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[11]It is noted that the $3d$ orbitals in the solid may be hybridized with other orbitals having similar transformation properties, and, as W. Marshall has pointed out to us, their radial extent may be considerably greater than that in the free atom.

INTERACTION OF PHONONS AND SPIN WAVES IN YTTRIUM IRON GARNET

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Schlömann[1] has shown that certain spin wave pairs can be made to grow in amplitude when coupled by a uniform rf magnetic field applied parallel to the dc biasing field. The strength of the rf field required to initiate unstable growth is a measure of the width, ΔH_k, of the spin wave resonance. If a given biasing field is applied to a small sample of ferrimagnetic material in a microwave cavity, measurement of the power level at which the return loss from the cavity changes discontinuously allows one to plot a curve such as Fig. 1. The branch labelled $\theta = \pi/2$ is of particular interest since it corresponds to spin waves of known wavelength propagating in a particular direction. The linewidth of these spin waves is given by[1] $4\pi\gamma M h_{\text{rf}}/\omega_p = \Delta H_k$, where ω_p is the pumping frequency and the wave number, k, of the $\omega_p/2$ spin waves is specified by[2]

$$Dk^2/\gamma\hbar = H_m - H. \tag{1}$$

Here H is the applied dc field and H_m is the limiting value of H for $\frac{1}{2}\pi$-directed spin waves as k approaches zero. Since the ΔH_k of specific spin waves is determined by this experiment, one can check the adequacy of the Kasuya, Sparks, and Kittel[3,4] linewidth theory and measure D at a higher temperature than is possible with other techniques.[5-7] This experiment is still in progress and will be reported on jointly with E. G. Spencer and R. C. LeCraw later.

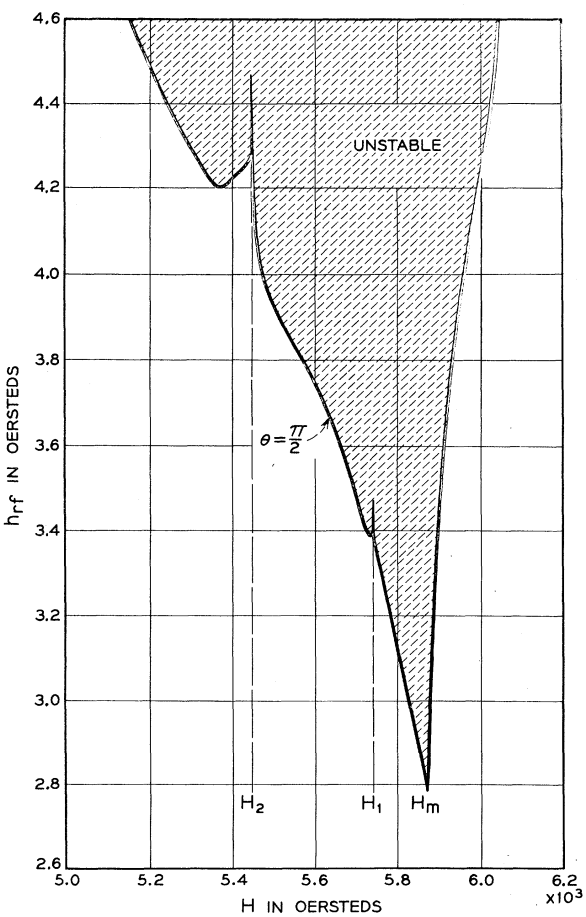

FIG. 1. Rf field strength required to excite spin wave pairs as a function of applied field. Pumping frequency is 34.627 kMc/sec, and fields are along [111] crystal axis.

The magnitude of ΔH_k is shown in Fig. 2 as a function of $(H_m - H)^{1/2}$ for a 0.019-inch yttrium

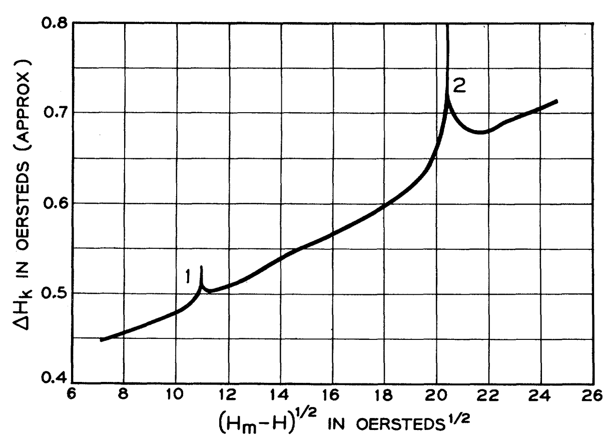

FIG. 2. ΔH_k as a function of $(H_m - H)^{1/2}$. The anomalies are indicated at 1 and 2.

iron garnet (YIG) sphere at 300°K and with a pumping frequency 34.627 kMc/sec. According to the dispersion relation (1), the abscissa should be proportional to k. The value of H_m used is the experimentally observed value. Fortunately, this agrees within experimental error with the theoretical value of H for $\frac{1}{2}\pi$-directed spin waves with $k=0$, so one has some confidence in treating H_m as a known rather than an adjustable parameter. The sharp peaks in ΔH_k at H_1 and H_2 are believed to be caused by coupling of spin waves to phonons[8] of the same frequency $(\omega_p/2)$ and the same $\vec{k}$. A 4.5% reduction in pumping frequency reduced $(H_m - H_{1,2})^{1/2}$ by 4.5%, as it should if the phonon dispersion relation is $\omega_s = vk_s$.

Further evidence on the frequency dependence has been obtained by LeCraw and Spencer who performed the same experiment at 11.4-kMc/sec and 9.2-kMc/sec pump frequencies and found the anomalies in ΔH_k at very nearly the predicted values of H. The deviation from the predicted value indicates that $(\partial\omega/\partial k)$ has decreased slightly at 17 kMc/sec.

The peak in ΔH_k observed at H_2 is seen to be considerably larger than that at H_1. This may be caused by a difference in the nature of the phonons involved in the two peaks or it may be simply that higher k waves are more strongly coupled. The latter argument is supported by the fact that the interaction is considerably weaker at lower frequencies. Examination of the curves near the peak at H_2 shows some distortion associated with the peak, indicating the need to deal with the coupled system of magneto-acoustic waves. The apparent sharpness of the interaction is probably due to the fact that $(\partial\omega/\partial k)$ is very different for the acoustic waves and spin waves at the crossover region and this, rather than the Q of the acoustic waves, is important. The large attenuation constant of the acoustic waves at room temperature primarily reduces the magnitude of the interaction.

Data on the elastic constants of single-crystal YIG are not yet available, but with certain simple assumptions one can use McSkimin's values of sound velocity in polycrystalline material[9]: $v_t = 3.87\times10^5$ cm sec^{-1}, $v_l = 7.17\times10^5$ cm sec^{-1}. If YIG is elastically isotropic, then one can assign the peak at H_1 to longitudinal phonons and the peak at H_2 to transverse phonons since the ratio $(H_m - H_2)^{1/2}/(H_m - H_1)^{1/2} = 1.86$ and $v_l/v_t = 1.85$. Using the relation (1), $D = 0.94\times10^{-28}$ erg cm^{-2} from 11.4-kMc/sec data, or 0.99×10^{-28} erg cm^{-2} from 34.6-kMc/sec data at room temperature. On the other hand, if YIG follows the Cauchy relation for a cubic crystal and we assign both peaks to transverse waves with $v_{t1} = [(C_{11} - C_{44})/\rho]^{1/2}$ and $v_{t2} = (C_{44}/\rho)^{1/2}$, then $D = 0.45\times10^{-28}$ erg cm^{-2} from 34.6-kMc/sec data. These values of D are to be compared with low-temperature specific heat[5-7] values of 0.55×10^{-28} to 0.86×10^{-28} erg cm^{-2}.

Assuming that the observed effects are due to phonons, measurement of the elastic constants of YIG will permit a determination of D as a function of temperature by this method and the magneto-acoustic interaction can be studied rather directly.

It is a pleasure to acknowledge helpful conversations with several colleagues, including I. P. Kaminow, L. R. Walker, and particularly R. C. LeCraw. The author is much indebted to F. Dacey who performed many of the experiments.

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