s-f exchange mechanism of magnon generation in an antiferromagnetic in a quantizing magnetic field

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There have been many studies, both theoretical and experimental,[1, 2] of spin waves emitted in a ferromagnetic by charged particles moving at a sufficiently high velocity. In particular, the Cherenkov mechanism of magnum generation by conduction electrons moving at a speed $\boldsymbol{v}>\boldsymbol{v}_s$ (where $\boldsymbol{v}_s$ is the spin wave phase velocity) has been disussed.[2] It was assumed that the main contribution to the emission comes from the relativistic interaction

$$H = -\frac{e}{m^* c} A(r)\hat{P}, \tag{1}$$

where $\boldsymbol{A}(\boldsymbol{r})$ is the vector potential of the field due to magnetization oscillators; $\hat{P}$ and $\boldsymbol{m}^*$ are the carrier momentum and effective mass. An important point is that the contribution to the emission from the ***s-f*** exchange interaction is zero here because of the conservation of the total angular momentum of the system at $\boldsymbol{T}=0$.

The situation is quite different for carriers in an antiferromagnetic. Here, the total number of magnons at $\boldsymbol{T}=0$ in the system consisting of the electron and the magnetic atom spins is not an integral of the motion, and the main contribution to the emission comes from the ***s-f*** exchange interaction

$$H = -A(S_r, \sigma(r)), \tag{2}$$

where $\boldsymbol{A}$ is the ***s-f*** exchange constant and $\boldsymbol{S_r}$ the magnetic atom spin. The effect is most noticeable in a strong magnetic field, when the quantization of the conduction electrons in the field has to be taken into account. For an antiferromagnetic in a quantizing magnetic field, the magnon generation rate γ is governed by the decay in the electron spectrum state; with the results of a previous paper,[3] we have

$$\gamma_k = \frac{2\pi}{\hbar} \sum_q C_q^2 \delta\left(\varepsilon_{k_z} - \varepsilon_{k_z - q_z} - \omega_q\right), \tag{3}$$

where $\varepsilon_{k_z} = \hbar^2 k_z^2 / 2m^*$ is the unrenormalized energy of a conduction electron. In the extreme quantum limit, when the approximation of the first Landau level is valid, we have[3]

$$C_q = \frac{A}{4\sqrt{2}} \sqrt{\frac{S}{N}} (qa)^{1/2} \left(1-h^2\right)^{1/4} exp\left\{-\rho_0^2 q_\perp^2 / 4\right\}, \tag{4}$$

where $\boldsymbol{h}=\boldsymbol{H}/\boldsymbol{H_c}$; $\boldsymbol{H_C}$ is the antiferromagnetic spin flip field $\rho_0 = \sqrt{c\hbar / eH}$ is the magnetic length; $q_\perp^2 = q_x^2 + q_y^2$. When the electron velocity exceeds the spin wave velocity, $\boldsymbol{v} \gg \boldsymbol{v}_s$, the magnon frequency in Eq. (3) may be neglected. Changing from summation there to integration, we get from Eqs. (3) and (4)

$$\gamma = \frac{\sqrt{2}}{16\pi} \frac{A^2 S a^4}{\rho_0^3 \hbar v} \sqrt{1-h^2}\, e^b \,\Gamma\left(\frac{3}{2}, b\right), \qquad b = \frac{m^{*2} v^2 \rho_0^2}{8h^2}, \tag{5}$$

where $\boldsymbol{\Gamma}$ **(3/2, b)** is the incomplete gamma function. It follows from Eq. (5) that $\gamma(\boldsymbol{h})$ has a maximum at

$H \approx 0.8H$ and is zero at the transition to the ferromagnetic state in a field $H \geq H_c$. In the limit $b \gg 1$ or $b \gg 1$, we get from Eq, (5)

$$\gamma \approx \frac{1}{16\pi\hbar^3}\left(\frac{a}{\rho_{0_c}}\right)^2 A^2 S m^* a^2 h \sqrt{1-h^2}, \qquad b \gg 1, \tag{6}$$

$$\gamma \approx \frac{\sqrt{2}}{16\pi}\Gamma\left(\frac{3}{2}\right)\frac{A^2 S a^4}{\hbar^2 \rho_{0_c} v} h^{3/2}\sqrt{1-h^2}, \qquad b \ll 1, \tag{7}$$

where ρ_{0c} is the magnetic length corresponding to the spin flip field $\left(\rho_{0_c} = \sqrt{h}\,\rho_0\right)$. To estimate the generation rate, we take $H_C = 2 \cdot 10^7$Oe, $AS = 1$eV, $S = 1$, $a \approx 3\ 10^{-8}$cm, $v = 10^7$cm/sec, $h = 0.1$, $m^* \approx m$. In this case $b \sim 0.1 \ll 1$. Then, from Eq. (6a), the magnon generation rate is $\gamma = 10^{13}$ sec^{-1}. It is easily verified that with these parameter values the weak-coupling conditions[3] are satisfied and so only the interaction terms linear in the magnon operators need be considered.

The s-f exchange mechanism of magnon generation has been proposed earlier[4] for ferromagnetic. As mentioned above, this contribution must be zero at $T=0$. The nonzero result found[4] is due to an incorrect form of the ferromagnetic Hamiltonian; the contribution of the quadratic terms in this case is exactly canceled by that of the terms linear in the magnons.

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