

FIG. 1. A comparison of the theoretical dispersion curves with the experimental results of Brockhouse and Iyengar.

fect is that the calculated frequency of the LA mode is too low when  $\bar{q}$  is near the zone boundary in the [111] direction.

It is remarkable that such a simple model should fit the data as well as it does. Our procedure, however, finds theoretical backing in the work of Mashkevich and Tolpygo.<sup>13</sup> Using the Hartree-Fock and adiabatic approximations, they have shown that the energy perturbation should be expressed as a quadratic function of the nuclear displacements and the atomic dipole moments. It

can be shown that the shell model represents the most general (and probably the simplest) way of accomplishing this.

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## DETECTION OF COLLOIDAL CENTERS IN LITHIUM HYDRIDE BY ELECTRON RESONANCE

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This Letter reports electron resonance measurements on lithium hydride which has been irradiated with ultraviolet light and the results show that the lithium hydride contains colloidal centers of lithium metal, with diameters small compared with the microwave skin depth. The lithium hydride was irradiated for about fifteen minutes with 2537A radiation from a 250-watt mercury lamp and a fairly dark coloration was produced. These samples were then inserted in a 3-cm wavelength electron resonance spectrometer employing 100-kc/sec field modulation and phase-sensitive detection, and their electron

resonance spectra recorded. All the irradiated samples gave a single resonance line at  $g=2.002 \pm 0.001$  with a half-width of 0.3 gauss—the latter being determined by the magnetic field inhomogeneity. In contrast to this, no signals at all were obtained from the unirradiated material.

This very narrow signal shows that the paramagnetic entity cannot be due to normal electron excess centers, which have wide inhomogeneously broadened lines.<sup>1</sup> It was therefore postulated that the absorption was in fact due to the conduction electrons in colloidal particles of lithium. In order to test this hypothesis a careful inves-

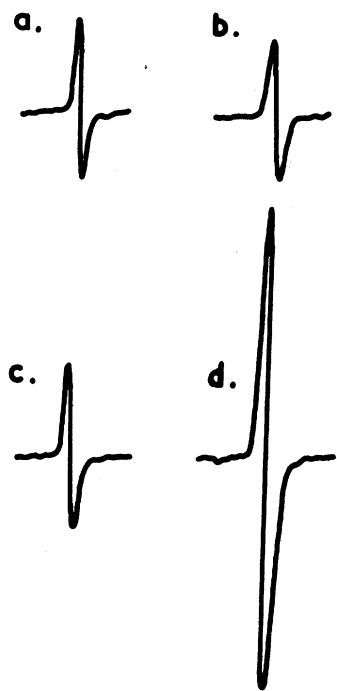


FIG. 1. Electron spin resonance of irradiated LiH. Curves (a) and (b) show the derivative of the absorption signals obtained from LiH and from a standard free-radical sample, respectively, at room temperature. Curves (c) and (d) show the corresponding signals at liquid oxygen temperature.

tigation on the temperature dependence of the intensity of the electron resonance was made, and the results are summarized in Fig. 1. Measurements were made at room temperature and at  $90^{\circ}\text{K}$ , and in each case the curves from the lithium sample and a standard free-radical sample were recorded under identical conditions. It can be seen from the figure that, whereas the intensity of the signal from the free radical increases markedly as the temperature is lowered, as would be expected, that from the irradiated lithium hydride remains constant. The fact that narrow symmetrical electron resonance lines are obtained with intensities independent of temperature shows that they must originate from colloidal particles of lithium with diameters small compared with the skin depth at microwave frequencies.<sup>2</sup>

Further confirmation of the presence of such colloidal particles is obtained from the optical absorption spectra. Optical absorption measurements have been made on a very small single crystal and the differential absorption of the irradiated and nonirradiated crystal is plotted in

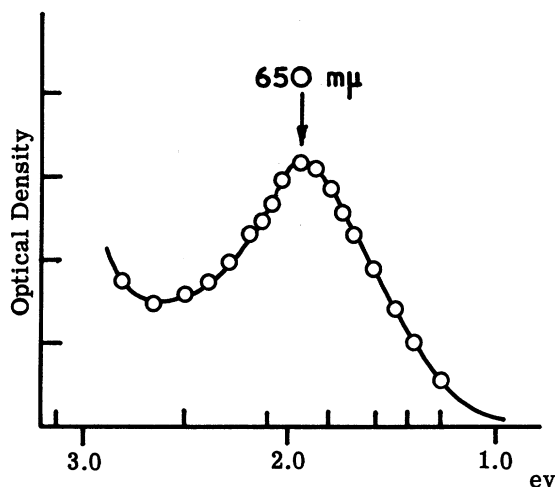


FIG. 2. Differential optical absorption spectrum of irradiated LiH. Optical density is plotted against photon energy in eV.

Fig. 2. It is evident that the irradiation has produced a strong band at  $650\text{ m}\mu$ . The position of this band does not agree at all with the positions predicted for  $F$  or aggregate bands in the hydrides,<sup>3</sup> whereas a strong band at  $2512\text{ \AA}$  has been reported<sup>4</sup> and its position agrees well with that predicted for the  $F$  band. Preliminary estimates on the expected position of the colloid absorption band, based on the index of refraction of the host medium<sup>5</sup> and the plasma wavelength<sup>6</sup> of the alkali metal, can be made, however. These preliminary calculations suggest that, although very small colloidal particles would be expected to give rise to an absorption at a considerably shorter wavelength than  $650\text{ m}\mu$ , it is nevertheless quite possible for the band to be shifted to this region if larger colloidal particles are involved. The electron resonance measurements show that at least  $10^{16}$  unpaired electrons per gram are present in the specimens, and hence a relatively large colloidal content of lithium is present.

The general conclusion is that both the electron resonance and optical absorption spectra show that colloidal centers of metallic lithium are formed when lithium hydride is irradiated with ultraviolet light. It would appear that this may be a very general effect, and initial studies on the thermal and optical decomposition of various azides have also yielded narrow electron spin resonance lines. Further work on these and other centers, employing much more homogeneous magnetic fields, is now in hand so that the

theories relating the width of the lines, the spin-orbit coupling, and the mean free path of the conduction electrons, can be checked in detail.

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### EFFECTIVE EXCHANGE CONSTANT IN YTTRIUM IRON GARNET\*

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We have measured the specific heat of a pure (99.99% yttrium) polycrystalline sample of yttrium iron garnet (YIG) in the temperature range of 1°K to 4°K. We find that the specific heat may be analyzed into a part that depends on temperature as  $T^{3/2}$  (the spin-wave contribution) and a part that depends on temperature as  $T^3$  (the contribution from the lattice) as illustrated in Fig. 1.

We thus obtain

$$C_v = 68.9T^{3/2} + 29.3T^3 \text{ erg/cm}^3 \text{ deg K}, \quad (1)$$

where  $C_v$  is the specific heat per  $\text{cm}^3$  based on

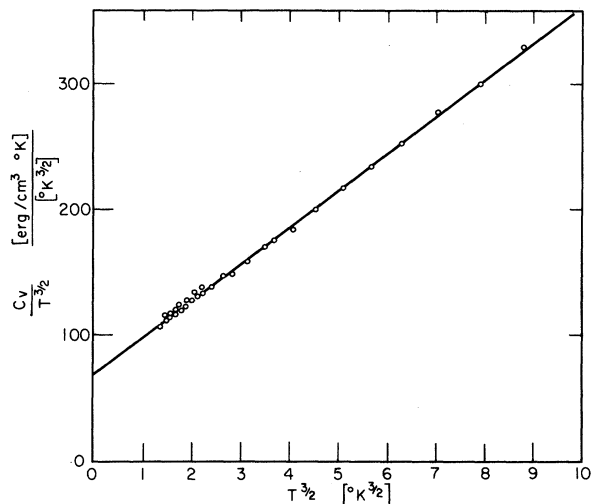


FIG. 1. The specific heat per unit volume of polycrystalline YIG analyzed into its two components by plotting  $C_v/T^{3/2}$  against  $T^{3/2}$ . The points give the results obtained in one experiment. Another experiment performed on the same specimen at the extremes of the temperature range yielded results in agreement with those plotted to within 2%.

the x-ray density<sup>1</sup> of 5.19  $\text{g/cm}^3$ .

Using the equation

$$C_v(\text{lattice}) = (12/5) \pi^4 N k_B (T/\theta)^3, \quad (2)$$

where  $k_B$  is the Boltzmann constant, we obtain for the Debye temperature  $\theta = 454^\circ\text{K}$ , if we take  $N$  to be the total number of atoms of all kinds in unit volume.

Assuming a dispersion relation for the spin waves of

$$\hbar\omega = Dk^2, \quad k = 2\pi/\lambda, \quad (3)$$

one has the standard result for the magnon specific heat per unit volume:

$$\begin{aligned} C_v(\text{magnons}) &= [(15/32)(1.341)\pi^{-3/2}] k_B (k_B T/D)^{3/2} \\ &= 0.113 k_B (k_B T/D)^{3/2}. \end{aligned} \quad (4)$$

The constant  $D$  may be expressed<sup>2</sup> in terms of the Landau-Lifshitz exchange constant  $A$ , the saturation magnetization  $M_S$ , and the spectroscopic splitting factor  $g$  as

$$D = 2Ag(\mu_B/M_S), \quad (5)$$

where  $\mu_B$  is the Bohr magneton. In this manner we obtain from our measurement of the spin-wave contribution to the specific heat,

$$A(\text{YIG}) = 0.192 \times 10^{-6} \text{ erg/cm}, \quad (6)$$

where we have taken the value<sup>3</sup>  $4\pi M_S = 1740$  gauss for YIG. This is to be compared with a value of

$$A(\text{Fe}) \cong 2 \times 10^{-6} \text{ erg/cm}$$

in iron. If we analyze in this manner the results of Kouvel<sup>4</sup> who measured the specific heat of