POSSIBLE EXISTENCE OF "SECOND" SPIN WAVES IN FERROMAGNETS

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Many authors have advanced the opinion that "secondary" excitations can exist in the elementary-excitation "gas" describing the weakly-excited state of any many-particle system. Examples of such excitations are second sound in liquid helium II [1] and in solids [2], where it constitutes excitations in a system of "primary" elementary excitations, namely phonons.

We consider in this note the possible existence of secondary excitations in the system of elementary excitations in a ferromagnet - a system of magnons. In analogy with second sound, we shall call these secondary excitations "second spin waves," to distinguish them from the "first" waves, which are the magnons themselves.

Neglecting magnetic dipole-dipole interaction between the spins of the atoms, and also the spin-orbit interaction, the law governing the magnon dispersion coincides with the law of dispersion of ordinary nonrelativistic free particles with mass [3]

$$m^* = \frac{h^2}{2Ia^2} \tag{1}$$

where I is the exchange integral, equal in order of magnitude to $\kappa\theta_C$ (θ_C - Curie temperature, κ - Boltzmann's constant), and $\underline{a}$ is the lattice constant. The interaction of magnons with one another and with phonons [1)] is described by two scattering processes: (i) collisions of the magnons with one another, in which the number of particles is conserved (in complete analogy with elastic collisions between molecules in an ordinary gas), and (ii) scattering with a change in the number of magnons, i.e., in the total magnetic moment of the system. As shown in [3], in the temperature region

$$\theta_C \gg T \gg \theta_C \left(\frac{\mu M_0}{\kappa_C}\right)^{4/7} \tag{2}$$

(μ - elementary magnetic moment of the order of the Bohr magneton, M_0 - saturation magnetic moment of the ferromagnet), processes of type (i), which are connected with the exchange interaction between magnons, are much more probable than processes of type (ii), which are due mainly to magnetic dipole interaction, to the anisotropy energy, and to the interaction between the magnons and the phonons. Thus, in this temperature range, the magnon gas in the ferromagnet is perfectly analogous to a gas of molecules that collide relatively frequently with one another and only rarely experience inelastic collisions accompanied generally speaking by a change in the number of particles (say, adhesion to the walls of the vessel and detachment from the walls after some time). Weakly damped longitudinal sound waves can propagate in such a gas. For reasons indicated above, we shall call these waves in the magnon gas "second spin waves."

It is easy to estimate immediately the velocity (v_{II}) of the second spin wave by replacing m in the expression for the speed of sound ($S \cong \sqrt{[\kappa T/m]}$) in a gas of molecules with mass m by the quantity m^* from (1):

$$v_{II} = (a/h)\sqrt{[2\kappa TI]} \cong (a\kappa/h)\sqrt{[2T\theta_C]} \qquad (3)$$

At room temperature, the velocity v_{II} for most ferromagnets is on the order of 10^6 cm/sec.

If we assign to the processes of "elastic" scattering of magnons by one another (processes of type (i), see above) a relaxation time τ_1, and to scattering processes of type (ii) a time τ_2 (in the temperature region which we are considering $\tau_2 \gg \tau_1$), then in the frequency region

$$\frac{1}{\tau_2} \ll \omega \ll \frac{1}{\tau_1} \qquad (4)$$

the customary quasihydrodynamic description is perfectly applicable to the second spin waves (see, for example, [4]). In typical cases (see [3]) $\tau_1 \cong 10^{-13}$ sec and $\tau_2 \cong 10^{-6}$ sec, so that the frequency range (4) is quite broad. Introducing the hydrostatic "pressure" of the magnons and linearizing the system of hydrodynamic equations relative to a small variable increment (n) in the magnon density, we obtain for n the equation

$$\frac{\partial^2 n}{\partial t^2} - \frac{1}{\tau_2} \cdot \frac{\partial n}{\partial t} - v_{II}^2 \Delta n = 0 \qquad (5)$$

where the velocity v_{II} is given by (3). Thus, neglecting attenuation, the dispersion law for the second spin waves is of the form

$$\omega = v_{II} k \qquad (6)$$

(k - wave number, ω - wave frequency), i.e., it is linear, as expected.

It is easy to see that the second spin waves should manifest themselves as macroscopic waves of the magnetization, of the spin specific heat (or the spin "temperature"), and of similar thermodynamic quantities. Measurement of the velocity of second spin waves could yield independent information on the magnitude of the exchange integral I. In addition, we can apparently expect a unique resonant interaction in a crystal between second spin waves and ordinary sound waves that also possess a linear dispersion law and a nearly equal propagation velocity.

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[2] M. Chester, Phys. Rev. 131, 2013 (1963).

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[4] V. L. Ginzburg, Rasprostranenie elektromagnitnykh voln v plazme (Propagation of Electromagnetic Waves in a Plasma), Fizmatgiz, 1960.

1) We are considering an ideal ferromagnetic dielectric, where the only elementary excitations apart from magnons are phonons.