MAGNON DROPS: A NEW TYPE OF COLLECTIVE EXCITATIONS OF FERROMAGNET

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Résumé.- On a analysé les équations classiques et quantiques décrivant la dynamique de l’aimantation d’un système ferromagnétique suivant l’”axe facile”. Pour un système tridimensionnel on obtient une solution du type soliton magnétique stable. L’analogue quantique de cette solution est présenté par un état lié d’un grand nombre des magnons (goutte magnétique). Pour un système unidimensionnel, on a trouvé un nouveau type de solitons magnétiques à deux paramètres. Le soliton se déplace à la vitesse \( V \) et le vecteur de l’aimantation qui lui est lié précesse à la fréquence \( \omega \).

Abstract.- Classical and quantum equations describing the intensity of magnetization in the easy axis ferromagnet have been analysed. In a three-dimensional case, a stable magnetic flux solution is obtained. The quantum analogue of this solution is the bound state of a large number of magnons (magnon drop). In the one-dimensional case, a new type of two-parameter magnetic solitons has been found. The soliton moves with a velocity, \( V \), and the magnetization vector precesses in it with a frequency \( \omega \).

Elementary single-particle quantum excitations of a ferromagnet are magnons, which, in case of low density, make up almost ideal Bose gas. Therefore ferromagnet weakly excited states are usually described in terms of almost non-interacting magnons. This kind of description fails in case of strongly excited states contributed to by the magnon-magnon interaction as a major factor. Such states are not restricted to single-particle excitations and automatically become collective.

Strongly excited ferromagnet states are usually described in terms of classical solutions of non-linear equations for the magnetization vector \( \vec{M} \). In the model under consideration, these dynamic equations contain two parameters characterizing the physical properties of the magnet : the exchange constant, \( a \), and the anisotropy constant \( b \) responsible for the "easy axis". Among the non-linear waves, the most interesting are space-localized solitary waves, or solitons. We have shown that the self-localized magnetization wave is a bound state of a large number, \( N \), of magnons. In particular, it was found that in case of a large number of magnons \( (N \gg 1) \), the quantum problem solution indeed changes to the self-localized solution of classical non-linear equations for the magnetization vector. To write out this solution, represent \( \vec{M} \) as

\[
\begin{align*}
M_x &= M_0 \cdot \sin \theta \cdot \cos \phi, \\
M_y &= M_0 \cdot \sin \theta \cdot \sin \phi, \\
M_z &= M_0 \cdot \cos \theta
\end{align*}
\]

where \( M_0 = 2 \mu_0 S/a^3 \), \( \mu_0 \) is the Bohr magneton magnitude, \( a^3 \) - the unit cell volume, \( S \) - the atom spin.

The magnetic soliton is a solution of equation (1) having \( \theta = 0 \) at the infinity and \( \theta \neq 0 \) in a finite region of space.

In the three-dimensional case, the following solution was considered :

\[
\begin{align*}
\theta &= \theta(\tau), \\
\phi &= \text{cst} \quad (\tau^2 = x^2 + y^2 + z^2),
\end{align*}
\]

where angle \( \theta(\tau) \to 0 \) with \( |\tau| \to \infty \). Figure 1 shows plots for \( \theta \) for different frequencies \( \omega \). These states correspond to a new branch of the system excitation spectrum, namely to collective type excitations (magnon drops). Figure 2 shows the \( \omega-N \) relation for the magnon drop, the lower and the upper branches representing stable and unstable states, respectively. The magnon drop is characterized by energy \( E \) depending in a certain manner on \( N \) so that the energy amount per magnon, \( \epsilon \), in a stable bound state \( (E = cN) \) is lower than the free magnon energy (figure 3).

In the one-dimensional model, an explicit
analytical solution was obtained, as

\[ \theta = \theta (x - Vt), \quad \phi = \psi (x - Vt) + \omega t, \]

where \( \theta (x) = 0 \) for \( |x| \to \infty \) and \( V \) is the magnetic soliton velocity.

A comparison was made with results of an investigation of exactly soluble quantum magnet models.

Clearly, a magnon-drop-type state can exist only under an external action which can make up for the "destruction" of the drop due to relaxation in the magnet.

An analysis of the magnetic system enabled a conclusion concerning any non-ideal gas of Bose quasi-particles in the three-dimensional case. For any weak attraction of the gas quasi-particles, there is always such their number which is the lower margin of a quasi-particle group capable of making up a bound state.