II MICROWAVE PHYSICS

A MICROWAVE SPECTROSCOPY

1 Microwave-Frequency Bridge (5 mm)

Staff M W P Strandberg
J G Ingersoll

The measurement of the spectrum of oxygen in the 5-mm range has been completed One line has been isolated and the line breadth measured Measurements of the absorption of oxygen and nitrogen mixtures have given some unexpected results, so that a program studying the dependence of the absorption with various gas mixtures with intermediate ground state spins is being started

2 Sweep Spectroscope

Staff M W P Strandberg
R Hillger
T Wentink
R L Kyhl, Laboratory for Insulation Research

The precision measurement of the spectrum of ammonia has been completed and reported (Phys Rev 71, 326 (1947) The series of transitions in carbon oxy-sulfide has been measured These transitions are those involving a change of J from 1 to 2, 3 to 4, 4 to 5 The S^{34} isotope transition 3 to 4 has also been measured and the bond distances for this energy computed

The spectrum of molecules such as deutero-ammonia, methyl fluroform, etc are now being studied in the 10,000-Mc/sec region

3 Audio-Frequency Bridge

Staff C I Beard

In continuing the search for D_2O and HDO lines predicted at 0 55 cm^{-1} and 0 56 cm^{-1}, respectively, by King, Hainer and Cross, the system was pushed to 1 87 cm without finding these lines The region from 0 883 cm to 0 97 cm was then searched for the HDO line predicted at 1 13 cm^{-1} without finding it Because of tube limitations 0 883 cm was the lowest wavelength obtainable, and that at a barely workable r-f power level With available oscillator tubes, the system works best between 0 9 cm and 1 8 cm, and unfortunately both of these groups of lines are just outside this range at present

Meanwhile calculations of transition frequencies for several symmetric top molecules have been made and approximate intensities estimated by means of a formula developed by Professor E B Wilson of Harvard Methyl isothrocyanate was selected from this group to be investigated, and absorption at two different frequencies has been detected but the numerical data are as yet too tentative to be reported The absorption can be detected only by using the bridge to plot out the absorption lines on a point-by-point basis at a few millimeters pressure When the pressure is reduced to say 50 microns to use the sweep method the absorption lines cannot be seen on the scope Since the lines are quite broad at a few millimeters pressure, a possible explanation is that the broad line, corresponding to a certain J value, is actually split into its K-components because of centrifugal stretching of the molecule Then these split lines would overlap and add at higher pressures, but are each too weak to be seen when

they are resolved at the lower pressures required for the sweep method

Work is in progress to find the next higher frequency absorption line in the hope that the resolved lines will be strong enough to be seen by the sweep method and thus to determine whether the interpretation above is correct

Work is continuing to complete the point-by-point intensity measurement of the absorption lines found When measuring intensities, it is necessary to take account of the fact that when gas is admitted to the waveguide its dielectric constant shifts the standing-wave pattern in the guide and this shift would therefore give rise to false absorption values This effect is circumvented by inserting a phase shifter at the beginning of the gas arm

In calculating intensities, the formula given in the last Progress Report is used To obtain $\Delta P/P_o$ in the formula, the calibration of the crystal characteristic differs considerably from a square law and changes with respect to practically every variable Since in this system only the slope of the crystal output voltage versus the input r-f power curve is needed, a calibrated r-f attenuator placed before the crystal is a convenient way of determining this slope The crystal law can thus be found for every point taken The r-f attenuator is calibrated over the frequency range covered against a naked-wire bolometer as a standard

4 Nuclear Magnetic Moment of Hydrogen

Staff R B Lawrance

The two frequency-stabilized 1400-kc oscillators have been completed and are apparently satisfactory A modified Pound i-f type stabilizer is used The plumbing, which is entirely coaxial, utilizes a transmission-type cavity with variable coupling, this will allow considerable adjustment of power level in the hydrogen cavity without disturbing the stabilizer operation The stability obtainable with all a-c operation is such that spurious side frequencies are contained within a one or two-kc band, or approximately one part in 10^6

The hydrogen cavity itself will be started in the immediate future Attention is being given to the possibility of obtaining increased sensitivity by a magnetic analogue of the Stark effect apparatus used successfully at Harvard

5 Caesium Hyperfine Structure

Staff Professor A G Hill
M W P Strandberg

Work continues on the techniques of handling caesium at pressures in the range 10^{-3} to 10^{-1} mm of Hg

II B MOLECULAR BEAM RESEARCH

Staff Professor J R Zacharias
Dr B T Feld
L Davis, Jr
R S Julian
D E Nagle
C W Zabel

The frequency standard described in the January Progress Report has been completed

A beam of hydrogen has been observed in the apparatus recently constructed With the present arc source, about 20 per cent of the hydrogen shows magnetic deflections of the magnitude expected for hydrogen atoms at temperatures below 1000°K A new source has been constructed which may increase this fraction So far no radio-frequency transitions have been seen

A second apparatus is under construction which differs from the present one principally in the following ways

(1) The length of the homogeneous field has been increased to one meter, the increased length reducing by a factor of ten the broadening due to the finite time spent by a molecule in the transition field

(2) The lengths of the deflecting fields have been increased, and also the magnitude of their gradients This should give rise to observable deflections from very small nuclear magnetic moments Removable pole pieces are planned, so that both atomic and molecular experiments will be convenient

C LOW PRESSURE GAS DISCHARGES

Staff Professor S C Brown
Professor W P Allis
M A Biondi
E Everhart
M A Herlin
Donald E Kerr

The study of steady-state low-current density uhf discharge characteristics has been extended to a number of different gases and the effect of impurities has been investigated The previously reported results for the current-voltage characteristics were for helium (January Progress Report) These studies have been extended to neon, argon, krypton, nitrogen, and hydrogen The effect of impurities of mercury vapor have been investigated and the experimental technique evolved for keeping its vapor pressure below a value where it will affect the gas characteristics to a detectable degree

The experiments on the complex dielectric coefficient of a mercury arc have continued Careful temperature control of the arc has permitted studies of the change of the dielectric coefficient with arc current at fixed pressures The experimental data now seem to be satisfactory The mathematical formulation of the problem has been made, but the solution involves complex Bessel functions of the first and second kind Since these have not been completely tabulated, the problem has met a mathematical barrier which may be most easily resolved by redesigning the experiment to arrange the geometrical form of the discharge to one more amenable to mathematical solution The

preliminary steps in setting up such an experiment have been taken Present plans would require taking standing-wave measurements under pulsed operation as a function of time after breakdown of the discharge Standard test apparatus is not available to make such measurements and apparatus is being designed and built to meet these requirements

Progress in the transient discharge studies has been directed primarily toward understanding the physical behavior of the transient phenomena The experimental results obtained so far do not agree with published values of ambipolar diffusion, and a general study of the theory of the major premises of the electron diffusion process is under way

Substantial progress has been made in the design of an ultra-high frequency discharge counter as a detector of ionizing radiation It was previously reported that the turning off of the discharge was the greatest problem Coincident with our progress in understanding the electron diffusion problem, this problem has gradually been controlled At present these uhf counters have resolving times of the order 5×10^{-5} sec The problem which keeps these counters from being practical at present is our inability to handle the uhf power generators at this speed on randomly time-distributed pulses

II D LOW TEMPERATURE RESEARCH

1 Helium Liquefiers

Staff Professor F Bitter
Professor S C Collins
Professor C F Squire
R P Cavileer

During the past three months the helium liquefiers have been run twenty-nine times The A D Little Co liquefier made twenty-one consecutive runs without overhaul or failure, this is a most gratifying performance and demonstrates a remarkable reliability Several new experiences with those machines have occurred during this period and are

(a) Liquid helium has been transferred out into external flasks on four separate occasions An improved technique has been developed

(b) Liquid hydrogen has been transferred out of the condensing pot at the rate of 2 liters per hour

(c) The maximum amount of liquid helium which can be accommodated within the Little Co machine is about 4 2 liters The lowest temperature is 2 0°K

2 Studies on Liquid Helium

Staff Professor C F Squire
J R Pellam

See "Ultrasonics" Section III B

3 Studies on Beryllium

Staff Professor C F Squire

Pure beryllium has been obtained for the purpose of examining its physical properties over a wide temperature range Interest centers on this metal because of its unusual physical properties Published results present the following problems

(a) Specific heat to fit experimental data the Debye characteristic θ would have to rise from a value 800 at 300°K to 1000 at 50°K and then fall sharply at 20°K in short the Debye theory does not work

(b) The magnetic susceptibility has been measured to be diamagnetic $-1\ 85 \times 10^{-6}$ and computed by theory to be paramagnetic $1\ 38 \times 10^{-6}$

(c) The cohesive energy has been computed to be 53 to 36 kg cal/mol and observed to be 75 kg cal/mol

We are looking for an explanation of these effects in terms of the formation of a molecule of Be within the lattice - a molecule such as Be_2 or Be_6 The electrical resistance has been measured by us from 300°K to 4°K We are presently making a careful study of x-ray diffraction patterns Results of these and other measurements will be submitted when completed

Specific Electrical Resistance of Be in Ohm-cm

Temperature	300°K	166°K	82°K	22°K	4 2°K
Resistivity	$7\ 83 \times 10^{-6}$	$4\ 21 \times 10^{-6}$	$2\ 59 \times 10^{-6}$	$2\ 52 \times 10^{-6}$	$2\ 50 \times 10^{-6}$

II D 4 Superconductivity at 1.25 cm

a Theoretical Studies

Staff Dr P M Marcus National Research Fellow in Physics 1946-47

The application of the London phenomenological description of superconductivity to interpretation of the high-frequency measurements on superconductors is being investigated The theory should account for the frequency dependence of the conductivity of the superconductors by introducing the notion of the simultaneous presence of superconducting electrons (which do not interact with the metal lattice) and normal electrons (which have the usual interaction with the lattice) Simple calculations based on this picture lead to information about the number of superconducting electrons present in the metal as a function of temperature which can be compared with information obtained from thermodynamic and other measurements on superconductors

b Experimental Studies

Staff Professor J C Slater
J B Garrison
E Maxwell

Further progress has been made since the last Quarterly Progress Report in improving the technique of high-Q measurement Power is fed into one arm of a magic T and a detector is placed in the opposite arm The cavity is placed in one of the remaining arms, and an adjustable impedance, consisting of a calibrated attenuator backed by a variable plunger, in the last arm The magic T is thus used as a balanced bridge, the detector indicating zero power if the adjustable impedance equals the cavity impedance By sweeping the frequency of the input signal and putting the output on an oscilloscope it is easy by matching the display to vary the adjustable impedance to produce match at resonance By using this device more accurate measurements can be made than by the unbalanced bridge described in the last Quarterly Progress Report We find that these more accurate values check with the results of the earlier method

With the use of both the balanced and the unbalanced bridge methods measurements have been made on a number of samples of Hilger lead a very pure material These measurements all agree in showing a much larger change of Q at the transition than was found in the earlier runs on less pure lead In fact the change of resistance is now found to be of the order of magnitude of 400 as compared with 20 with less pure material The question of whether the resistance continues to fall as the temperature is reduced or whether it approaches a fixed residual value is not entirely clear different runs being somewhat inconsistent These results indicate the need of further experimentation at both 1 25 and 3 cm with materials of various degrees of purity before reliable statements can be made regarding the experimental facts and their relation to theoretical expectations

II D 5 Magnetic Nuclear Resonance Experiments

Staff Professor F Bitter
N L Albert
G G Lehr
S T Lin
H L Poss

Summary

Preliminary work with a small electromagnet and a few days of experimentation with the MIT cyclotron magnet, using a circuit similar to that developed by Purcell yielded the following results

(a) Confirming previous observations by Purcell, narrow resonance lines were observed for proton and fluorine nuclei in liquids (water benzene ether glycerine HF solution, liquid hydrogen) and broad resonance lines were observed in most solids (ice, a frozen mixture of 95 per cent D_2O + 5 per cent H_2O, paraffin, LiOH LiF, and glycerine at liquid N_2 temperatures) The difference is due to the rotation of the molecules in the liquid state

(b) The broad line shown by NH_4Cl at room temperature confirms previous conclusions that this molecule does not rotate in the solid state above the λ-point (-30°C)

(c) Solid methane at liquid N_2 temperatures showed a sharp line and a broad line at liquid He temperatures On being allowed to warm up, a sharp line appeared presumably at the λ-point (20°K)

(d) In general the magnitude of the resonance peak increased as the temperature was decreased

Theoretical Background A theoretical analysis of the behavior of a rotating magnetic dipole in a constant magnetic field H_0 with a superimposed oscillating field of amplitude H_1 perpendicular to H_0 has been given by F Bloch Phys Rev 70 460 1946 The result of this analysis may be summarized in terms of the following simple description When a rotating magnetic dipole with spin $\frac{1}{2}$ (a proton, for example) is placed in a constant field it can exist in a stationary state with its magnetic moment either parallel or anti-parallel to the field The energy difference between these two states is $g\mu_0 H_0$, where g is the gyromagnetic ratio of the particle μ_0 is the nuclear magneton, and H_0 the applied constant field If the dipole is also exposed to an oscillating electromagnetic field of frequency ν there will be selective absorption when

$$g\mu_0 H_0 = h\nu \qquad (1)$$

If we are dealing with many nuclei in a solid, a similar resonance effect is to be expected At resonance, there will be a component of the magnetization out of phase with the oscillating field This gives rise to the absorption of energy from the circuit producing the oscillating field A resonance curve may be plotted by observing the magnitude of this out-of-phase component of the magnetization as a function of H_0 in the neighborhood of resonance The half-width of this resonance curve may be shown

to be

$$\Delta H = \sqrt{\frac{1}{(\gamma T_2)^2} + H_1^2 \frac{T_1}{T_2}} \qquad (2)$$

where

$$\gamma = \frac{ge}{2m_p c} \text{ and } m_p = \text{mass of proton}$$

T_1 and T_2 are characteristic relaxation times determined by the coupling of the nuclear spins with the vibrational degress of freedom of the lattice and of the nuclear spins with each other

If thermal equilibrium is assumed the magnitude of the out-of-phase component of the magnetization at resonance may be shown to be

$$v = \frac{\gamma H_1 T_2}{1 + (\gamma H_1)^2 T_1 T_2} M_o \qquad (3)$$

where M_o is the equilibrium intensity of magnetization of the nuclei in the constant field H_o alone M_o varies inversely as the absolute temperature and larger signals are therefore to be expected at low temperatures When equilibrium conditions are established this out-of-phase component v is constant in magnitude and rotates with the applied frequency ν about the constant field H_o

If for some fixed frequency ν and field H_o we do not have equilibrium conditions it may be shown that the magnetization may oscillate around its equilibrium position with a frequency ν

$$2\pi\nu' = \sqrt{(\gamma H_1)^2 + (2\pi\nu - \gamma H_o)^2} \qquad (4)$$

This oscillation is then damped out exponentially at a rate determined by the characteristic relaxation times

In the experiments reported below, accurate checks on Eqs (1)-(4) were not attempted for lack of time Suffice it to say that Eq (1) was satisfied within the observable accuracy and that most of the resonances observed for small values of H_1 so that the line width and amplitudes observed were given by (2) and (3) in the form

$$\Delta H = (\gamma T_2)^{-1} \qquad (2a)$$

$$v = \gamma H_1 T_2 M_o \qquad (3a)$$

From Eq (2a) the line width is given as $(\gamma T_2)^{-1}$ This may be interpreted as being a measure of H_2 the variation of the actual magnetic field at the nuclei in various parts of the sample In other words if the local field is not precisely the same for all nuclei they will come to resonance under slightly different conditions, and the observed resonance curve is broadened

For narrow resonance lines it is important first of all that the field of the magnet be very uniform If for example a line has a natural width of 0 1 gauss and occurs for H_o = 7 000 gauss (approximately the field used for proton resonances at 30 Mc) it is necessary that the field of the magnet be uniform over the sample (approximately one inch in our experiments) to one part in 10^5 Otherwise

an artificially broadened line will be observed This brings out the advantage of using the cyclotron magnet which has a $9\frac{1}{2}$-inch gap and consequently an extremely uniform field

Secondly, in estimating local fields, account must be taken of the field which one nucleus produces at a neighboring nucleus This is of the order of a few gauss for protons We should therefore expect line widths of a few gauss, as found in solids

The explanation of much narrower lines in liquids is due to Purcell In a lecture at MIT he pointed out that in liquids, molecules rotate with frequencies far above the Larmor frequency of 30 Mc used in this experiment The local fields in liquids therefore change sign many times in one Larmor precession and effectively average out to zero The only parts of the local field that are effective in broadening a resonance line are those Fourier components having frequencies below the Larmor frequency

The experimental results described below are in agreement with this explanation

Description of Apparatus In order to observe a nuclear resonance one can sweep through the resonant condition by varying either the frequency of the oscillating r-f field or the magnitude of the steady magnetic field We have so far confined ourselves to the latter, but propose to investigate the alternative method in the future A coil placed in the magnet and fed by a power amplifier enables us to modulate sinusoidally the field by up to about 40 gauss, if necessary, at a frequency of 30 cycles This sweep frequency has been selected mainly for convenience any other frequency being equally suitable provided its period is long compared to the relaxation time, T_2, of the sample

If the amplitude of the modulating field is sufficient to cover the entire resonance the signal will appear as a pulse of r-f energy repeated twice during each modulation cycle These pulses will manifest themselves as very small changes in the amplitude of the r-f voltage across the coil surrounding the sample, and if this voltage is fed directly to a receiver, it will be entirely unnoticed. It is therefore necessary to add to the receiver input a voltage equal in magnitude and opposite in phase to that supplying the coil This balancing-out must be complete enough so that the receiver's full gain can be made use of without saturation setting in The small unbalance produced by the occurrence of a resonance will then be detectable

The arrangement of the apparatus is indicated in the accompanying block diagram (Fig 1) where for simplicity the modulating coil and 30-cycle amplifier have been left out Radio-frequency energy at 30 Mc is supplied by the signal generator both to the tuned circuit B, containing the sample and to a similar tuned circuit A, outside the magnet The outputs of both circuits are fed to the receiver which is an intermediate amplifier and detector from an AN/APS-13 Some of the load resistors across its tuned circuits were removed to increase its gain since its broadbanded feature was not required for our purposes and in fact would just serve to increase the noise background in oscilloscope observations The line marked a'b is one-half wavelength longer than the line ab to give us the necessary 180° phase shift for balancing out A section of line of adjustable length provides a fine phase control Amplitude variation is provided by a differential capacitor which adds or subtracts capacity from the tuned circuit in A while

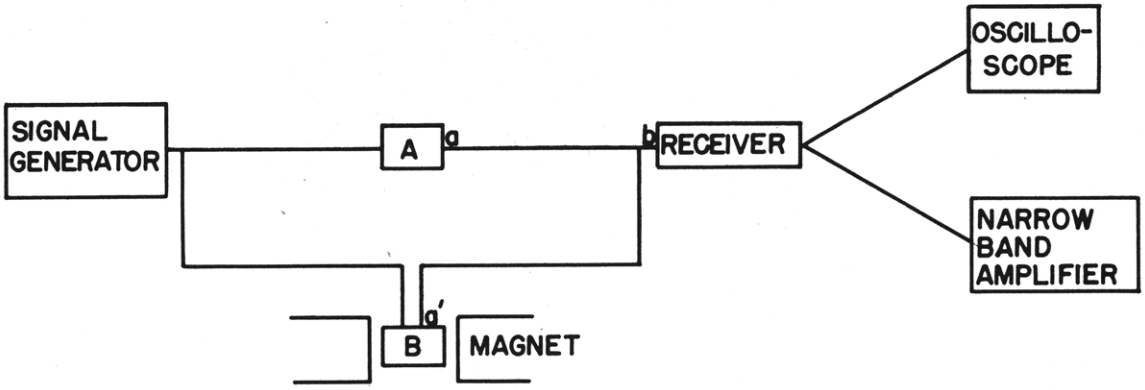

Figure 1. Block diagram of apparatus

decreasing or increasing the coupling capacity between this tuned circuit and the signal generator by the same amount. With resonable care in the adjustments, the residual voltage can be reduced to about 1/10,000-th of the unbalanced input.

For visual representation of the narrow resonances, the detected output of the receiver is applied to an oscilloscope, the sweep frequency of which is in synchronism with the 30-cycle modulating current. The accompanying photographs (Figs. 2-4) show some of the results obtained.

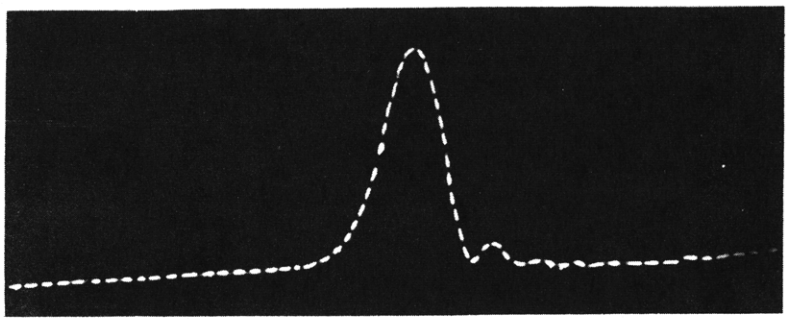

Figure 2. Intensified photograph of resonance in glycerine at room temperature.

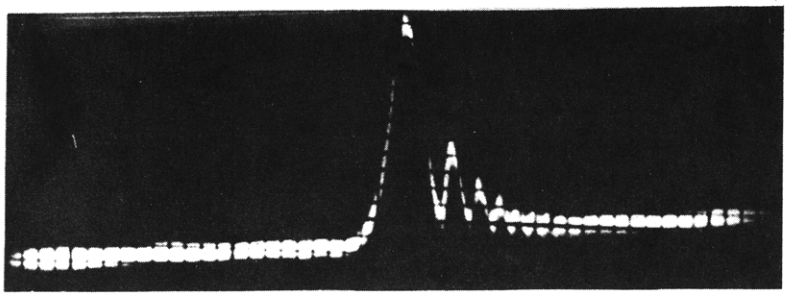

Figure 3. Photograph of resonance in H_2O at room temperature.

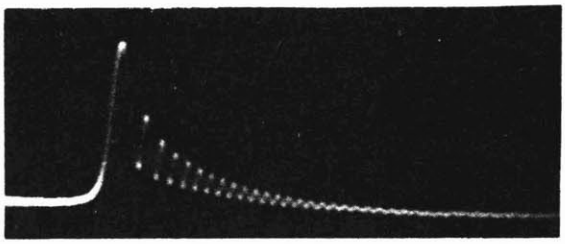

Figure 4. Photograph of proton resonance in liquid hydrogen (20.5°K).

In order to measure the broad resonances, where the wide distribution of energy greatly reduces the signal, the amplitude of the modulating field is reduced so that it covers just part of the resonance and the magnet current is slowly varied to cover the region of resonance. The output from the receiver in this case is proportional to the slope of the resonance curve, and it is fed to a selective 30-cycle amplifier. The amplifier is of the lock-in type and in addition contains a stage employing a twin-T feedback circuit which further narrows its bandwidth. A plot is then made of the output-meter readings on the amplifier vs. corresponding values of magnet current.

Oscillations near Resonance. The three resonance curves in Figs. 2-4 show, in addition to the resonance lines themselves, oscillations in amplitude following the resonance. It may be assumed that the changes in magnetization at resonance were so violent and rapid that thermal equilibrium was disturbed. It is tempting to associate these oscillations with those predicted in Eq. (4). A sufficient analysis to clinch this point has not yet been made.

Figure 5 is a plot of ν' as a function of the distance from resonance,

$$\Delta H = \left(\frac{2\pi\nu}{\gamma} - H_0\right)$$

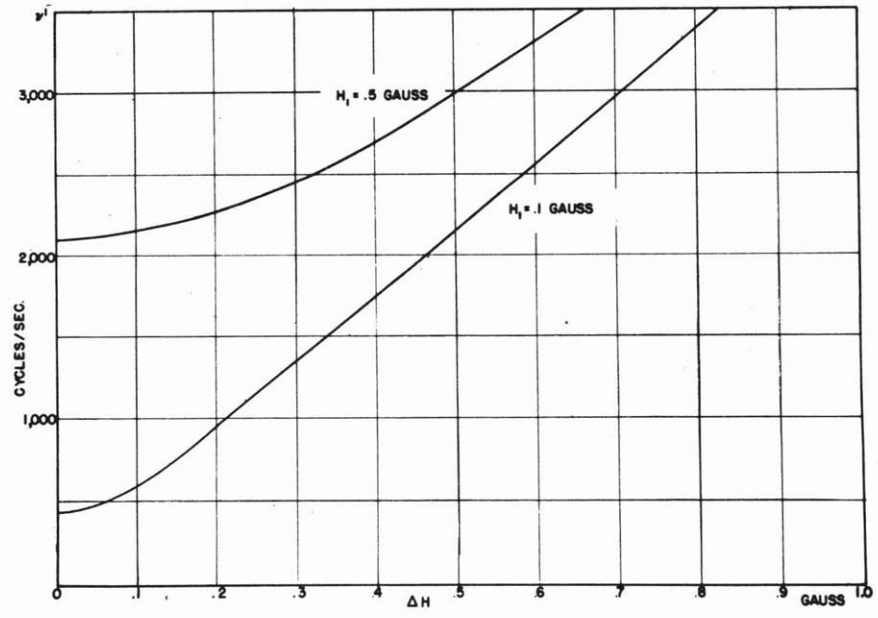

Figure 5. Plot of nutational frequency vs. distance from resonance for two values of r-f field.

for two values of H_1 Both the absolute values of ν' and the general tendency of ν to increase as ΔH increases are qualitatively in agreement with our observations

Effect of Temperature on Amplitude and Line Width During the few days that the cyclotron magnet was available a series of low-temperature experiments was run in the $9\frac{1}{2}$-inch gap of this magnet Low temperatures used ranged from dry ice (195°K) through liquid nitrogen (77°K), liquid hydrogen (20 5°K), and liquid helium (4 3°K) The results indicate that the resonance effect is enhanced at the lower temperatures as predicted by the inverse temperature factor in the theory We therefore conclude that there are no drastic changes in the relaxation times at low temperatures For resonances in liquid hydrogen signal-to-noise ratios of from 300 to 1000 were obtained on the oscilloscope, without using the narrow band 30-cycle amplifier

The principally qualitative data obtained in these experiments clearly point out the potentialities of this method in studies of properties of the solid and liquid state For example, the line width in a glycerine sample increased by a factor of about 20 from room temperatures to dry ice temperatures This increase is presumably due to a change in the frequency distribution of the local fields

Molecular Rotation in the Solid State Results obtained with NH_4Cl crystals and solid methane (CH_4) are of considerable interest Both of these substances have specific heat anomalies (NH_4Cl at -30°C, CH_4 at 20°K) which are due to some change in the properties of the solids at these λ-points For the NH_4Cl, Lawson (Phys Rev 57 417, 1940) has concluded from an analysis of thermodynamic data that the transition across the λ-point is an order-disorder change rather than a freezing out of rotational states. On this basis, the proton resonances for NH_4Cl both above and below the λ-point, would have the broad widths characteristic of resonances in solids A broad resonance (about 10 gauss wide) was actually observed at room temperatures thus bearing out Lawson's conclusion On cooling to liquid air temperatures the resonance line doubled in width

The proton resonance in solid methane as a function of temperature had entirely different charcteristics Above the λ-point, at liquid air and liquid hydrogen temperatures a very narrow line, characteristic of resonances in liquids, was observed (less than 1 gauss wide) This indicates that rotational states exist in solid methane above the λ-point since it is the presence of rotational states in liquids which causes the characteristically narrow lines In order to check the conclusion that it is the freezing out of these rotational states at the λ-point that causes the anomaly in the specific heat, we placed the methane sample in a liquid helium bath bringing its temperature well below the λ-point As predicted we observed a broad resonance (over 10 gauss wide) at these temperatures Permitting the helium to evaporate and the specimen to warm slowly through the λ-point we found a sharp transition from a broad to narrow line somewhere in the vicinity of the λ-point

Summary of Line Widths The following table summarizes our results on line widths No other substances were examined

Table of Line Widths in Gauss (± 30 per cent)

Substance	Temperature				
	Room	Dry ice	Liq N_2	Liq H_2	Liq He
LiF	>25				
LiOH	20				
Paraffin	>20				
Ether	Narrow				
Benzene	Narrow				
HF (protons)	Narrow				
HF (Fluorine)	Narrow				
H_2O 100%	≤ 0 3	16	17		
D_2O,95% + H_2O 5%	≤ 0 3		15		
Glycerine	1	16			
NH_4Cl	8	8	20		
H_2				0 7	
CH_4			~1	0 6	12

Acknowledgement We gratefully acknowledge the assistance given by many people in the MIT laboratories particularly Professor C F Squire who gave us valuable assistance in the liquid hydrogen and helium experiments and Dr E T Clarke through whose cooperation we were able to use the cyclotron magnet We also wish to thank Professor E M Purcell of Harvard for his valuable suggestions in the development of the circuit used

II D 6 Adiabatic Demagnetization

a Theoretical Studies

Staff Professor L Tisza
J M Luttinger

We have investigated the effect of a small amount of entropy on the magnetization curves of paramagnetic alums Previously[1] we had treated the case of zero entropy It has now been found possible to give both classical and quantum mechanical treatments in limiting cases These are

(1) High fields, moderately low temperatures (ca 10°K), and

(2) Weak fields very low temperatures (ca 10^{-3}°K)

Field strength is here measured relative to the internal field due to the permanent dipoles, which is of the order of 50 to 100 gauss These results are roughly applicable to the adiabatic demagnetization process and predict only a small deviation from zero entropy behavior

b Experimental Studies

Staff Professor F Bitter
Professor C F Squire

The program on adiabatic demagnetization is progressing in that the 1700-kw motor-generator of the Magnet Laboratory has been re-installed and the magnets for this work are being overhauled It is hoped to include in these experiments both paramagnetic cooling (particularly with Ti-alum), and nuclear magnetic resonances described in Section II D 5

7 Phase Transitions in the Hydrogen Halides

Staff Professor L Tisza

The well-known transition points of HCl HBr and HI have been alternately interpreted either as transitions from hindered to free molecular rotation, or as transitions between ordered and disordered arrays of dipoles Neither of these attempts has accounted for the fact that more than one transition point appears for HBr and HI The values of the transition points are presented in Fig 1 The transitions in the solid

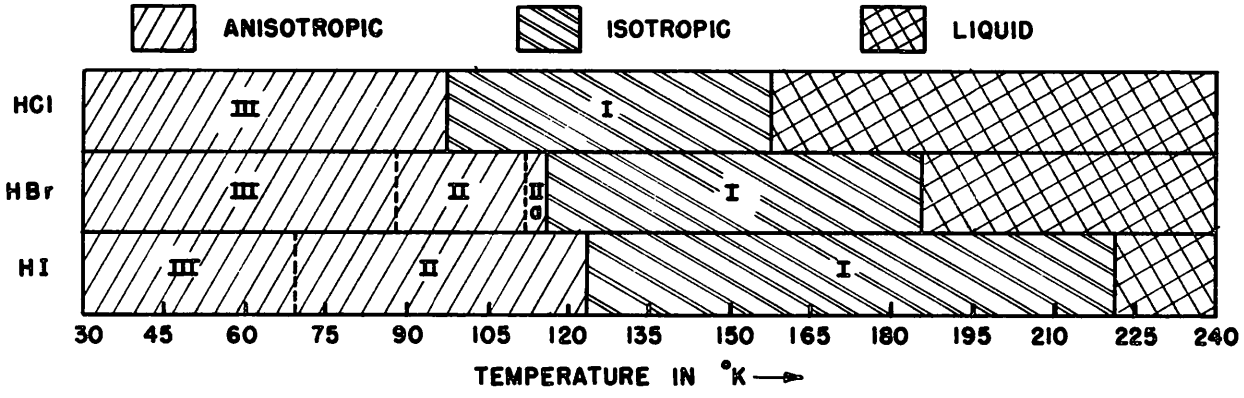

Figure 1 Transitions in the hydrogen halides

1 J M Luttinger and L Tisza Phys Rev 70 954 (1946)

phases are all of the second order (λ-points of the specific heat) with the exception of that in HCl which is a first-order transition with latent heat The same diagram displays the result of measurements with the polarization microscope[1], according to which the phases I are optically isotropic, while all the others are birefringent Figure 2 gives the dielectric constant of HBr [2] An analysis of these data leads to the following picture

In the lowest modification (III), the dipoles are arranged in an ordered (probably non-polarized) array The lowest transition point (III-II) marks the breakdown of the ordered structure of the dipoles, the axes of the spheroidal molecules remain parallel to each other, although they can point in either of two directions The transition II-I is connected with the disappearance of this tendency of parallelism the individual molecular orientation becoming isotropic The shift of the transition temperatures from one compound to another is in good agreement with these assumptions since the Van der Waals forces (responsible for the I-II transition) increases with the molecular weight, while the dipole moments and hence the II-III transition temperatures show the opposite trend For HCl the two transitions merge and phase III goes directly into I For HBr, on the contrary an extra transition occurs within phase II, the meaning of which cannot be assigned with certainty at present Another open question is whether the molecules in phase I are in a state of rotation or whether they vibrate merely about directions distributed at random It is hoped that this question will soon be settled experimentally by the method of nuclear resonances

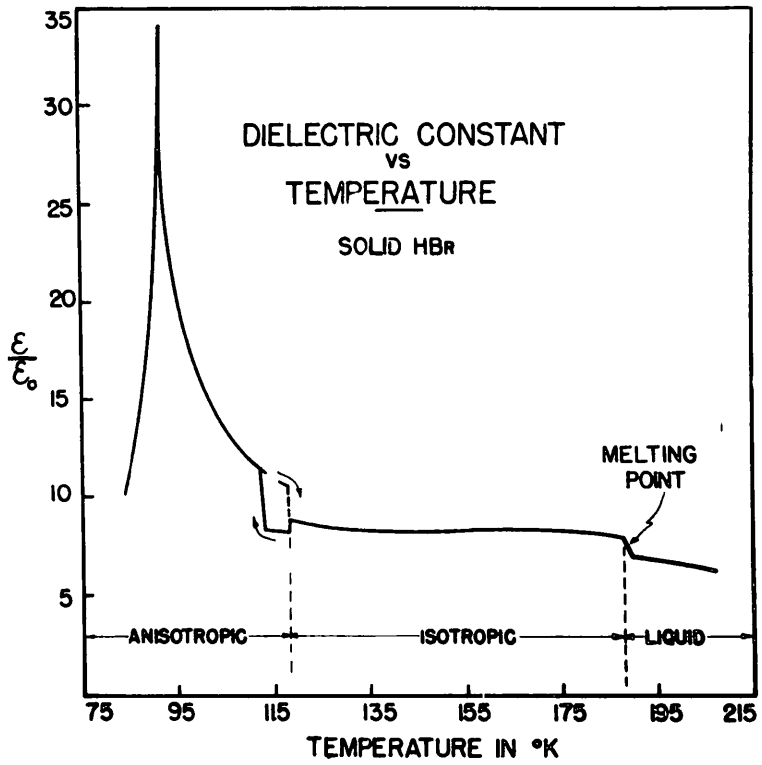

Figure 2

1 A Kruis and R Kaischew Z fur Phys Chem B41, 427 (1938)

2 C P Smyth and C S Hitchcock, J Amer Chem Soc 55, 1830 (1933)

II E FERROMAGNETISM AT MICROWAVE FREQUENCIES

Staff Dr C Kittel

In this period, a theoretical explanation has been given of the resonance frequencies observed by J H Griffiths[1] at Oxford in an experiment which is the ferromagnetic analogue of the Purcell-Torrey-Pound nuclear resonance experiment When one considers the effect of the demagnetizing field normal to the surface of the specimen, the theoretical resonance frequency turns out to be the Larmor frequency calculated for the fictitious field $\sqrt{BH}$ This result[2] is in quite good agreement with Griffiths' experimental results

It is planned by Garrison and Maxwell to repeat the ferromagnetic resonance experiment using a single crystal A preliminary experiment by Garrison and Maxwell using polycrystalline nickel foil is in general agreement with Griffiths' results In nickel the resonance peak for K-band occurs near 5000 oersteds

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1 Nature 158, 670 (1946)

2 Phys Rev 71 270 (1947)