An Electrical Quadrupole Moment of the Deuteron*

The molecular beam magnetic resonance method[1] applied to HD molecules at liquid nitrogen temperature gives the magnetic moment of the proton and the deuteron. When applied to H_2 and D_2 molecules the method reveals the close groups of sharp resonance minima shown in Figs. 1 and 2. The resonance minima for H_2 agree in number and location with predictions based on the assumption of spin-spin magnetic interaction of the two protons $(\mu_1 \cdot \mu_2/r^3 - 3(\mu_1 \cdot r)(\mu_2 \cdot r)/r^5)$ and a spin-orbit interaction of the protons with the rotation of the molecule $(2\mu_P \bar{H} I \cdot J)$. All symbols here have their usual significance except $\bar{H}$ which is the spin-orbit interaction constant. The only state of the molecule to be considered is the lowest rotational state of orthohydrogen: $J=1$ and total nuclear spin $I=1$. The nine energy levels which arise from these interactions and from the external magnetic field give six possible transitions for the nuclear spin because $\Delta M_N = \pm 1$. The pattern can be accounted for completely on the basis of the known value of the proton moment $(\mu_P = 2.78)$ with the known value of the internuclear distance and a value for $\bar{H}$ of 27 gauss.

In the case of D_2 the deep central minimum arises from the states with $I=2$ and $J=0$. The six smaller peaks arise from the states with $J=1$ and $I=1$. The states with $J=2$ are not abundant enough at these low temperatures for observation. Since the internuclear distance in the D_2 molecule is the same as in H_2 and the mass is twice as great the spin-orbit interaction constant $\bar{H}$ is half as great. The deuteron magnetic moment $(\mu_D = 0.853)$ is 0.307 times

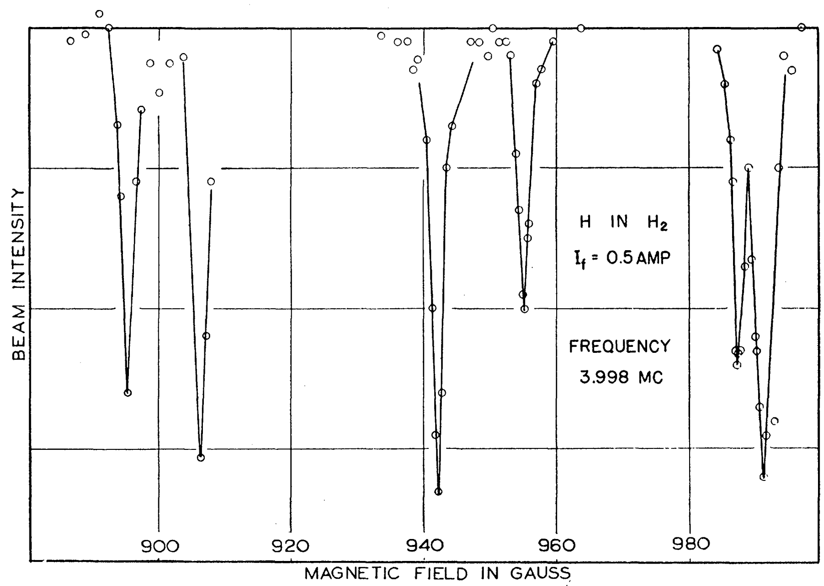

FIG. 1. Resonance minima for H in H_2.

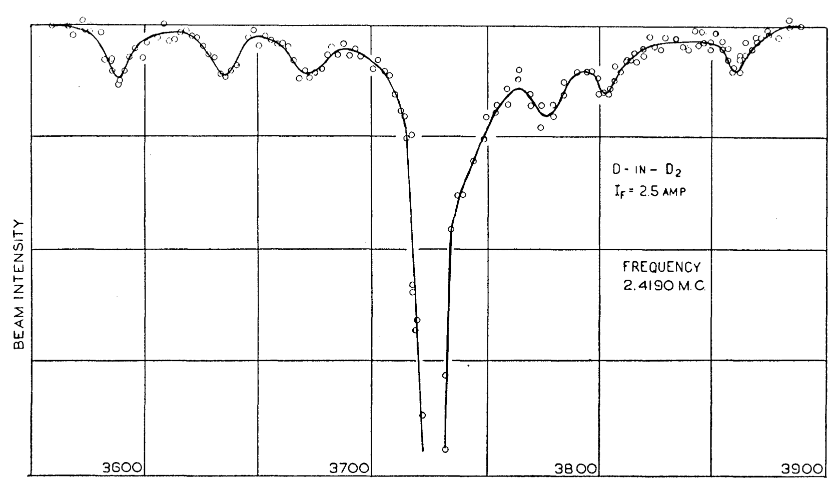

FIG. 2. Resonance minima for D in D_2.

that of the proton and therefore the magnetic spin-spin interaction is proportionately smaller. It was expected that the theory of the resonance minima for H_2 when applied to D_2 should give the locations of the minima from the constants given above. The displacements of the minima from the center should be much less than those of H_2. However experiment shows the displacements to be six times greater than the predicted values.

This effect can be accounted for by the presence of an electrical quadrupole moment in the deuteron. The interaction energy which gives rise to the large displacements is that of the nuclear quadrupole moment with the gradient of the molecular electric field. This form of interaction contributes to the nine energy levels exactly as the spin-spin and therefore appears as a larger spin-spin interaction.

To prove that the large displacements in D_2 are of nuclear origin rather than molecular, similar experiments were performed on the proton and the deuteron in the HD molecule. The group of resonance minima for H was narrow as expected and that for D had large displacements as in D_2. Furthermore, the experimentally evaluated spin-orbit interaction constant for D_2 is one-half as great as that for H_2 as predicted. We therefore believe that the apparent large spin-spin interaction is not magnetic, nor is it of molecular origin and must be a nuclear effect which behaves like a quadrupole moment.

To obtain the magnitude of this quadrupole moment one must know the molecular electric field. This value can be calculated from the various wave functions which have been suggested for the hydrogen molecule. The result of such a calculation by Dr. A. Nordsieck with Wang wave functions when combined with our data yields a quadrupole moment $Q=(3z^2-r^2)_{\mathrm{Av}}$ of about 2×10^{-27} cm^2. The chief source of error lies in the inaccuracy of the wave functions.

The sign of the quadrupole moment may also be inferred from our measurements in two ways. Present indications are that it is positive, that is, the charge configuration is prolate along the spin axis. Full details of these experiments will be published later in this journal.

We are greatly indebted to Dr. Nordsieck for making available to us the results of his calculations and to Dr. Brickwedde of the National Bureau of Standards for preparation of the sample of pure HD used in the experiments. The experiments were supported in part by a grant from the Research Corporation.

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Thermal Dilatation of Superconductors

In recent years there has been much speculation as to the underlying cause of the superconducting state of metals, and many experiments have been performed to investigate possible abrupt changes in other physical properties of materials in passing through the transition temperature. In 1925 Sizoo and Onnes[1] reported that the application of pressure lowered the transition temperatures for tin and indium, which indicated that metals may expand on passing into the superconducting state. This possibility was investigated by McLennan, Allen and Wilhelm[2] in 1931. They measured the thermal dilatation of lead and Rose's metal in the neighborhood of their respective transition temperatures, but when they plotted the thermal dilatation against the temperature they obtained essentially smooth curves and, hence, concluded that there was no discontinuity in the thermal dilatation at the transition temperature. As recently as 1934[3] and 1935[4] their work was still being quoted as providing evidence that no discontinuity exists in this region. As a matter of fact, when their data are plotted on a magnified scale, as illustrated in Fig. 1, we see that there appears to

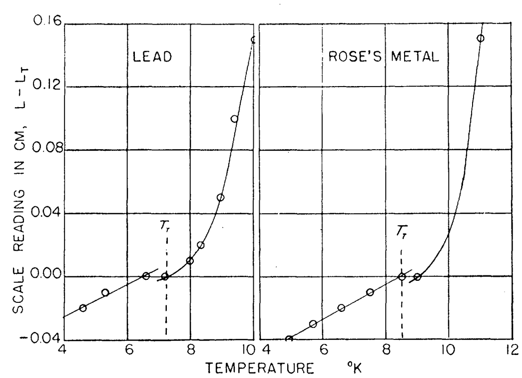

FIG. 1. Thermal expansion curves.

be a discontinuity which is just within the range of resolution of their apparatus. Since the magnitude of the apparent discontinuity is of the order of one unit in their last significant figure, their experiments cannot be accepted as definitely demonstrating its existence. The mutual consistency of the two curves, however, does seem to indicate that the discontinuity is real, and makes it appear desirable to repeat the experiment with somewhat more refined apparatus and to obtain a larger number of points in the immediate neighborhood of the transition temperature. From their report, the Toronto group seem to have pushed the sensitivity of the optical lever almost to its limit, however, there is the possibility of developing other methods such as one involving the displacement of interference fringes for monochromatic light reflected from mirrors attached to the ends of a superconducting metal rod.

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May 12, 1938.

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