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Spin waves in paramagnetic Boltzmann gases

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Abstract. As the temperature is lowered we get an interesting temperature region $\varepsilon_d \ll T \ll \hbar^2/mr_0^2$ (where ε_d is the quantum degeneracy temperature, m the mass of a gas molecule, r_0 the radius of interparticle interaction) in which the thermal de Broglie wavelength Λ of a particle is considerably greater than its size r_0 though Λ turns out to be less than the mean interparticle distance $N^{-1/3} \gg \Lambda \gg r_0$. Although the gas molecules obey the classical Boltzmann-Maxwell statistics the system as a whole begins to exhibit a large number of essentially quantum macroscopic collective features. One of the most interesting and dramatic features is the possibility of propagation of weakly damped spin oscillations in spin-polarized gases (external magnetic field, optical pumping). Such oscillations can propagate both in the low-frequency $\omega\tau \ll 1$ regime and the high frequency $\omega\tau \gg 1$. The last case is highly non-trivial for a Boltzmann gas with a short range interaction between particles. The weakness of relaxation damping of spin modes implies that the degree of polarization is high enough $1 \geqslant |\alpha| \gg |a|/\Lambda$, where $\alpha = (N_+ - N_-)N$, a is the two-particle s-wave scattering length. Under these conditions the spectrum of magnons has the form (Bashkin 1981, 1984; Lhuillier and Laloe 1982)

$$\omega = \Omega_H + (K^2 v_T^2/\Omega_{\text{int}})(1 - i/\Omega_{\text{int}}\tau), \quad \Omega_{\text{int}} = -4\pi a\hbar N\alpha/m, \quad v_T^2 = T/m, \tag{1}$$

where Ω_H is the Larmor precession frequency for spins in the magnetic field $\mathbf{H}$. Collisionless Landau damping restricts the region of applicability of (1) with not too large wave vectors $Kv_T \ll |\Omega_{\text{int}}|$. The existence of collective spin waves has been experimentally confirmed in NMR-experiments with gaseous atomic hydrogen H↑ (Johnson *et al* 1984). The presence of undamped spin oscillations means automatically the existence of long range correlations for transverse magnetization. Such correlations decrease with the distance according to the power law

$$\delta_{ik}(r) = 2|a| \frac{(\beta N\alpha)^2}{\gamma} \delta_{ik}. \tag{2}$$

Here β is the molecule magnetic moment. Spin waves being even damped can nevertheless reveal themselves at $T \gtrsim \hbar^2/mr_0^2$ or when $|\alpha| \lesssim r_0/\Lambda$. The first experimental discovery or damped spin waves in gaseous ^{3}He↑ has been done in Nacher *et al* 1984. Oscillations of magnetization can also propagate in some condensed media such as liquid ^{3}He-^{4}He solutions, semimagnetic semiconductors etc.

Keywords. Spin waves; Boltzmann gas.

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