SPIN-LATTICE RELAXATION IN YTTRIUM IRON GARNET

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(Received December 21, 1959)

Spin-lattice relaxation times have been measured at low temperatures in a sphere of yttrium iron garnet (YIG) grown using the highly purified yttrium oxide.[1] The final polish was Linde-A. The observations indicate the existence of an additional process whose nature is not included in present theories[2] of low-temperature spin-lattice relaxation. These theories indicate spin-lattice relaxation times of the order of a second at 1°K and an exponential temperature dependence of the inverse spin-lattice relaxation times. Our measurements yield a spin-lattice relaxation time of approximately 1.5×10^{-6} sec at 2.5°K and a linear temperature dependence of the reciprocal relaxation time. Since the concentration of rare earth impurity ions has been greatly reduced, the low-temperature linewidth maximum has been almost eliminated.[1] Consequently, attempts can now be made to relate the measurements to the ferric ion lattice. At present, however, the evidence is not sufficient to conclude definitely that we are observing relaxation due to the ferric ion lattice alone.

A technique[3,4] is used in which the microwave source at ferromagnetic resonance is frequency modulated at a frequency much lower than $1/T_1$, T_1 being the spin-lattice relaxation time. The resultant modulation in M_z induces a voltage in a pickup coil around the sample. At a fixed modulation frequency, the second harmonic of this voltage is proportional to ΔM_z which depends on the power absorbed by the sample and upon T_1. Thus, measuring the relative second-harmonic voltage in the coil vs T and χ'' vs T yields the value of T_1. The magnitude of the applied rf field h is essentially constant during the modulation and at all temperatures. The measurements were made for $h<h_{crit}$ in every case.

Because the modulation frequency is lower than $1/T_1$, the magnetization follows the modulation with no phase lag and the steady state discussion in reference 4 applies. We then have

$$T_1=\tfrac{1}{2}T_2[1+\textstyle\sum(T_{1k}/T_{2k})], \qquad (1)$$

where T_1 is the measured spin-lattice relaxation time, T_2 is the measured spin-spin relaxation time, T_{2k} is the coupling time from the principal mode to the kth spin mode, T_{10} is the relaxation time of the principal mode directly to the lattice, and T_{1k} is the relaxation time of the kth spin mode to the lattice. In the absence of spin-wave excitation it follows that

$$2T_1=T_2. \qquad (2)$$

Figure 1 shows $1/T_1$ vs T from 2.4° to 30°K, measured at 9340 Mc/sec. It is convenient to compare $1/\gamma T_1$, in oersteds, with the measured linewidth $\Delta H=2/\gamma T_2$ (full width between half χ''_{max} values). We have then $1/\gamma T_1=44$ milli-oersteds at 2.5°K compared to a measured $\Delta H=2/\gamma T_2=140$ millioersteds. It may be concluded that the 96 millioersteds difference results from scattering into spin waves by surface and volume imperfections. This discussion is given to emphasize that the measured T_1 is the net spin-lattice relaxation of the spin waves and the uniform precession.

In these crystals of YIG, grown from the high-purity yttrium oxide, a certain amount of the low-temperature linewidth maximum is still present. By examining the $\Delta H(T)$ curve in reference 1 for a sample in which the rare earth impurity linewidth predominates at 39°K, we obtain the shape of the low-temperature linewidth maximum due to the impurity spin-lattice relaxation. Using this shape factor and normalizing

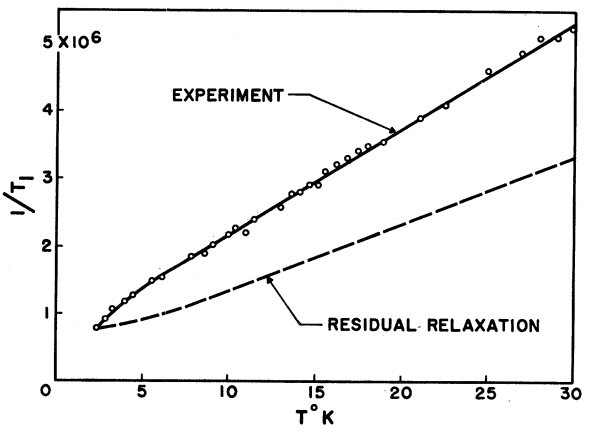

FIG. 1. The upper curve shows the experimental values of $1/T_1$ vs T for yttrium iron garnet. The lower curve shows the residual relaxation after subtracting off the estimated rare earth impurity contribution.

to the high-purity sample, a conservative estimate is that at no point on the curve is more than one-third of $1/T_1$ due to the rare earth impurities. In the figure this contribution to $1/T_1$ is subtracted from the experimental curve to yield a curve of the residual relaxation. The lower curve is then our closest approach to the spin-lattice relaxation time of the ferric ion lattice alone as a function of temperature.

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LOW-TEMPERATURE NEUTRON MODERATION

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(Received December 28, 1959)

Experimental studies show inelastic scattering of very low energy (0.005 ev) neutrons from water at laboratory temperatures.[1] The occurrence of two satellite lines displaced 0.0007 ev from the exciting line is of considerable theoretical as well as empirical interest. The independent observation of an energy level in the microwave spectrum of water vapor supports the neutron measurements.

The spin flip in molecular hydrogen is the principal mechanism accounting for the large incoherent cross section. Early measurements on the ortho and para forms showed that these interactions were not very different for the liquid as compared to the gaseous state. The ortho-para transition requires a change in rotational quantum number as well as reorientation of one proton spin. The transition energy is 0.0075 ev. Considering water to have analogous ortho and para states, the transition energy will be inversely proportional to the moment of inertia of the molecule. The largest moment of inertia of water is 7.2 times that of hydrogen, giving a transition energy of 0.001 ev. The dense environment tends to shift transitions measured in the gaseous state to low energy and is thought to account for the 30% difference between the predicted and observed values.

The importance of these measurements and this interpretation for neutron moderation is great, since this is the only well-defined mechanism for moderating neutrons to temperatures of a few degrees Kelvin. The usual moderation mechanism of coherent scattering from free or bound atoms disappears at the Bragg cutoff for graphite, beryllium, and probably for heavy ice. Phonon scattering is strongly temperature dependent. Liquid helium has an extremely small scattering cross section. The incoherent scattering of hydrogen seems to be one of the few interactions which can be depended upon. Since the hydrogen atoms will be strongly bound, their effective mass will be large and the fractional energy transfer in an elastic process will be small.

Spin-flip scattering inducing rotational transitions in polyhydrogen molecules appears to be an inelastic process whose transition energy can be controlled by the proper choice of molecule. Molecular hydrogen should be effective to temperatures somewhat less than 100°K; water, <10°K; acetylene, <1°K. Methane and higher hydrocarbons should provide a multiplicity of interactions particularly appropriate to the problem.

An estimate of the inelastic process as compared to elastic scattering[1] gives a ratio of cross sections of about ten. The inelastic cross section is, therefore, 8 barns for $HO_{1/2}$ at room temperature.

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