period. Then it was rapidly cooled to room temperature, and the glow curve was measured.

The peak of the glow curve shifts continuously to higher temperatures with increasing period of decay and with higher decay temperatures. Therefore it is concluded that there exist in glass some unresolved groups of trapping centers, each group of which has its distribution around its center.

The induced absorption bands at room temperature are shown in Fig. 4.

A comparison of glow and absorption curves shows that the resolution in glow curves is better than in absorption curves, although the resolution in absorption curves increases generally at low temperature.

The above results show clearly that fused quartz—the glassy state of quartz—has a disordered lattice but preserves to some extent the local order of the crystal.

A full account will appear in the *Journal of the Physical Society of Japan*.

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An Ultra-High-Frequency Rotational Line of HDO†

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AN asymmetric top molecule whose dipole moment is oblique to its axes of principal moments may be expected to have a rotational absorption spectrum extending to very low frequencies. Some of these low-frequency lines may be transitions between levels of low J and may have appreciable intensities. King, Hainer, and Cross[1] have predicted that the $3_2 \rightarrow 3_3$ transition of HDO would occur in the uhf region with remarkable intensity, 2×10^{-7} cm^{-1}. Because of the possibility of observing deuteron quadrupole structure and of the novelty of working at such low frequencies, we have searched for this line.

Since the predicted frequency lay below the cutoff of our $1\frac{1}{2}$-in.$\times$3-in.$\times$20-ft wave-guide absorption cell, it was necessary to devise a method whereby the cell could operate in its TEM mode. The rf power, supplied by a 6AF4 triode in a Mallory TV-101 television converter, and the 5000-cps square-wave generator were both connected to the Stark septum through a matching and decoupling network near one end of the cell. At the other end was connected a crystal detector with a special adapter which effected capacitative coupling to the Stark septum through the mica window. The crystal detector was connected to a tuned amplifier and phase-sensitive detector in the conventional manner. With this equipment the line was found.

The measured frequency is given in the first line of Table I. Also contained in Table I are revised values of the frequencies of the three Q-branch and one P-branch S-band lines which we have reported previously.[2]

The constants of the centrifugal distortion formula for Q-branch transitions due to Kivelson and Wilson[3] were adjusted to obtain the best fit with the three S-band lines and six higher-frequency lines.[4–7] The calculated frequencies using the parameters $(a-c)/2=8.4895$ cm^{-1} and $\kappa=-0.6830$ are given in the last column of Table I. It is to be noted that the agreement is excellent.

TABLE I. Observed low-frequency lines of HDO.

Transition $(J_\tau \rightarrow J_{\tau'})$	Measured frequency (Mc/sec)	Calculated frequency (Mc/sec)
$3_2 \rightarrow 3_3$	824.64 ±0.05	824.61
$6_1 \rightarrow 6_2$	2394.56 ±0.05	2394.5
$4_0 \rightarrow 5_{-5}$	2887.4 ±0.1	
$12_{-1} \rightarrow 12_0$	2961 ±1	2963
$9_0 \rightarrow 9_1$	3044.71 ±0.10	3043.5

Satellite lines 30 kc/sec on either side of the main $3_2 \rightarrow 3_3$ line were partially resolved. The satellites are undoubtedly due to the deuteron quadrupole hyperfine structure. They will be studied for obtaining values of the coupling constants.

We wish to thank Dr. D. W. Posener and Professor M. W. P. Strandberg of M.I.T. for access to their unpublished results. Also thanks are due Professor C. H. Townes of Columbia University, who suggested that we look for the quadrupole splitting. We acknowledge the help of Mr. Gabriel Herrmann, who participated in the S-band work, and Mr. Leon Arnell, Mr. Leonard Yarmus, and Mr. Sol Krongelb for construction of some of the apparatus.

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Quadrupole Coupling of the Deuteron in DCCCl and DCN*

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THE $J=1\rightarrow2$ transition of deuterated chloroacetylene has been studied with a high-resolution bridge spectrometer.[1] DCCCl is a linear molecule containing two nuclei with quadrupole moments. The spectrum of this compound at lower resolution has been described in the literature,[2] as has the procedures for treating the two-quadrupole molecule.[3] For the $F_1=\frac{1}{2}\rightarrow\frac{1}{2}$ transition, where $F_1=J+I_{Cl}$, it can be calculated that no splitting caused by the deuteron quadrupole moment would be expected, whereas for the $F_1=\frac{3}{2}\rightarrow\frac{3}{2}$ transition the splitting should be most easily observed. Recorder traces of these lines were obtained, from which it was ascertained that $(eqQ)_D=+175\pm20$ kc/sec. The pattern is not symmetric, so ths sign of the coupling is unambiguously determined. A more detailed description of the experimental evidence and its interpretation will be published in the near future.

The investigation reported above was suggested by line broadening in DCN observed while studying asymmetries of the nitrogen quadrupole coupling in HCN and DCN. Line widths of 50 kc/sec could be obtained for HCN, while DCN produced lines of 70 kc/sec width under the same conditions of temperature, pressure, and power. From the line broadening a value $(eqQ)_D=300$ kc/sec±150 was inferred. The large uncertainty is caused primarily by the circumstance that the transition involved, being $\Delta J=0$, is most unfavorable for the quadrupole coupling investigation. Accordingly, the molecule DCCCl described above, with the same bond structure and a more favorable transition was examined.

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Measurement of Permeability Tensor in Ferrites*

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A NUMBER of investigators have measured the imaginary component of the magnetic permeability in ferromagnetic semiconductors.[1] The usual method has been to introduce a small ferrite sample into a microwave cavity and to note the resulting perturbing effect on the cavity Q upon application of a dc mag-

netic field. The real part of the permeability, which causes a shift in cavity resonance frequency, has also been measured.[2]

It is well known that ferromagnetic materials become anisotropic upon application of a magnetic field, and that consequently the permeability must be described by a tensor. The experimental results cited above yield only the diagonal tensor components. If Polder's theory[3] is assumed to hold, then the off-diagonal terms of the tensor can, in principle, be computed from measurements of the diagonal components. According to a suggestion by Lax,[4] the off-diagonal terms can be determined experimentally if the sample is placed in a microwave cavity which is degenerate in two orthogonal modes. If a microwave field excites one mode of oscillation, the electron spins which are precessing about the applied dc magnetic field will couple to and excite the orthogonal mode. The dc field removes the cavity degeneracy and causes a splitting of the cavity resonance—analogous to optical Zeeman splitting.

We have constructed a single input, right-circular cylindrical cavity, resonating at 9060 Mc/sec in the circular TE_{111} mode, which proved to be perfectly degenerate. Figure 1 shows the effect

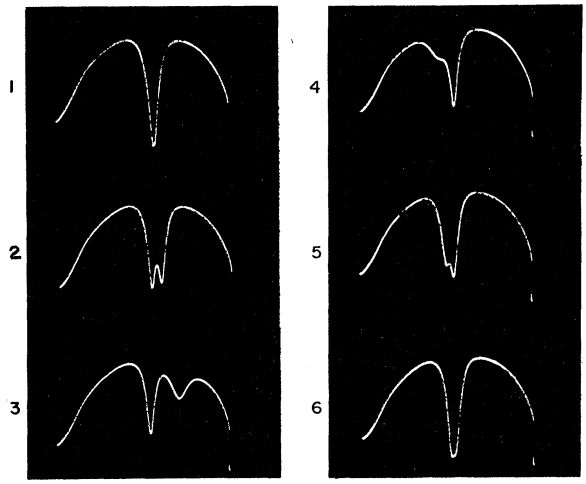

FIG. 1. Splitting of degenerate cavity modes in magnetic field. 1: 0 gauss; 2: 1400 gauss; 3: 2400 gauss; 4: 3600 gauss; 5: 4150 gauss; 6: 4950 gauss.

of introducing a small ferrite sample (Ni—Zn) into a region of maximum H and minimum E fields and applying a dc magnetic field perpendicular to the microwave H vector. The dips represent resonance absorption as seen by observing the microwave signal reflected from the cavity. The horizontal axis is proportional to the microwave frequency. As the dc magnetic field is applied, the single resonance is seen to split into two. The two linear orthogonal modes can be combined into either one of two oppositely rotating vibrations; that mode which rotates in the same direction as the electron spin precession may be designated as the "extraordinary mode." As expected from theory, the frequency shift of the extraordinary mode at first increases with the field; it then becomes negative beyond resonance, reappearing on the other side of the so-called ordinary mode. At approximately twice the resonance field the two modes coalesce again.

A plot of frequency shift *vs* magnetic field is shown in Fig. 2. It has the dispersion character described above. The solid curve is the frequency shift derived from theory[4] and has the form

$$\Delta\omega = C\omega(x'+k') = C\omega_r M/(H_r - H),$$

where x' and k' are the real parts of the diagonal and off-diagonal tensor components, respectively; ω_r is the fixed cavity resonant frequency; H_r is the magnetic field corresponding to gyromagnetic resonance at ω_r ($\gamma H_r = \omega_r$, where γ is the gyromagnetic ratio); C is a constant depending on the cavity geometry and size of ferrite; and M is the saturation magnetization, which is measured

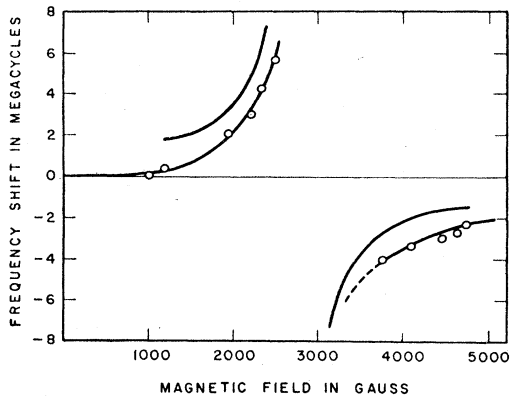

FIG. 2. Frequency shift of "extraordinary" mode due to ferrite in a dc magnetic field. Solid line is theoretical curve.

independently. Because it neglects resonance losses, the seconds equality holds provided H is not close to H_r.

The complete perturbation theory also gives expressions for the frequency shift of the ordinary mode and for the changes in Q of the ordinary and extraordinary modes as a function of magnetic field. The ordinary shift is too small to be measured accurately by our present frequency measuring techniques. We have qualitatively verified the changes in Q, but data which are interpretable in terms of the theory have been limited so far to the small region of H between saturation of the sample and resonance. At K-band frequencies this region would be extended because resonance occurs at a higher magnetic field strength. We have constructed a K-band cavity and have demonstrated the splitting effect.

Experimental refinements are in progress which we expect will make possible complete determination of the permeability tensor components.

We should like to express our thanks to Dr. Benjamin Lax for his stimulating interest.

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Thermal Acceptors in Vacuum Heat-Treated Germanium

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WE wish to report studies on the solubility of thermal acceptors in copper-free germanium. Finn[1] has shown by measurements using radioactive copper as well as by electrical measurements that copper can be evaporated from germanium in high vacuum. In order to take advantage of evaporation as a means of purifying the germanium before heat treatment, we heat our specimen at a pressure of less than 4×10^{-7} mm of Hg by passing current directly through the germanium. Only the germanium becomes hot; and the possibility of contamination of the germanium is greatly reduced because the walls of the vacuum chamber cannot act as a source of impurity atoms as might the hot walls of a conventional vacuum furnace.

The germanium single crystal has dimensions $0.10\times0.33\times1.10$ cm and tantalum current leads are welded to its ends. Hall measurements give a value of the excess of donor impurities over