SPIN WAVES ON DISLOCATIONS

V. L. Pokrovskii
L. D. Landau Institute of Theoretical Physics, USSR Academy of Sciences
Submitted 15 January 1970
ZhETF Pis. Red. 11, No. 4, 233 - 235 (20 February 1970)

A dislocation in an alkali-halide crystal or a semiconductor is not merely the end of an excess plane in a lattice, but a chain of uncompnsated spins. This raises the question of the magnetic properties of such a system. We consider this question mainly as applied to semiconductors. Obviously, the neighboring uncompensated spins on dislocations, spaced 4 Å apart, interact weakly, and this leads to magnetic ordering along the line at zero temperature. At $T \neq 0$, the average length ℓ of the section of dislocation on which the spins are ordered is proportional to I/T, where I is the overlap integral, or to $\exp(I_1/T)$, where I_1 is the anisotropy constant. The unit length is taken to be the lattice constant. According to Read [1], the uncompensated spins on a dislocation can capture a free electron like acceptors with deep levels (~0.2 eV). Therefore there is always a number of charges on the dislocation. Their number is determined by the concentrations N_d and N_a of the donor and acceptor impurities if $N_d - N_a$ is small, or by the balance of the energies of the acceptor dislocation traps and the Coulomb repulsion in the case of a sufficiently large $N_d - N_a \geq 10^{14}$ cm^{-3}. In the latter case, there is approximately one charge for each ten sites on the dislocation. It is important that in both cases the Coulomb interaction causes the charges to be arranged on the dislocation equidistantly with high accuracy. The estimated deviation $\Delta m/m$ from equidistant arrangement in the case of silicon is

$$\Delta m/m \sim 10^{-3}Tm/\ln(m\sqrt{N}), \tag{1}$$

where N is the dislocation density, m the average distance between charges, and T the temperature in degrees Kelvin.

In those sites where the charges have settled, the coupling between the neighboring spins on the dislocations are appreciably weakened. We assume as a rough approximation that these couplings vanish. If $\ell \gg m$, the spins on the section between the charges are ordered with an overwhelming probability, whereas the neighboring sections are independent even at low temperatures. In such a chain, the wave vectors of the excited spin waves assume discrete values, just as in a string of finite length: $k_n = \pi n/m$ ($n = 0, 1, 2, \ldots$). The oscillation spectrum depends on the character of the ordering. In the ferromagnetic case the frequencies are determined by the formula

$$\hbar\omega_n = gH + Jk_n^2, \tag{2}$$

where H is the magnetic field and J and g are constants. In the antiferromagnetic case we have

$$\hbar\omega_n = [(gH)^2 + (Jk_n)^2]^{1/2}. \tag{3}$$

In their experiment, Grazhulis and Osip'yan [2] observed a fine structure of the paramagnetic resonance line in plastically-deformed silicon; this structure is probably connected with excitation of spin waves. Unfortunately, the experimental data were obtained with a sample having all possible dislocation orientations, making a comparison with formulas (2) and (3) difficult.

The structure of the spectrum should depend significantly on the impurity concentration or the free-carrier concentration, if it is due to the spin vibrations of the "strings," The line widths are determined mainly by the scatter of the lengths (see formula (1)) or by the intrinsic damping of the spin waves $\gamma \sim Jk_n^4$ (cf., e.g., [3]) if the scatter of the lengths is small.

Finally, when the temperature rises the number of fluctuation spin flips increases, and this leads to a line broadening on the order of $J_1 k_n \exp(-J_1/T)$ (under the condition that $k_n \exp(J_1/T) \gg 1$).

Assuming that the EPR line structure observed in [2] is connected with standing spin waves, we obtain for I a value $\sim 100°K$ and $k_n \sim 10^{-3}$. This means that approximately 10^{-3} of the total number of free valence bonds are filled, in agreement with the independently measured impurity and dislocation concentrations. The experiment of [2] was performed at very low impurity concentrations. By increasing the number of impurities one can arrive at Read's case, where the bond filling coefficient is approximately equal to 0.1. In this case the spectrum lies in the infrared region (with the exception, of course, of the line $k_n = 0$).

We note that the charges on the dislocation line break the three-dimensional grid of coupled spins and prevent occurrence of "dislocation" ferromagnetism (Sharp and Avery [4], Kosevich and Shklovskii [5]).

I thank A. I. Larkin for a valuable remark.

[1] W. T. Read, Phil. Mag. 45, 775 (1954); 46, 111 (1955).
[2] V. A. Grazhulis and Yu. A. Osip'yan, Zh. Eksp.Teor. Fiz. 58, No. 4 (1970) [Sov. Phys.-JETP 31, No. 4 (1970)].
[3] A. I. Akhiezer, V. G. Bar'yakhtar, and S. V. Peletminskii, Spinovye volny (Spin Waves), IFML, 1968.
[4] E. J. Sharp and D. A. Avery, Phys. Rev. 158, 511 (1967).
[5] A. M. Kosevich and V. A. Shklovskii, Zh. Eksp. Teor. Fiz. 55, 1131 (1968) [Sov. Phys.-JETP 28, 590 (1969)].

CONCERNING A BOUND NEUTRON IN MATTER

Yu. Kagan
Submitted 16 January 1970
ZhETF Pis. Red. 11, No. 4, 235 - 240 (20 February 1970)

1. This paper is devoted to an analysis demonstrating the possibility of existence of a long-lived bound state of a neutron in matter. Such a state arises under certain conditions in an irregular medium at low temperature as a result of ordinary nuclear interaction when the collective effects of the medium are taken into account.

The direct impetus for the analysis was the reported [1] experimental observation of neutrons emitted with a delay on the order of several times ten seconds (after the cessation of the neutron exposure) from a previously irradiated LiF crystal at helium temperature. The authors start from the premise that this effect is due to the appearance of a bound state of the neutron with the electron of an F-center due to a Foldy-type interaction. However, even a cursory analysis shows that this interaction is very weak, and is at any rate small compared with the magnetic interaction of the neutron with the spin and orbital electron current. But