \) is the coefficient of heat conductivity, and \( \gamma \) the ratio of specific heats \( c_p / c_v \). The similarity to viscous absorption is evident.

4.3. Relaxation Absorption
For thermal relaxation a similar loss in recoverable energy occurs through transfer of heat into internal vibrational degrees of freedom of the molecules themselves. As before, more work is done in compressing a portion of liquid than is regained from it. This is due to a phase difference between the temperatures of the external and internal degrees of freedom. As one might expect this leads to an
attenuation which is more pronounced at the higher frequencies. In fact, for liquids the frequency-squared law is obeyed within the frequency ranges investigated up to the present, so that the general behavior is to this extent the same as for previous cases. At high enough frequencies however, the half-cycle period should be less than the effective time required for thermal equilibrium, i.e., the relaxation time. Under such conditions, the frequency-squared dependence for $\alpha_{\text{relax}}$ should break down entirely and an upper limit would eventually occur. This phenomenon has been observed only in the case of gases (which have relatively large relaxation times). A primary aim in the present effort towards higher frequencies is to observe the effect in liquids.

5 Measurement Projects in 15-Mc/sec Range

The projects undertaken by the Ultrasonics Group will be described in the order taken in Sec. 1. Accordingly, projects in the 15-Mc/sec range follow.

5.1. Velocity and Attenuation Measurements in Organic Liquids. The first undertaking\(^1\) was the systematic measurement of a variety of organic liquids selected on the basis of their chemical similarities. In connection with these measurements, a theoretical study\(^2\) was conducted in an effort to explain the results, at least qualitatively. The following table gives representative samples of the absorption measurements. Since liquids obey the frequency-squared law (at least up to frequencies far higher than 15 Mc/sec) the attenuation is expressed as $(\alpha/f^2) \times 10^{17}$ in the usual manner. The measured values are given in Column 2 of Table I and the classical values computed on the basis of viscosity and heat conductivity in Column 3. Since the pressure in the wave also varies as $e^{-\alpha x}$, $\alpha$ is commonly called the pressure attenuation. The discrepancies between the measured and classical values are evident.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Temp. °C</th>
<th>$\alpha/f^2 \times 10^{17}$</th>
<th>$\alpha/f^2 \times 10^{17}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Measured</td>
<td>Classical</td>
</tr>
<tr>
<td>Carbon tetrachloride</td>
<td>23.5</td>
<td>533</td>
<td>20</td>
</tr>
<tr>
<td>Benzene</td>
<td>7.5</td>
<td>680</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>21.8</td>
<td>800</td>
<td>8</td>
</tr>
<tr>
<td>Nitrobenzene</td>
<td>7.5</td>
<td>73</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>23.3</td>
<td>79</td>
<td>14</td>
</tr>
<tr>
<td>Chlorobenzene</td>
<td>7.5</td>
<td>123</td>
<td>10</td>
</tr>
<tr>
<td>Methyl alcohol</td>
<td>2.0</td>
<td>45</td>
<td>15</td>
</tr>
<tr>
<td>$N$-propyl alcohol</td>
<td>2.0</td>
<td>87</td>
<td>55</td>
</tr>
</tbody>
</table>


The absorption of sound in organic liquids is determined chiefly by the relaxation frequencies of the liquid. If the relaxation frequency is very high (~ $10^{12}$ cycles/sec), the absorption will be low. This appears to be the case in polar associated liquids such as water and the alcohols. In non-polar liquids such as benzene, CS$_2$, and COCl$_2$, the relaxation frequency appears tentatively, to be at lower frequencies and it is supposed that this accounts for the observed high attenuations in these liquids at 15 Me/sec.

A check on these conclusions may in some cases be obtained by studying the temperature coefficient of the attenuation. This coefficient will be negative if the effect of classical viscosity is predominant, or if the experimental frequency is << relaxation frequency. On the other hand, if the experimental frequency is >> relaxation frequency, the temperature coefficient is likely to be positive.

5.2. Ultrasonic Propagation in Liquid Argon. As explained, the predominant contribution to absorption in the organic liquid measurement program appeared to be due usually to relaxation effects ($\alpha_{\text{relax}}$) since viscosity and heat conduction effects could not account for the observed attenuation. In an effort to render this explanation more convincing, it was decided to initiate a program of measurements on liquefied monatomic gases.

Already published values for Hg (which is monatomic) agreed reasonably well with theoretical values based on $\alpha_{\text{vis}}$ and $\alpha_{\text{th}}$, since both argon and helium are monatomic, a similar check with these should strengthen the assumption.

Accordingly, joint programs with the Low Temperature Group were initiated, and gear developed for ultrasonic measurements in liquefied gases. The gear employed for argon measurements is that pictured in the Progress Report of January 15, 1947 (pp 62-63) under the subject of liquid helium. Measurements were conducted at 15 Me/sec in liquid argon which gave order-of-magnitude checks with these calculated values. Because of negligible heat conduction effects and low viscosity, however, the absorption is of too low a value (roughly 1 db/inch) for obtaining an accuracy of more than about 50 per cent. Therefore, measurements are planned for argon at 45 Me/sec, where attenuation should be increased to about 10 db/inch (frequency squared dependence). Attenuations of this magnitude can be measured with great accuracy.

5.3. Ultrasonic Propagation in Liquid Helium. Since the viscosity of liquid helium is about 100 times smaller than that of liquid argon, it might be supposed that attenuation at these frequencies would not be measurable. This, however, is not the case for because of compensating factors, absorption in liquid HeI is actually comparatively high (about 15 db/inch at 15 Me/sec). The compensating factor is the $\rho c^3$ in the denominator of the expressions for attenuation [Eq (3) or (4)]; it is smaller for helium than for argon by an even greater factor than the viscosity. Hence helium, although the least viscous substance known, has rather high acoustical attenuation.

First measurements, with the previously described gear, were possible down to about 1.77°K. However, since the most revealing temperature range in liquid helium is from 2.2°K down to about 1.1°K, the need for gear capable of lower temperatures became evident. Furthermore, anticipated efforts to produce so-called "second sound" (see below) in HeII required equipment which could be operated in HeII on a continuous basis.
Figure 4. Helium ultrasonic gear:
(A) Inner cylinder (B) outer cylinder
(C) transducer (D) reflector (E) hand-drive (F) coaxial line.
without stopping the liquefier. Such a device is shown in the photographs of Fig 4.

The gear is designed to fit within the Dewar of the Collins liquefier, in such a manner that the lower portions (within the cylindrical containers A and B) are immersed in liquid helium. The crystal transducer C projects ultrasonic pulses upward against the reflector D, which may be moved vertically by means of a calibrated hand-drive E. Signals (15 Mc/sec) reach the transducer through a coaxial line within the tube F.

Two concentric "shells" A and B are used so that the space between them may be evacuated when desired, thus thermally isolating the measurement chamber A from the remainder of the system. Thus, upon going to extremely low temperatures (by pumping out the inner chamber A), the echo-ranging will be done essentially within a Dewar. On the other hand, when helium is condensed into A, the space will contain helium for thermal contact with the liquefier Dewar.

**Helium I** Figures 5 and 6 give velocity and absorption respectively for liquid helium. We consider first only the results in Hel, i.e., above the λ-point which is 2.20 K. The circles of Fig 5 give the measured values of velocity, and are compared with previous data obtained at Toronto at a lower frequency (1.3 Mc/sec), no dispersion is apparent. The circles and solid curve of Fig 6 give values of α at 15 Mc/sec and are compared, above the λ-point, with theoretical values based on viscosity and heat conduction. The theoretical curve is indicated by the broken line. Note that at the higher temperatures the correlation is nearly complete. In view of the fact that polyatomic liquids are often hundreds of times as absorbing as predicted on this basis, the agreement for Hel is further evidence that ultrasonic absorption in monatomic liquids may be accounted for by α\textsubscript{vis} plus α\textsubscript{th}.

**Helium II** For Hel, i.e., below 2.20 K, the attenuation measured should not be expected to follow the classical absorption formulas (even though it is considered monatomic), because Hel is known to behave in a strictly non-classical manner; it is often referred to as a quantum liquid. Thus, if the broken curve of Fig 6, (α\textsubscript{vis} plus α\textsubscript{th}), were extended below the λ-point, its value would steadily approach zero. The reverse situation is actually found. This is presumably tied in with the fact that Hel may be regarded as a mixture of Hel-type fluid with a so-called "superfluid." This superfluid has zero viscosity and may vibrate either in phase or out of phase with the other component, such effects might give rise to the observed absorption behavior. By extending the measurements from the present lower limit of 1.77 K to about 1.10 K with the new gear, the complete temperature dependence of absorption should be obtained; it should become maximum at an intermediate temperature, and then fall toward zero.

**Mechanical Excitation of Second Sound** The dual nature of the Hel liquid makes possible the propagation of sound in two modes of vibration.\(^1\) Generation of second sound, which has heretofore been excited only by thermal methods, will be attempted by mechanical means; first sound which is generated by vibrating crystals (and

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Figure 5  Ultrasonic velocity in liquid helium vs temperature

Figure 6  Pressure absorption coefficient (\( \alpha \)) vs temperature
is the type considered above) will be sent in the form of pulses against a porous surface, which should result in formation of second sound pulses.

5.4 Paramagnetic Relaxation Experiment. An experiment has been undertaken to investigate with ultrasonics a somewhat different type of relaxation effect which should occur in paramagnetic salts. Although the results have been negative thus far, it is hoped to repeat the experiment under more favorable conditions later.

The array of electron spins which is created by a magnetic field in a paramagnetic salt has degrees of freedom which also make a contribution to the specific heat. Consequently, if the process of transferring energy in and out of this array takes a finite time, energy should be lost to this system as an ultrasonic wave, whose period is near this time, travels through the medium. Hence the ultrasonic attenuation should change when the medium is put into a magnetic field. The fact that this energy interchange in NaCl$_2$, 4H$_2$O and FeNH$_4$(SO$_4$)$_2$, 12H$_2$O takes place in times of the order of 0.1 microsecond has been shown by Gorter and his co-workers at Leiden.

Equipment was therefore set up to see if this effect could be observed in a 10,000-gauss field at a frequency of 15 Mc/sec in solutions of the two salts mentioned above. It could not; the thermal fluctuations which the ultrasonic wave produced in the liquid produced effects large enough to mask it. It is hoped to repeat the experiment with an increased magnetic field and a crystal of one of the salts when the crystal becomes available.

5.5. Single Crystals of the Alkali Halides. Experiments have also been undertaken to investigate the mechanical properties of single crystals of the alkali halides and Rochelle salt. This program is still in progress at the present time. It is divided roughly into four parts.

First, both shear and compressional wave velocities are measured in various crystallographic directions. These velocities are determined by the elastic constants which characterize the elastic behavior of the material, and sufficient different measurements are made on each crystal to determine all these constants. Most of these constants have been measured with the use of other techniques. This work provides a check on them, and in general produces more accurate data. This part of the program has now been completed, and a report on it (RLR Technical Report No. 10) will appear soon.

Second, the attenuations at low signal level at 10 and 30 Mc are measured. It is of interest to see whether this also varies with crystallographic direction. In particular, it might be expected that shear waves propagated perpendicular to the slip planes (110 planes) might be attenuated more than in other directions. This part of the work is just finished for NaCl. The attenuations are all small, and it is felt that it will only be possible to set an upper limit to them. No change with crystallographic direction is apparent. Work is progressing on making this measurement in the other alkali halides.

1 Physica Z, 33, (1940)
The technique for making these measurements in solids is of course somewhat different from that used in the liquid measurements, since the length of the path traveled in the medium cannot be adjusted conveniently; furthermore, the quartz crystal must be affixed firmly to the sample in some way, especially for measurements with shear waves. The quartz is affixed with a low melting point crystalline substance (usually salol). The film is applied carefully, and allowed to cool slowly under slight pressure. The technique for getting around the path length difficulty is to allow the pulse to travel back and forth along the crystal several times, and make measurements on the successive signals which are received each time the ultrasonic pulse strikes the quartz crystal. A typical set of these successive echoes is shown in Fig. 7 (deflection is downward). The wave is completely reflected at each end of the crystal, since the impedance mismatch is rather large there (the electrical connections to the quartz must be made so that this condition is fulfilled at the end). From the differences in times of arrival of different echoes and the dimensions of the sample, velocities are determined. From the differences in amplitudes and the sample dimensions, one determines attenuation.

The third part of the single crystal program is to raise the amplitude of the ultrasonic waves until permanent strains are produced in the sample, and thus measure yield stress dynamically. This is known to be a function of crystallographic direction in the static case, and it has been found so here in the dynamic case in NaCl. It is a minimum for shear in the slip (110) planes. Permanent strains have been produced in an NaCl crystal in these planes. The presence of permanent strains and much of their character are determined by placing the sample between two crossed polaroids, and examining the pattern of the transmitted light.

The last part of the single crystal program is to make measurements on the
strain optical constants in these substances by measurements of the polarization and intensity of the light diffracted by them as an ultrasonic wave passes through them (Debye-Sears Effect) Pulsed sound has not been used to produce optical diffraction patterns before, but this part of the work has progressed to the point where a pattern has been observed, so that no essential difficulty is expected in making the method work

6 Extension of the Frequency Range

The frequency range has now been extended to cover continuously the 1-100 Mc/sec range, and measurements up to 300 Mc/sec in steps of 30 Mc/sec are now in progress

6.1. Absorption in Metals (up to 100 Mc/sec) The previous section has discussed the application of ultrasonic pulsed techniques to the study of velocity and absorption in single crystals Similar techniques can be employed to study these phenomena in polycrystalline solids as well, with particular emphasis on metals This information can be directly applied to determine the effects of such things as alloy content, grain size due to particular forming and annealing processes employed, and many other metallurgical variables which at present are not well understood

If many different metal samples are to be used, it is quite time consuming to use the foregoing technique although this is perfectly satisfactory The bothersome necessity for cementing the quartz crystals to the metal samples can be avoided by employing a liquid bath in which the metals are suspended Here, the liquid transmits the acoustic pulse packet to the metal although a loss in signal strength occurs since the acoustic impedance of the two media are not the same The pulses are reflected internally in the metal sample and a fraction of the pulse is sampled via the liquid once each round trip The detailed aspects of the method will be discussed more fully in the following section, since in the latter work this method is found quite necessary while here it is principally more convenient

The present work is concerned with the variation of the attenuation as a function of the grain structure of the metal samples Since the medium presented to the acoustic wave by a polycrystalline material is not homogeneous, it is to be expected that scattering will occur This leads to an absorption coefficient which is greater than that found in a single crystal of the same material Scattering should be a function of the ratio of grain size to wavelength employed hence by varying the grain size of the samples under test, a measure of the scattered energy for a given wavelength is determined Similarly, by varying the wavelength for a given grain size, other relations will be obtained for the effect of the scattered energy on the attenuation The two sets of experiments should evidently be compatible and should serve to determine certain dimensionless constants which will be useful in extrapolating existing data to other grain size and wavelength conditions

For this work, equipment has been designed and constructed for operation throughout the 1 to 100-Mc/sec frequency range In most metals this corresponds to wavelengths varying from about 2 to 0.02 mm This region is convenient since the wavelengths can be about equal to the grain size (at least for the larger grain size
samples) and resonance effects can be investigated. The limitations to the upper frequency usable are the increase in attenuation as frequency increases and the practical consideration of minimum sample thicknesses which can be used. At this time, it is quite doubtful whether the entire range of the present equipment will be usable because of these limitations, although it is hoped that similar work on scattering can be started with the present equipment and colloidal scattering solutions rather than solids.

6.2. Measurements above 100 Mc/sec in Liquids. By driving crystals at high overtones, measurements are being made in liquids up to 300 Mc/sec. Operation at frequencies in the hundred-megacycle range requires an efficient transducer. It was found that some otherwise satisfactory crystals behaved very poorly when operated at high overtones. Selection of crystals made it possible to obtain transducers having low internal losses, low coupling to undesirable modes, and reasonable impedance values. Crystals having a fundamental of about 15 Mc/sec were chosen arbitrarily, mainly because of availability.

The chief difficulties encountered in the acoustical part of the problem are those associated with "beam width" and attenuation. The beam width varies inversely with frequency, so that more exact adjustment of the reflector is required with increasing frequency. This puts rigid requirements upon the driving mechanism of the reflector. With the method described in Sec 3, an upper limit (200 db/cm) to the measurable attenuation is reached when the reflector must be placed so close to the transducer that the returned echo is obscured because it returns before the transmitted pulse is completed.

This limitation has been successfully countered as follows. A rod of fused quartz with faces polished and parallel is used in place of the reflector. Some of the sound striking its surface penetrates and travels with small attenuation through the quartz and is reflected from the far surface. This delayed reflected echo is thus returned well after the transmitted pulse is over, so that attenuation through a very thin layer of liquid can be measured. Although originally devised for this purpose, this technique appears to be applicable to the measurement of attenuation in solids, since multiple echoes are received from sound trapped inside the solid. It is particularly applicable to work with low attenuating solids such as fused quartz and single crystals, since the loss at the liquid-solid interface can be calculated very accurately. Application of this technique has made possible the measurement of attenuations of 2000 db/cm, and with associated accurate mechanical equipment it appears that attenuations as high as 20,000 db/cm may be measured.

As can be seen from the last paragraph, a high degree of mechanical precision is required for work at very high frequencies and attenuations. Present equipment is limited, but equipment under construction will have provision for optical measurement of reflector travel as well as for very accurate maintenance of parallelism. A short table of results to date is appended. As yet no deviation from the frequency-squared law for the attenuation in liquids has been observed to indicate arrival at a relaxation frequency.
<table>
<thead>
<tr>
<th>Substance</th>
<th>Frequency Range</th>
<th>$\alpha_{-1}$</th>
<th>Max Atten. Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>75-250</td>
<td>$20.9 \times 10^{-17} \text{ cm}^{-2}$</td>
<td>118 db/cm</td>
</tr>
<tr>
<td>Ethanol</td>
<td>75-225</td>
<td>$53.7 \times 10^{-17} \text{ cm}^{-2}$</td>
<td>230 db/cm</td>
</tr>
<tr>
<td>Benzene</td>
<td>75-165</td>
<td>$900 \times 10^{-17} \text{ cm}^{-2}$</td>
<td>2100 db/cm</td>
</tr>
<tr>
<td>Carbon tetrachloride</td>
<td>75-105</td>
<td>$540 \times 10^{-17} \text{ cm}^{-2}$</td>
<td>440 db/cm</td>
</tr>
<tr>
<td>Carbon disulfide</td>
<td>75-105</td>
<td>$1400 \times 10^{-17} \text{ cm}^{-2}$</td>
<td>1280 db/cm</td>
</tr>
<tr>
<td>Fused quartz</td>
<td>75-195</td>
<td>$\sim 5 \times 10^{-10} \text{ cm}$</td>
<td>100 db/cm</td>
</tr>
</tbody>
</table>
Figure 1  Electrical and light characteristics of the FT-17 flash tube (initial voltage 4000 volts)
III C DEVELOPMENT OF FLASH TUBE

Staff: Professor H E Edgerton
      B F Logan, Jr

Description of Project. The project endeavors to accumulate accurate data on the basic electrical and light characteristics of the electric flash tube as used by the Air Forces for night photography.

Present Status. Oscillogram techniques have been perfected to measure light voltage, and current as a function of time during the discharge. A set of these curves for one FT-17 flash tube has been recorded and is presented in Fig. 1. For each set of curves the capacitor which discharges through the lamp is initially charged to 4000 volts. Curves for four different values of the capacitance are shown. Additional tubes are being compared to determine variations in electrical and light characteristics of physically similar tubes. A method of integrating the total luminous flux during a flash is being perfected so that the output, and therefore a measure of the efficiency of the lamp may be determined. A study is being started of the relative spectral output of the flash tube as a function of initial voltage and capacitance.

D CYCLOTRON R-F PROJECT

Staff: Professor G G Harvey
       T Moreno
       M Plotkin Brookhaven National Laboratory

Description of Project. Problems associated with the design of r-f circuits for large frequency-modulated cyclotrons are being investigated. The work to date has been directed toward the design of a cavity-resonator circuit for use with a proposed 600-Mev proton cyclotron for Brookhaven National Laboratory. This cyclotron will require pole pieces twenty feet in diameter and the operating frequency will be modulated over a range from 26 to 13 Mc/sec. It is planned to modulate the cavity with a mechanically rotating condenser.

Status. Three one-fifth scale models of proposed resonator designs have been constructed, and tests are being made with these cavities.

Cavity No. 1. Essentially a quarter-wave coaxial line resonator flattened to a rectangular cross section to fit in the 24-inch gap between the magnet pole faces. The open end of the line is placed on the diameter of the pole faces and the voltage developed across this open end will be used to accelerate the protons. Frequency modulation is to be accomplished with a pair of mechanically rotating condensers at the open end of the line between the magnet pole faces.

Cavity No. 2. Similar to Cavity No. 1 but designed for a 30-inch gap between the pole faces. This increases the shunt impedance of the circuit and reduces the required tuning capacity.

Cavity No. 3. Essentially a half-wave coaxial line, flattened to a rectangular cross section, open-circuited at both ends. Protons will be accelerated by the voltage developed at one end of the cavity, which is placed on the diameter of the pole faces. Frequency modulation will be accomplished with a rotating condenser at the other end of the cavity, outside of the magnetic field. The tuning range is increased by a discontinu-
ity in the line impedance. The center conductor is supported on insulators.

With the cavities excited from an external signal source, measurements have been made of their resonant frequency as a function of the tuning capacity. Capacities variable in fixed steps rather than continuously variable have been used. Results have been correlated with theoretical predictions for Cavities No 1 and No 2, the correlation has been poorer with Cavity No 3. Measurements of Q have been made on Cavities No 1 and No 2, and are in the order of one-half the theoretically predicted values, the discrepancy increasing with increasing tuning capacity. The frequencies of various higher modes have been investigated.

Some attempts have been made to design an oscillator that will drive the cavity in the desired mode while it is tuned. To prevent the oscillator from driving the cavity in the wrong mode, it has been found necessary to use a tuned plate, tuned grid circuit with the grid line tuned to the frequency of the desired cavity mode. The tuning of the grid line must then track the tuning of the cavity. Tests have not yet been made with a continuously tunable oscillator, but a cavity has been constructed for this purpose and the tests will be made shortly.

Models of tuning condensers for Cavity No 2 have been constructed and tested for tuning range. With a 0.400-in spacing between stator and rotor blades, the capacity varies over only a 6.1 range, which is insufficient. Reducing the spacing to 0.250-in increased the tuning to a 10.5:1 range, which is satisfactory, and gave more than adequate total capacity in the space available.

III E THREE-CM SWEEP-FREQUENCY OSCILLATOR

Staff
R M Fano
R B Adler
R Cohen

Description of project. The development of a sweep-frequency oscillator at about 3 cm is desirable for the design and alignment of microwave band-pass filters. About a ten per cent frequency-sweep range is required. The rate of sweep is expected to be 60 cps in order to facilitate oscillographic presentation of filter band-pass characteristics.

Status. Experiments with both a 2K49 and a 2K48 reflex oscillator have shown that they will not give appreciable power at 3 cm in either of the two coaxial cavities designed for them. Several types of coupling between waveguide and cavity have been tried. In all cases some power was obtained in the range 3.5 cm - 4 cm, but any attempt to push the frequency higher by reducing the cavity length caused the oscillator to select a mode of oscillation at about 7 cm, instead of going down to 3 cm. This situation was possible because at 7 cm the cavity is roughly λ/4 long, while it is simultaneously about 3λ/4 long for 3-cm oscillations. Since one of the cavities was designed originally to avoid this difficulty, it appears necessary to consider a completely different structure in order to accomplish the desired end. The design of a more standard type of cavity similar to that used in McNally tube applications is now in progress. No further work on the sweep aspects of the problem can be carried on until satisfactory operation of the tube is obtained.