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A joint scientific session of the General Physics and Astronomy and the Nuclear Physics Divisions of the USSR Academy of Sciences was held on November 30 and December 1, 1977. The following papers were presented at that session:

1. *A. F. Andreev,* Magnetic properties of disordered media.
2. *E. P. Bashkin and A. É. Meĭerovich,* He^3-He II solutions in a magnetic field.
3. *A. E. Chudakov,* The large underground scintillation telescope of the Institute for Nuclear Research, Academy of Sciences of the USSR.
4. *G. T. Zatsepin,* Prospects for neutrino astronomy.

Below we briefly review the contents of two of these papers.

A. F. Andreev, *Magnetic properties of disordered media.* This report is devoted to a macroscopic analysis of the magnetic properties of spatially disordered media, i.e. of systems in which the spatial distribution of magnetic atoms is uniform and isotropic on the average. We are dealing either with amorphous substances containing magnetic atoms, or with weak solutions of magnetic atoms in nonmagnetic crystals. We shall assume that the appearance of any magnetic structure in the substances under consideration is due mainly to exchange forces that are considerably stronger than the relativistic interactions.

A spatially disordered system may exhibit complete magnetic ordering. The only case of this type is the complete ferromagnetic ordering of the spins of magnetic atoms. Any other sort of magnetic ordering is obviously incompatible with spatial disorder. The macroscopic properties of such a ferromagnetic substance do not differ from those of ordinary ferromagnetic crystals and are described by the well known Landau-Lifshitz equation.

Disordered systems with magnetic structures of another type have been widely studied in recent years (see the reviews by Mydosh[1] and Cargill[2]). First, there are the so-called spin glasses (see Ref. 1) in which not only the positions, but also the directions of the spins of the different atoms are randomly distributed. And second, there exist systems (see Ref. 2) whose spontaneous magnetization, while it exists and is finite, differs considerably from the nominal value at zero temperature. The state of such a disordered ferromagnetic substance is similar to the state of a spin glass in an external magnetic field: there is a partial (spontaneous) ferromagnetic ordering superimposed on a generally rather chaotic distribution of spin directions. The system exhibits long range order described by the spontaneous magnetization vector M^α (α is a vector index for the spin). The quantity M^α is defined in the usual manner in terms of the average value of the spin of one of the magnetic atoms: $\langle S^\alpha \rangle = \text{const} \cdot M^\alpha$; here the average is taken not only over the time (this would be inadequate for magnetically disordered systems), but also over all the disordered configurations.

All types of such partial disordering that are possible in principle can be determined from symmetry considerations developed by Marchenko and the author.[3] It turns out that besides the disordered ferromagnetic substance, there exists just one other possible exchange structure—a disordered antiferromagnetic substance characterized by three antiferromagnetic moments M_i^α (i is a spatial vector index) that are mutually perpendicular: $M_i^\alpha M_k^\alpha = \delta_{ik}$. The quantities M_i^α can be defined in terms of the two-particle spin-coordinate correlation function:

$$\langle S_1^\alpha (\mathbf{r}_2 - \mathbf{r}_1)_i \rangle = \text{const} \cdot M_i^\alpha,$$

where S_1^α is the spin operator for the first atom, and r_1 and r_2 are the coordinates of the first and second magnetic atoms. In a disordered antiferromagnetic substance, the single-particle average $\langle S^\alpha \rangle$ vanishes.

If the weak relativistic interactions are neglected, the disordered antiferromagnetic substance (like the ferromagnetic substance) turns out to be spatially isotropic. Depending on the nature of the relativistic interactions, there exist three phases for an antiferromagnetic substance, which differ in symmetry and one of which is isotropic even when the relativistic interactions are taken into account.

Since the spin is a pseudovector and changes sign under the time reversal operator T, a disordered antiferromagnetic substance with moments M_i^α is not separately invariant under space inversion P and time reversal T, but is invariant under their product PT. If a dielectric acquires such a structure it should exhibit the magnetoelectric effect (the appearance of magnetization proportional to an applied external electric field), which is observed, for example, in the antiferromagnetic crystal Cr_2O_3[4].

The dynamical properties of *xx* disordered magnetic media can be described macroscopically in a manner similar to that used to describe ordinary amorphous bodies in the theory of elasticity. Here the vector describing the spatial displacement of the medium that occurs in elasticity theory is analogous to a rotation of all the spins through the same angle. Such a rotation

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does not alter the exchange energy. The change in energy is therefore determined by the time and space derivatives of the rotation angles, and these derivatives are analogous to the velocity and strain of the medium. However, there is an essential difference between elasticity theory and magnetic dynamics. Generally speaking, different rotations, unlike spatial displacements, do not commute with one another. Hence the equations for magnetic dynamics are nonlinear even at low velocities and small strains. Dynamical equations have been derived in our paper for all three types of disordered magnetic structures, i.e. for spin glass and disordered ferromagnetic and antiferromagnetic substances, taking into account an external magnetic field and relativistic interactions. If the effects of a magnetic field and the relativistic interactions are neglected, the equations obtained for a spin glass reduce, when they are linearized, to the equations obtained by Halperin and Saslow[5]. The equations for a disordered antiferromagnetic substance are very similar to the equations[6] for the spin dynamics of the superfluid *B* phase of liquid He[3].

The dynamical equations have been used to find the spectra of long-wave low-frequency spin waves and to determine magnetic resonance frequencies.

A detailed discussion of the work on which the present report is based will be published in the Zhurnal Eksperimental'noĭ i Teoreticheskoĭ Fiziki.[7]

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[1] T. A. Mydosh, in Magnetism and magnetic materials—1974 AIP Conference Proceedings (N. Y.), No. 24, 131 (1975).

[2] G. S. Cargill, *ibid.*, p. 138.

[3] A. F. Andreev and V. I. Marchenko, Zh. Eksp. Teor. Fiz. **70**, 1522 (1976) [Sov. Phys.-JETP **43**, 794 (1976)].

[4] I. E. Dzyaloshinskiĭ, Zh. Eksp. Teor. Fiz. **37**, 881 (1959) [Sov. Phys.-JETP **10**, 628 (1960)]. D. N. Astrov, Zh. Eksp. Teor. Fiz. **38**, 984 (1960) [Sov. Phys.-JETP **11**, 708 (1960)].

[5] B. I. Halperin and W. M. Saslow, Preprint, 1977.

[6] A. I. Leggett, Rev. Mod. Phys. **47**, 331 (1975). K. Maki, Phys. Rev. **B11**, 4264 (1978).

[7] A. F. Andreev, Zh. Eksp. Teor. Fiz. **74**, 786 (1978) [Sov. Phys.-JETP **47**, 411 (1978)].