A   DESIGN AND CONSTRUCTION OF A MICROWAVE ACCELERATOR

Staff   Professor J C Slater
        Professor A. F Kip
        Dr W H Bostick
        R J Debs
        P T Demos
        M Labitt
        B Lax
        L Maier
        S J Mason
        I Polk
        W V Smith
        J R Terrall

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 proceding 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
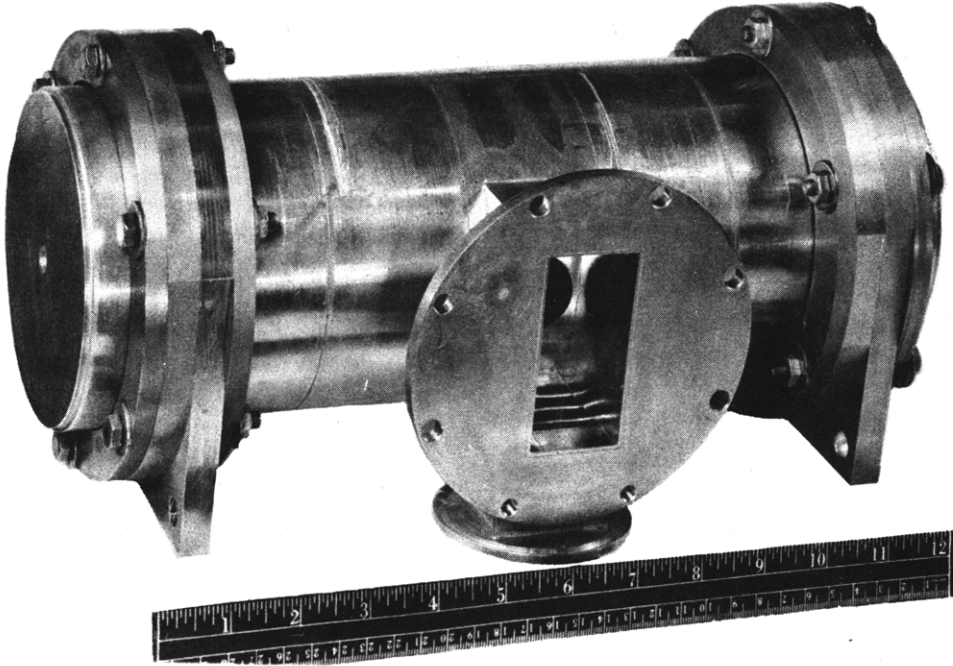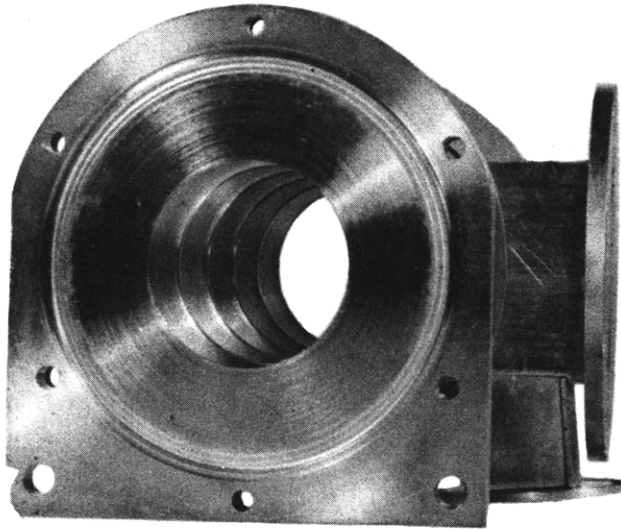
Figure 1. Linear accelerator, front view.

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 20-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 Graff 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 20-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

III B ULTRASONICS RESEARCH PROGRAM

    Staff Dr C Kittel
       J K Galt
       J R Pellam
       R A Rapuano
       W Roth
       Professor C F Squire, Low Temperature Group

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 CCl_4 and CS_2, the measurable absorption is many times greater (800 for CS_2) than accountable on that basis Such liquids owe their absorption primarily then 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 localiza-
tion 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 ultra-
sonic 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 ultra-
sonic energy, the experimental method will be described For directness, the least com-
plicated 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
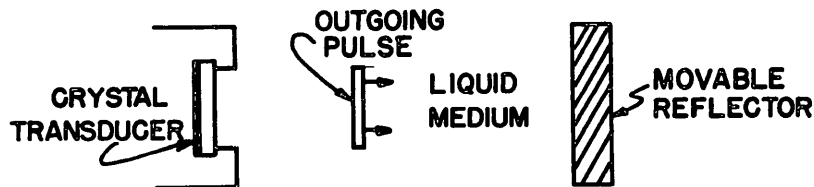later time The transducer-reflector distance is variable so that the increased delay

Figure 1   Transducer-reflector arrangement in liquids

produced by an increase in path length is a direct measure of wave velocity The atten-
uation 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 trans-
ducer 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-
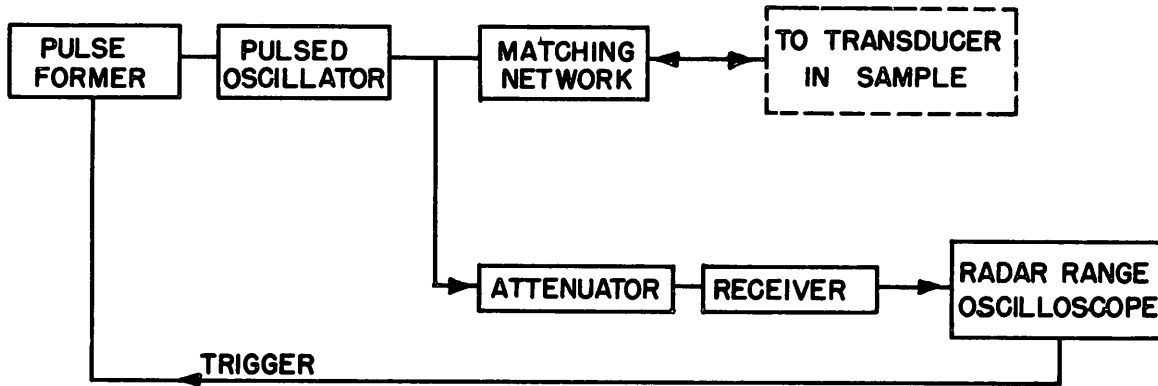
uator to the receiver

Figure 2   Block diagram for method of ultrasonic measurements

Both triggering and time measurements are accomplished by means of a crystal-controlled circuit in the oscilloscope (DuMont Type 256B 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
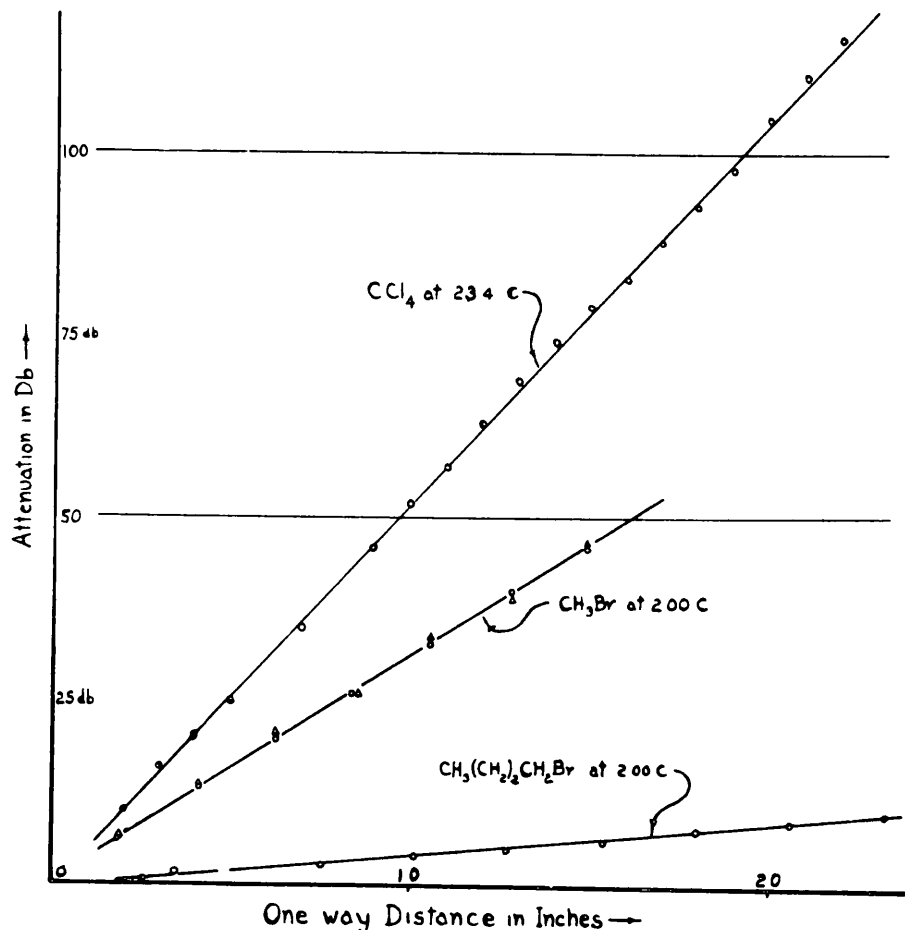bandwidth associated with the pulses is too narrow for a measurable effect to result

Figure 3   Sound Attenuation vs distance

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 radi-
ating 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)   There-
fore 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 coef-
ficients 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

$$\rho \frac{\partial^2 \xi}{\partial t^2} - \rho c^2 \frac{\partial^2 \xi}{\partial x^2} = \frac{4}{3} \eta \frac{\partial^3 \xi}{\partial x^2 \partial t} \tag{1}$$

The first term represents acceleration of the fluid of density ρ and particle displacement from equilibrium ξ 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 α

$$\xi = \xi_0 \, e^{-2\pi f i (t - \frac{x}{v}) - \alpha x} \tag{2}$$

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 α given by

$$\alpha_{vis} = \frac{8\pi^2}{3} \frac{\eta}{\rho c^3} f^2 \tag{3}$$

Thus α_{vis} is seen to vary as the square of the frequency f, and inversely as the quantity ρc^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 α_{th} is given by

$$\alpha_{th} = \frac{2\pi^2 (\gamma - 1) k}{c_p \rho c^3} f^2 \tag{4}$$

where k is the coefficient of heat conductivity, and γ 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 α_{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 $e^{-\alpha x}$, α is commonly called the pressure attenuation The discrepancies between the measured and classical values are evident

Table I	Ultrasonic Attenuation in Organic Liquids at 15 Mc/sec		
Substance	Temp. $^{\circ}$C	$\alpha/f^2 \times 10^{17}$ Measured	$\alpha/f^2 \times 10^{17}$ Classical
Carbon tetrachloride	23 5	533	20
Benzene	7 5	680	9
	21 8	800	8
Nitrobenzene	7 5	73	16
	23 8	79	14
Chlorobenzene	7 5	123	10
Methyl alcohol	2 0	45	15
N-propyl alcohol	2 0	87	55

1   J R Pellam and J K Galt, "Ultrasonic Propagation in Liquids I Application of Pulse Technique to Velocity and Absorption Measurements at 15 Mo", RLE Technical Report No 4 June 10, 1946

2   C Kittel, "Ultrasonic Propagation in Liquids II. Theoretical Study of the Free Volume Model of the Liquid State" RLE Technical Report No 5, June 10, 1946

The absorption of sound in organic liquids is determined chiefly by the relaxation frequencies of the liquid If the relaxation frequency is very high ($\sim 10^{12}$ 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 CCl_4 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 Mc/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 (α_{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 α_{vis} and α_{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 Mc/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 Mc/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 Mc/sec) The compensating factor is the ρc^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
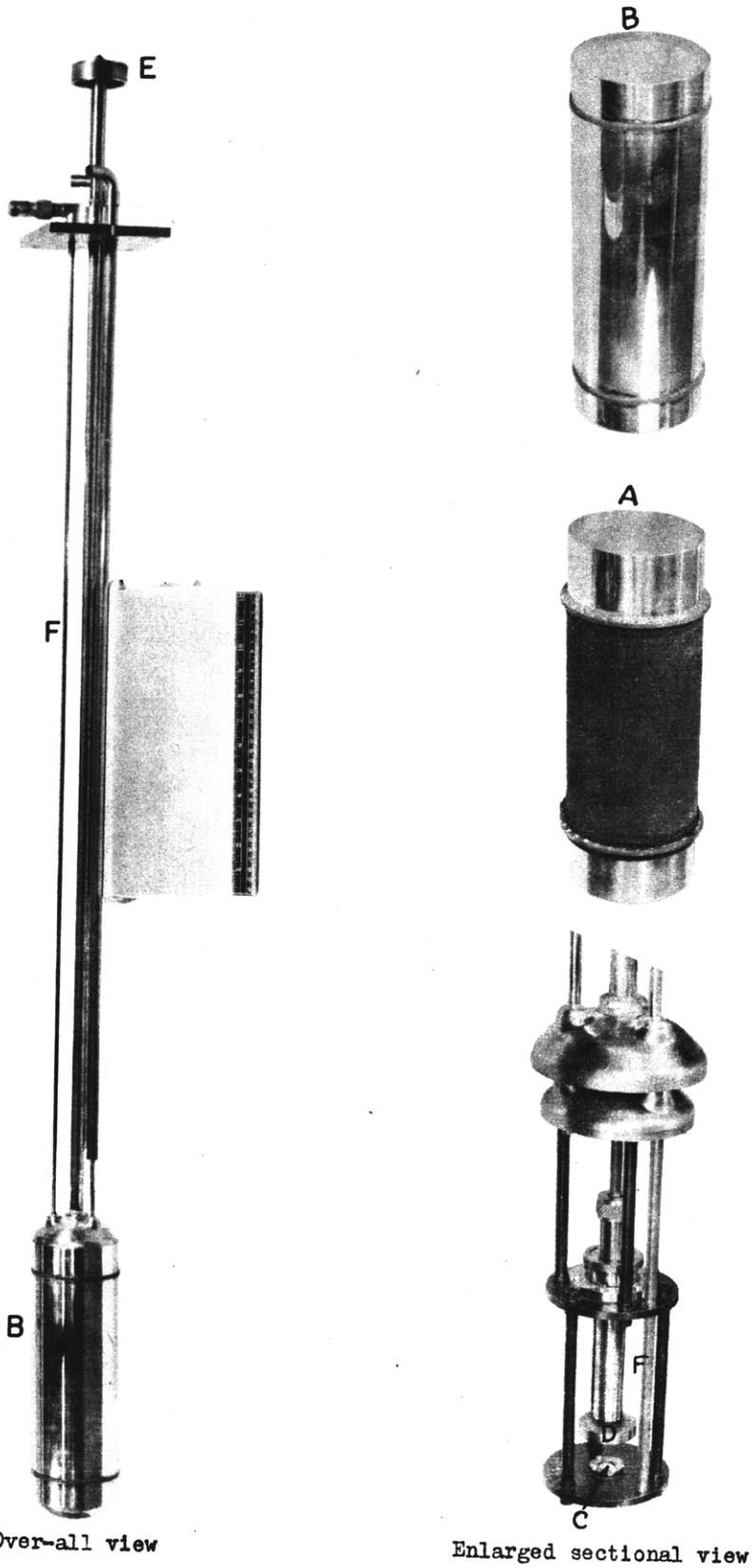
Over-all view   Enlarged sectional view

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 HeI, i e above the λ-point which is 2 2°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 HeI is further evidence that ultrasonic absorption in monatomic liquids may be accounted for by α_{vis} plus α_{th}

Helium II   For HeII, i e below 2 2°K, the attenuation measured should not be expected to follow the classical absorption formulas (even though it is considered monatomic), because HeII 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_{vis} plus α_{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 HeII may be regarded as a mixture of HeI-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 1°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 HeII 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

---

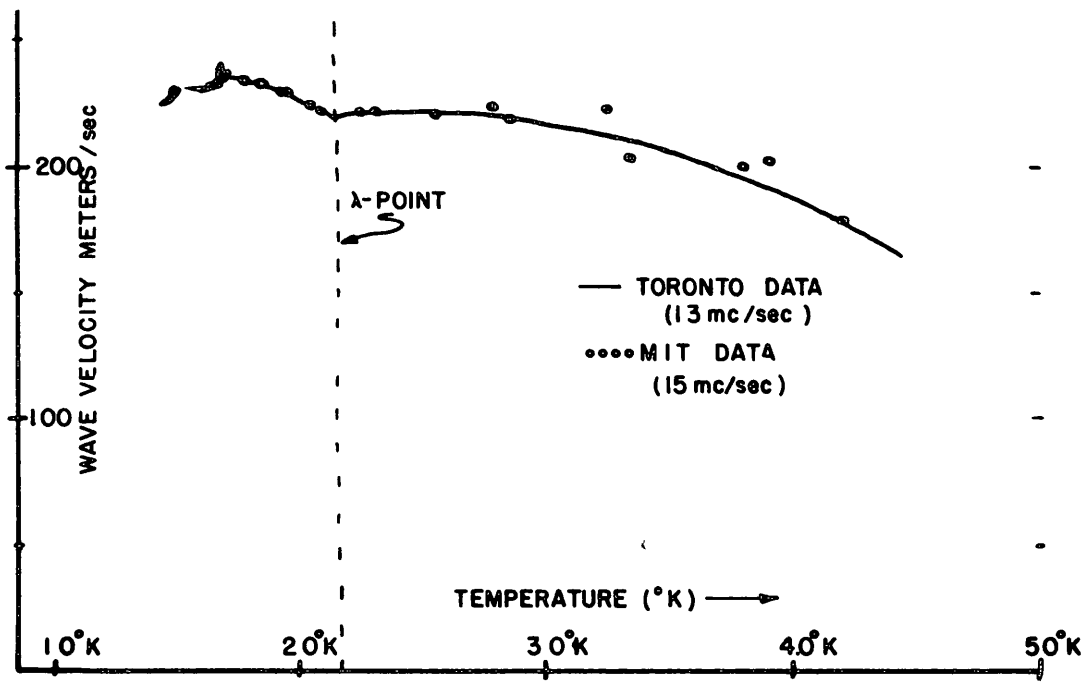1   L Tisza, J M Luttinger RLE Progress Report, p 56, January 15, 1947

Figure 5   Ultrasonic velocity in liquid helium vs   temperature
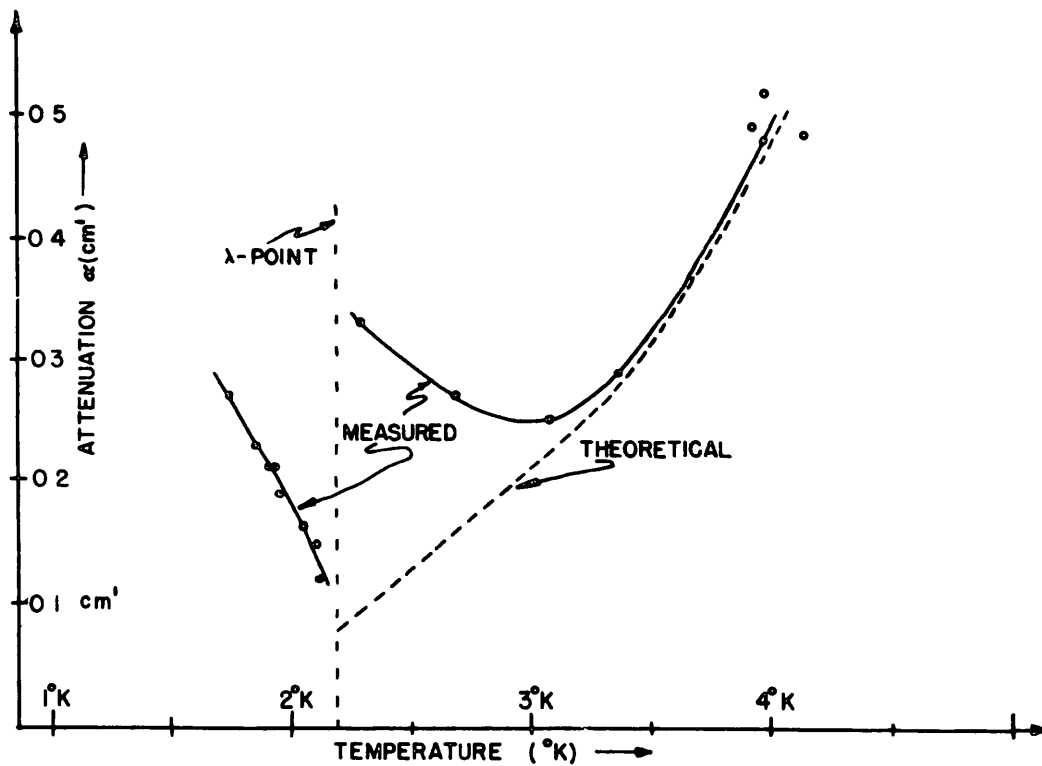

Figure 6   Pressure absorption coefficient (α) vs   temperature

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 <u>Paramagnetic Relaxation Experiment</u> 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 $MnCl_2$ $4H_2O$ and $FeNH_4(SO_4)_2$ $12H_2O$ takes place in times of the order of 0 1 microsecond has been shown by Gorter and his co-workers at Leiden [1]

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

<u>5.5. Single Crystals of the Alkali Halides</u> 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 (RLE 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 <u>7</u>, 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
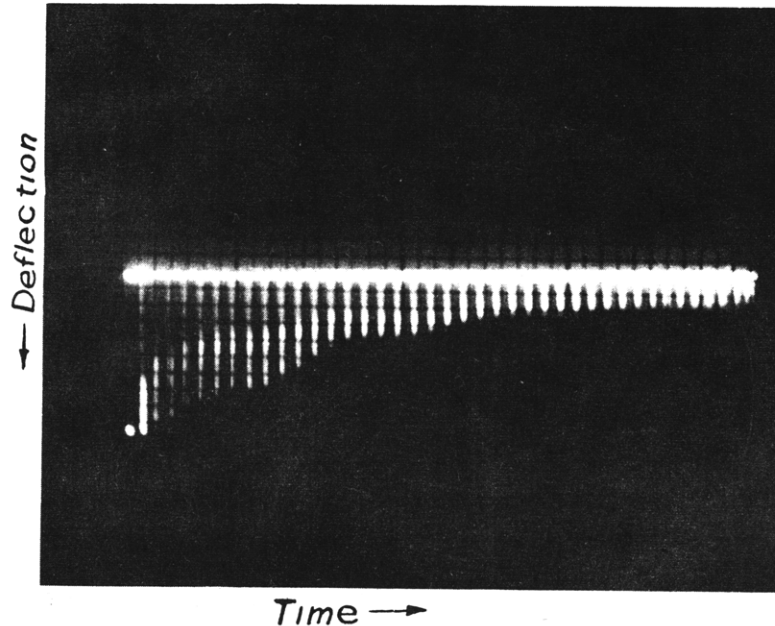

Figure 7. Successive echoes in NaCl block; shear waves propagated along the 100 direction.

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

-48-

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 (Debve-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 poly-crystalline 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 wave-length 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 atten-uation 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 fre-
quency 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 other-
wise satisfactory crystals behaved very poorly when operated at high overtones Selec-
tion of crystals made it possible to obtain transducers having low internal losses, low
coupling to undersirable 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 increas-
ing 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 atten-
uation 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 partic-
ularly 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 attenua-
tions 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 relaxa-
tion frequency

Table II <u>High-Frequency Attenuation Measurements in Liquids</u>

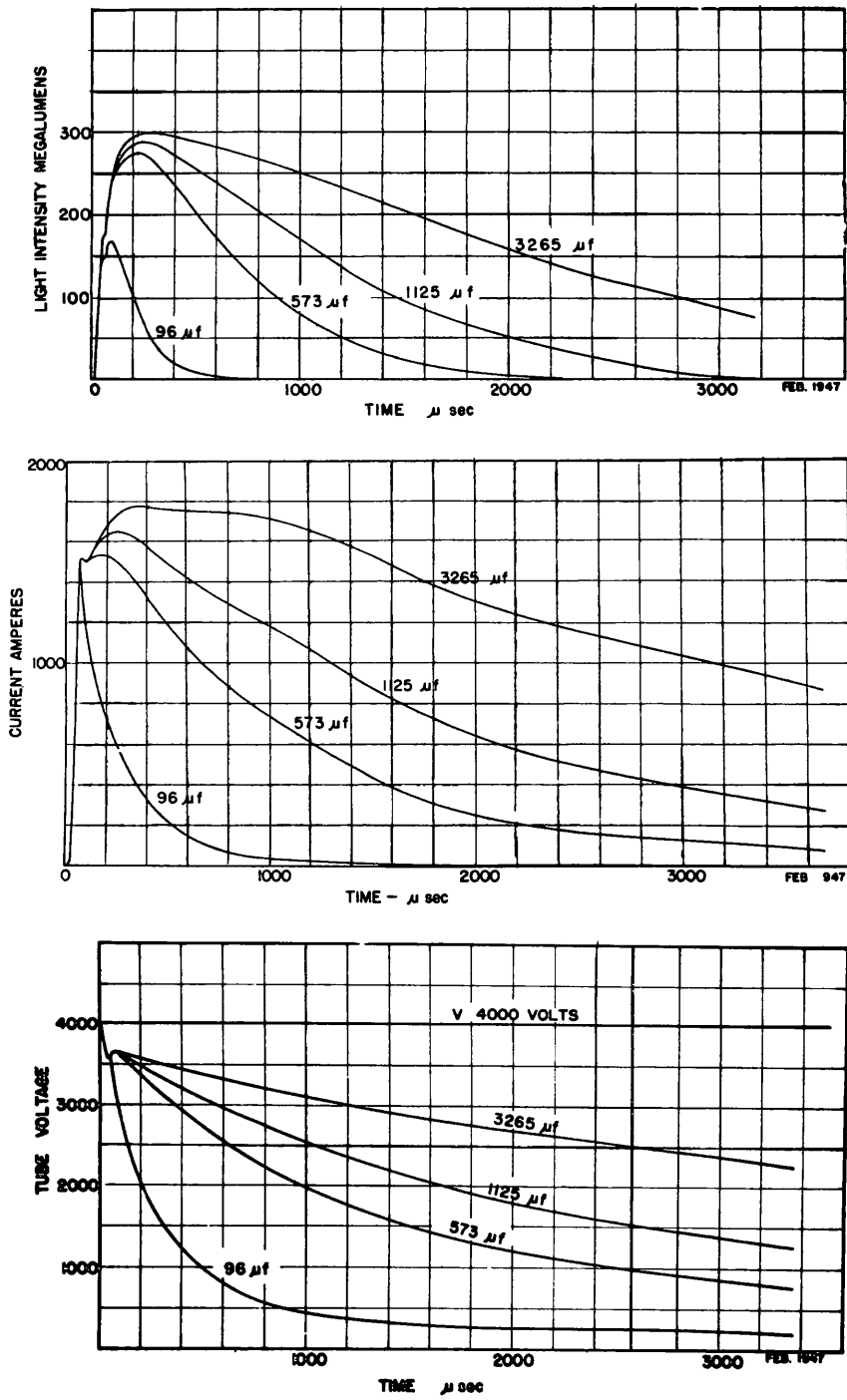| Substance	Frequency Range Mc/sec	$\frac{\alpha}{cm^{-1}}$	Max Atten. Measured db/cm
Water	75-250	$20\ 9 \times 10^{-17} f^2$	118
Ethanol	75-225	$53\ 7 \times 10^{-17} f^2$	230
Benzene	75-165	$900 \times 10^{-17} f^2$	2100
Carbon tetrachloride	75-105	$540 \times 10^{-17} f^2$	440
Carbon disulfide	75-105	$1400 \times 10^{-17} f^2$	1280
Fused quartz	75-195	$\sim 5 \times 10^{-10} f$	1 0

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 deter ned   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 $\lambda/4$ long, while it is simultaneously about $3\lambda/4$ 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.