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SELF-INDUCED TRANSPARENCY IN 1D MAGNETICS

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The evolution of spin system with the Fermi character of the relevant excitations under the strong magnetic field pulse is presented. The nonlinear dynamic equations describing interaction of the system and external magnetic field are found. It is shown that under certain conditions the initial state of the resonantly absorbing system does not change after passing of the field pulse (similar to optical self-induced transparency in two-level molecular gas).

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In condensed medium with delocalized excitations, microwave collective mode propagation may be accompanied in some cases with forming of special nonlinear excitations — resonance solitons (sound one in superconductors, helicons in metals). The fact that resonance solitons exist means that the self-induced transparency effect [1] arises. In this paper we have proved the resonance soliton existence in chain system of interacting spins. These solitons may be formed under the electromagnetic field and spin modes interaction in magnetic system. As follows from our results as well as from [2, 3] the self-induced transparency arises if the elementary excitations of condensed medium are Fermi-type. In a one-dimensional spin XY-system elementary excitations are fermions which naturally determines the choice of this model as an object of our investigation.

Let us consider the one-dimensional XY-system in magnetic field which is described by the Hamiltonian

$$H = -\sum_n \left(J_x S_n^x S_{n+1}^x + J_y S_n^y S_{n+1}^y + 2\mu h(na,t) S_n^z\right), \tag{1}$$

here $\boldsymbol{S}_n$ is the spin operator at site n ($S = 1/2$), J_x, J_y are the exchange constants, a is interatomic distance, $h(\xi,t)$ is nonuniform along spin chain (ξ-axis) magnetic field directed perpendicular to the chain (z-axis).

The full set of equations describing dynamics of the whole system (chain + electromagnetic field) consists of the Maxwell equation and kinetic equation for spin density matrix $\gamma(t)$:

$$\frac{\partial^2}{\partial t^2}h(\xi,t) - \frac{\partial^2}{\partial \xi^2}h(\xi,t) = -\frac{\partial^2}{\partial t^2}M(\xi,t), \tag{2a}$$

$$\mathrm{i}\frac{\partial}{\partial t}\gamma(t) = [H, \gamma(t)], \qquad \gamma(-\infty) = \exp(-\beta H_0), \tag{2b}$$

$$M(\xi, t) = \frac{2\mu}{a^3}\mathrm{Sp}\left(\gamma(t) S^z_{n(\xi)}\right),$$

here H_0 is Hamiltonian (1) at $h = 0$, $\beta = 1/T$ (T is temperature), $n(\xi) = [\xi/a]$ is a whole part, $\hbar = c = 1$. We established that the relaxation time τ_r is the largest time in our consideration and that scale of the nonuniform magnetic field is much greater than interatomic distance.

We investigated the XY-model having a special relation between the exchange constants ($J_x = -J_y = J$). Just in that very system the nonlinear response to the external uniform pulse magnetic field was previously under consideration and the possibility of zero influence of that field upon spin system under certain conditions was shown [3]. On the other hand, this restriction gives us the possibility to simplify Eq. (2b) and avoid the resonance approximation which is usually used for the investigation of the resonance solitons [2].

The Wigner transformation (see, e.g. Ref. [4]) enables us to describe such magnetic system in terms of the Fermi creation and annihilation operators a_n^+ and a_n. Since the XY-model ground state structure is antiferromagnetic, it is convenient to consider two-sublattice system with the Fermi operators on even ($c(n)$) and odd ($d(n)$) sites of the chain: $c(n) \equiv a_{2n}$, $d(n) \equiv a_{2n+1}$. As a result, we obtain

$$H = J\sum_n \left\{c^+(n)[d(n) - d(n-1)] + d^+(n)[c(n) - c(n+1)]\right\}$$
$$-2\mu\sum_n \left\{h(na, t)[c^+(n)c(n) - d^+(n)d(n)]\right\}. \tag{3}$$

By means of transition from discrete index n to continual variable value ξ and from the Fermi operators $c(n)$ and $d(n)$ to the Fermi fields $c(\xi)$ and $d(\xi)$ one may introduce two-component field Fermi operator

$$\Phi(\xi) \equiv \begin{pmatrix}\Phi_1(\xi)\\ \Phi_2(\xi)\end{pmatrix} \equiv (2)^{-1/2}\begin{pmatrix}c(\xi) - \mathrm{i}d(\xi)\\ \mathrm{i}c(\xi) - d(\xi)\end{pmatrix}$$

and rewrite the Hamiltonian (1) in the continuous limit as follows:

$$H = \int \left(\Phi^+(\xi), \tilde{H}\Phi(\xi)\right)\mathrm{d}\xi, \tag{4}$$

$$\tilde{H} = V\sigma_3\hat{p} + \mu\sigma_2 h(\xi, t), \qquad \hat{p} = \mathrm{i}\frac{\partial}{\partial\xi}, \qquad V = 2Ja,$$

σ_i is the Pauli matrix. From this we can see that if $h = 0$, excitation spectrum is linear with momentum p and consists of two branches $E_\kappa(p) = \kappa V p$, $\kappa = (\pm)$. The Hamiltonian (3) conserves the number of fermions and is an one-particle one. Therefore, the solving of Eq. (2b) is reduced to the investigation of the evolution equation with the Hamiltonian $\tilde{H}$ for the two-component wave function $|\Psi(\xi, t)\rangle$ and respective initial conditions. The set of Eqs. (2) may be rewritten as follows:

$$\mathrm{i}\frac{\partial}{\partial t}|\Psi^{p\kappa}(\xi, t)\rangle = -\mathrm{i}V\sigma_3\frac{\partial}{\partial\xi}|\Psi^{p\kappa}(\xi, t)\rangle - \mu h(\xi, t)\sigma_2|\Psi^{p\kappa}(\xi, t)\rangle,$$

$$\frac{\partial^2}{\partial t^2}h(\xi,t) - \frac{\partial^2}{\partial \xi^2}h(\xi,t)$$
$$= 4\pi\mu a^{-2}\frac{\partial^2}{\partial t^2}\left[\int \mathrm{d}p \sum_{\kappa} f_0(E_\kappa(p))\langle\Psi^{p\kappa}(\xi,t)|\sigma_2|\Psi^{p\kappa}(\xi,t)\rangle\right],$$

here $f_0(E_\kappa(p))$ is the Fermi distribution function,

$$|\Psi^{p+}(\xi,t=-\infty)\rangle = \begin{pmatrix}1\\0\end{pmatrix}\exp[\mathrm{i}Vp\xi + \mathrm{i}E_+(p)t],$$
$$|\Psi^{p-}(\xi,t=-\infty)\rangle = \begin{pmatrix}0\\1\end{pmatrix}\exp[\mathrm{i}Vp\xi + \mathrm{i}E_-(p)t].$$

At low amplitude $h(\xi,t)$ the obtained set of equations describes the linear response of the system to the field $h(\xi,t)$. In this case the field pulse is damped out at the length $l \approx Jd/VE_0$, d is the impulse space width, E_0 is anisotropic magnetodipole energy, $E_0 = 4\pi\mu^2/a^3$.

Then the soliton solution $h(\xi - vt)$ for the given set of nonlinear equations was found

$$h(\xi - vt) = (2v/\mu d)\mathrm{ch}^{-1}[(\xi - vt)/d], \qquad d = a\frac{v^2 - V^2}{vV}\exp\left[\frac{(v^{-2}-1)J}{E_0}\right].$$

This solution represents collision-free propagation of the electromagnetic field pulse with finite amplitude and width d through the magnetic medium. Consequently, if the pulse amplitude $h(\xi,t)$ increases (with fixed pulse width d) and becomes larger, then a certain value, the electromagnetic wave energy absorption decreases sharply. In other words, under condition $J_x = -J_y$ we have obtained self-induced transparency for the electromagnetic pulses.

Thus, if a chain of interacting spins and the shape of the resonance pumping field satisfy the conditions specified above, the transparency effect may arise. These phenomena may be observed with some one-dimensional complexes of the type TCNQ [5], since in these compounds the zero field static susceptibility can be described [6] in the framework of the XY model with $J_x = -J_y$.

The transparency effect considered in this report as well as self-induced acoustic transparency in a superconductor [2] enable us to suggest that similar phenomena may be observed in other systems with Fermi-like elementary excitations.

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References

[1] I.A. Poluektov, Yu.M. Popov, V.S. Roytberg, *Usp. Fiz. Nauk* **114**, 97 (1974).

[2] A.E. Borovick, E.N. Bratus, V.S. Shumeyko, *Zh. Eksp. Teor. Fiz.* **95**, 1430 (1989).

[3] A.E. Borovick, V.S. Borovikov, A.M. Frishman, *Phys. Lett. A* **140**, 436 (1989).

[4] S.A. Pikin, V.M. Tsukernik, *Zh. Eksp. Teor. Fiz.* **50**, 1377 (1966).

[5] I.F. Shchegolev, *Phys. Status Solidi A* **12**, 9 (1972).

[6] A.M. Frishman, *Fiz. Met. Metalloved.* **39**, 1156 (1975).