Solitons in a bound electron-nucleus magnetic system of an antiferromagnetic $CsMnF_3$

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A narrow line of the emission at the frequency between the natural frequencies of the stable states was detected in the bistable region of an antiferromagnet $CsMnF_3$ with strongly coupled nuclear and electronic magnetic systems. This line is assumed to correspond to the solitons in the nonequilibrium system of nuclear spin waves.

A strong dynamic coupling between a nuclear magnetic system and a magnetically ordered electronic system produces a low-frequency elementary excitation branch in a hexagonal antiferromagnet $CsMnF_3$ ($T_N = 53$ K). This branch is described by the expression[1,2]

$$\omega_n^k = \omega_{n0}\left[1 - \frac{2\gamma^2 H_E H_N}{\gamma^2(H^2 + 2H_E H_N) + v^2 k^2}\right]^{1/2}, \tag{1}$$

where ω_{n0} is the frequency of the nuclear magnetic resonance in the hyperfine field of the electronic system in the absence of a dynamic coupling ($\omega_{n0} = 666$ MHz), H_E is the effective exchange field, γ is the gyromagnetic ratio for the electronic system, H_N is the effective field produced by the nuclear magnetic system due to the hyperfine interaction at the antiferromagnetic sublattices, H is the external magnetic field, and v^2k^2 is the spatial dispersion term of the antiferromagnetic system. The effective field H_N is directly proportional to the average magnetization of the nuclear system. This quantity can easily change when the nuclear system becomes saturated by an rf magnetic field, which accounts for the strong nonlinearity of this branch of the spectrum.

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The bound electron-nucleus magnetic systems were studied in detail by one of the authors[3] in the particular case of the antiferromagnetic $MnCO_3$. The principal nonlinearity-induced effects are as follows.

1. In an rf field, which saturates the nuclear magnetic resonance at frequencies in the range $\omega_n^0 < \omega < \omega_{n0}$, the system can be in two stable states. One of these states corresponds to low power levels when $\langle m\rangle \approx \langle m\rangle_T$, where $\langle m\rangle_T$ is the average magnetization which is at equilibrium at the given temperature. The frequency of the nuclear resonance, which is specified by the external conditions, is generally not equal to the frequency of the exciting field. In the other state (high power level) the nuclear magnetic system is saturated to the level $\langle m\rangle_\omega$, which corresponds to the solution of Eq. (1) if the condition $\omega_n^0 \approx \omega$ holds (within the line width) ($\omega_n^0 \equiv \omega_n^k$ for $k=0$).

2. In a certain range of the saturating power, the system is bistable, i.e., it may be in either one of the two states described above, depending on its previous history, or it even may break up into domains of various states.

We have shown elsewhere[4] that a transition from an unsaturated state to a saturated state can be achieved as a result of a parametric excitation of the nuclear spin waves with $k \neq 0$ [Eq. (1)] by parallel pumping. In this case the saturation is achieved in a nonresonant manner through the nuclear-spin-wave system, a procedure which is more indirect and presumably more controllable. Both are steady states and the transition between them in this case is determined by the subtleties of the relaxation of the nuclear spin waves and their spectrum.

In $CsMnF_3$ this process may occur continuously, where the average nuclear magnetization changes its value from $\langle m\rangle_T$ to $\langle m\rangle_\omega$ and also in a continuous manner as a result of the change in the pumping power level, and also spasmodically accompanied by a hysteresis. The manner in which this process behaves depends on the direction of the external magnetic field in the basal plane of the sample ($CsMnF_3$ has a hexagonal symmetry).

We studied the emission spectrum of the sample at a minimum pumping level at which the saturated state of the nuclear magnetization still exists ($\langle m\rangle \approx \langle m\rangle_\omega$). The experiment was carried out at a temperature of 1.24 K in a magnetic field $H = 3.2$ kOe. The $CsMnF_3$ sample, a rectangular parallelepiped ($3\times2\times1$), was inserted into a spiral resonator in which the pump magnetic field was excited at a frequency $f_p = 1126$ MHz. A coil, which received radiation from the sample at a frequency of approximately $f_p/2$, was wound around the sample perpendicularly to the spiral resonator turns. This coil was connected by means of a coaxial cable either to a spectrum analyzer or to a device that measured the amplitude and frequency characteristics. In the first case we monitored the emission spectrum of the sample at a frequency of approximately $f_p/2$ and in the second case we controlled the position and shape of the NMR line ($k=0$). The external magnetic field was produced by an electromagnet. The static magnetic field, the polarization of the pump magnetic field and the polarization of the field received by the coil were positioned in a horizontal plane; the sixfold axis of the sample ran vertically.

Figure 1 is a plot of the spectrum of radiation from the sample at a frequency of $\sim f_p/2$ as the magnetization of the nuclear system is changed from $\langle m\rangle_\omega$ to $\langle m\rangle_T$

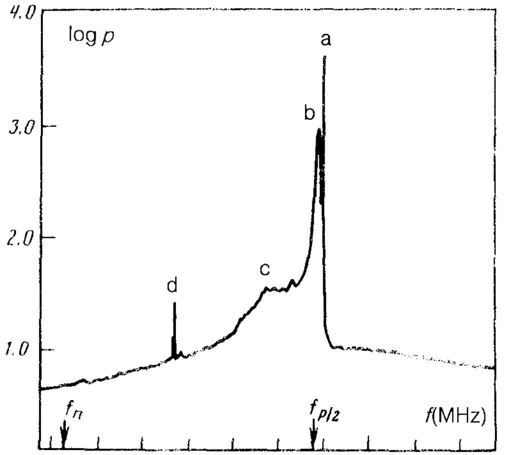

FIG. 1. Spectrum for the emission from a sample with parallel pumping at the frequency 1126 MHz in the existence domain of the d line.

upon approaching the critical power level. If $(2\pi f_p/2) \neq \omega_n^0$, the system emits radiation only in the superheated state $\langle m\rangle < \langle m\rangle_T$. The richest emission spectrum occurs when the external conditions correspond to those in Fig. 1 and those near it. Line (a), which corresponds to the frequency $f_p/2$, can be interpreted in a straightforward manner. This line corresponds to the emission of parametrically excitable magnons with a wave vector $k \approx 0$. The emission at other frequencies may be related to the crystal domains with a time-varying average nuclear magnetization or it may be due to a fluctuation, or motion in a domain with a magnetization different from $\langle m\rangle_\omega$. The emission regions (b) and (c) may be attributed to the fluctuational part. Here we call attention to line (d).

In contrast with the emission lines (b) and (c), line (d) has a narrow frequency width. This line is at the very least on the order of 30 kHz, consistent with the transmission band of the spectrum analyzer. The emission frequency of line (d) depends on the pump power (Fig. 2). When the power level at which this line can exist is

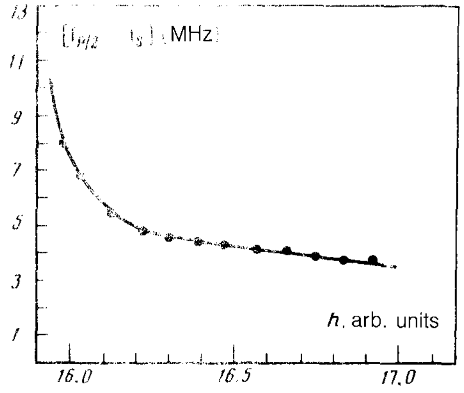

FIG. 2. Emission frequency of the d line (Fig. 1) versus the amplitude of the pump field.

maximum, the line appears on the left side of line (c). Therefore, the emission frequency decreases with decreasing power level, and line (d) moves uninterruptedly toward the position of the unshifted NMR line ($\langle m \rangle = \langle m \rangle_T$). Line (d) vanishes when the nuclear system undergoes a transition to a state which is at equilibrium with the lattice.

In the case of parallel pumping of nuclear spin waves near the critical power level at which the nuclear magnetization is restored before it reaches the value $\langle m \rangle_T$ which is at equilibrium with the lattice, $CsMnF_3$ will therefore have domains (or a single domain) that emit a magnetic field in the form of single narrow line at a frequency between ω_n^0 and $\omega_p/2$. The frequency of this radiation depends on the pump power level. These domains may be parts of a crystal whose nuclear magnetization is greater than $\langle m \rangle_\omega$. Their natural frequency may be determined by either the magnetization intermediate between $\langle m \rangle_\omega$ and $\langle m \rangle_T$, which changes with changing pump power level, or by the linear dimensions of the domains (due to the spatial dispersion), which also vary with the pump power level. Both these factors, in combination with the experimental features of line (d), give us a conceptual understanding of the soliton nature of the object responsible for this radiation.[5]

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