Observation of intrinsic spin-wave relaxation processes in a ferromagnetic material at 4.2 K

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(Submitted 20 July 1981)

Pis'ma Zh. Eksp. Teor. Fiz. **34**, No. 6, 344–346 (20 September 1981)

The dependence of the parameter of the spin-wave relaxation in $CdCr_2Se_4$ on the wave number at 4.2 K has been measured. The three-magnon dipole coalescence process accounts for the main contribution to this dependence for the ⟨100⟩ direction (in which the influence of fast-relaxing ions is small).

PACS numbers: 75.30.Ds, 75.50.Dd

The intrinsic spin-wave relaxation processes in ferromagnetic materials, i.e., those processes which occur in ideal crystals and, therefore, essentially cannot be eliminated, have been thoroughly investigated theoretically (see, for example, Refs. 1-3). An experimental study of the damping of spin waves in an yttrium-iron garnet (YIG)[4] showed that in high-quality single crystals of this ferromagnetic material, which contain a small amount of impurities, the contributions of the inherent three- and four-magnon processes to spin-wave damping are important at temperatures above ~100 K. The dependence of the spin-wave relaxation parameter $2\Delta H_k$ on the wave number k is almost completely determined by these processes at these temperatures.

As the temperature is decreased, however, the contributions of the intrinsic processes decrease rapidly, and at liquid-helium temperature the damping of spin waves in YIG is determined by extrinsic processes–those caused by fast-relaxing impurity ions and by scattering on inhomogeneities.[5] Until now, the contribution of intrinsic relaxation processes to spin-wave damping at low (helium) temperatures has not been observed in other materials. These contributions should increase with decreasing inhomogeneous-exchange constant D. In particular, the contributions of three-magnon dipole coalescence and splitting processes[1] and of the four-magnon exchange process[2,3] are proportional to D^{-2}. Therefore, they can be detected more easily in materials with a small D. The ferromagnetic material $CdCr_2Se_4$ is such a material. Its D value, which was determined[6] from the temperature dependence of magnetization,[7] was equal to 3.35×10^{-10} Oe • cm^2. This value is smaller than that for YIG by more than an order of magnitude.

The spin-wave relaxation parameter $2\Delta H_k$ was determined by measuring the parametric-excitation thresholds of spin waves for longitudinal pumping at a frequency of 9.4 GHz; a dielectric cavity was used to reduce the required oscillator power and increase the sensitivity. Such measurements had also been made previously[6] in $CdCr_2Se_4$, but the poor quality of the crystal prevented a reliable isolation of

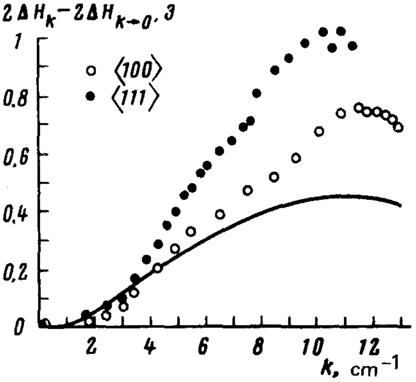

FIG. 1. Dependence of the spin-wave relaxation parameter on k for a $CdCr_2Se_4$ single crystal. The points correspond to an experiment for two directions of the constant magnetic field; the solid line represents the calculation for three-magnon dipole coalescence. $T = 4.2$ K.

the intrinsic relaxation processes. In our work we used a high-quality single crystal which was grown by using the gas-transport method[8] and which had an exceptionally narrow ferromagnetic-resonance line [1.6 Oe for the ⟨100⟩ direction in the temperature range 7–80 K (Ref. 9)].

The results of measurement of the k dependences of $2\Delta H_k$ at liquid-helium temperature are shown in Fig. 1. This figure also shows the result of a calculation of the contribution of three-magnon dipole coalescence according to Ref. 1. The four-magnon exchange scattering in this case (low temperature and high magnetization) is smaller by three orders of magnitude, and the three-magnon splitting is forbidden by the conservation laws for $k < 1.27 \times 10^6$ cm^{-1}. It was shown previously[4] that the results of calculations of the contribution of three-magnon coalescence agree well with the experimental data (for YIG) at comparatively high temperatures. In this case (low temperature and high magnetization), however, the approximations used in Ref. 1 are not as good, and the calculation is approximate in nature.

First, it can be seen in Fig. 1 that there is an anisotropy of the k-dependent part of the spin-wave relaxation parameter. The steepest $2\Delta H_k$ (k) dependence is observed for the ⟨111⟩ direction, for which there is a peak of the angular $2\Delta H_{k\to 0}$ dependence,[9] which is caused by the fast-relaxing Cr^{2+} ions. For the ⟨100⟩ direction, in which the Cr^{2+} ions exert almost no influence, the calculated (for the three-magnon dipole coalescence process) and experimental dependences of $2\Delta H_k - 2\Delta H_{k\to 0}$ on k differ little up to $k \sim 5 \times 10^5$ cm^{-1}, and subsequently the difference between them reaches 40%. Since the calculation is approximate in this case, we can conclude that the three-magnon dipole coalescence process contributes significantly to spin-wave damping. For the direction (⟨100⟩) in which the ion contribution is small, this process determines the dependence of $2\Delta H_k$ on the wave number.

Thus we have observed presumably for the first time the contribution of the intrinsic relaxation process, i.e., three-magnon dipole coalescence, to the spin-wave damping in a ferromagnetic material at liquid-helium temperature.

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Translated by Eugene R. Heath
Edited by S. J. Amoretty