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MAGNETIC ORDERING IN GARNETS WITH DIVALENT NICKEL AND COBALT IONS IN AN OCTA-HEDRAL LATTICE

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A number of garnets in which the 3d-metal ions occupy only one (octahedral) position have been synthesized recently [1]. Some of these garnets exhibit antiferromagnetic properties at low temperatures. Compounds of this type are of interest as systems in which the magnetic cations are separated by at least two oxygen ions and consequently cannot be coupled by the usual superexchange interaction. The magnetic structures of garnets with Mn^{3+} and Fe^{3+} ions were determined in [2 - 4]. The difference between the types of magnetic ordering in these compounds has induced us to carry out neutron-diffraction investigations of garnets with other magnetic ions, namely

$$\{NaCa_2\}[Ni_2^{2+}](V_3)O_{12}$$

and

$$\{NaCa_2\}[Co_2^{2+}](V_3)O_{12}.$$
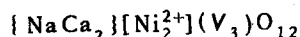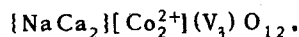
The neutron-diffraction patterns were obtained by the powder method from a cylindrical specimen at room and liquid-helium temperatures. Figure 1 shows the measurement results for nickel garnet. All the reflections obtained at room temperature correspond to the garnet lattice. At 4.2°K, the neutron-diffraction pattern reveals the additional magnetic peaks 200 and 222 and a noticeable contribution to the nuclear peak 420. These three magnetic reflections suffice to determine uniquely the magnetic structure (Fig. 2).
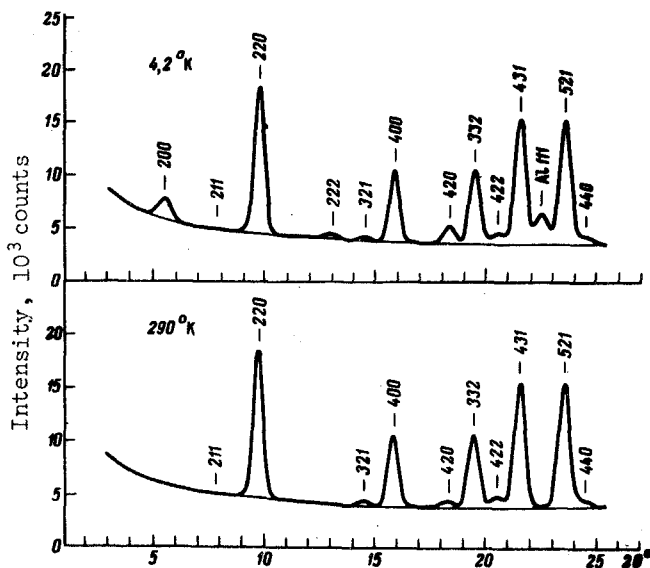

Fig. 1. Neutron diffraction pictures of nickel garnet at 3.2 and 290°K.

The magnetic unit cell coincides with the crystallographic cell. The spins of the atoms in the positions 000, ½00, 0½0, and 00½ are ferromagnetically ordered, as are also the spins of the atoms in the positions ¼¼¼, ¼¼¼, ¼¼¼, and ¼¼¼. The mutual ordering of these two sublattices is antiferromagnetic. Such a spin configuration conserves the cubic symmetry of the crystal, so that it is impossible to determine the orientation of the antiferromagnetism vector relative to the crystallographic axes.

Since the picture of magnetic scattering by a cobalt garnet is fully identical to the picture obtained with the nickel garnet, it can be concluded that the magnetic order is the same in both investigated compounds.

The octahedral site in the garnet lattice has a point symmetry $\bar{3}$. Therefore not all the eight nearest neighbors of the magnetic atom at this site are equivalent. The interaction with the two neighbors lying on the threefold axis should differ from the interaction with the six neighbors in the plane perpendicular to it. The corresponding exchange integrals are J_1' and J_1''. All six atoms in the second coordination sphere are equivalent (the exchange integral is J_2). Then we have in the molecular-field approximation [5]

$$T_N = (2/3) S (S + 1) (-2J_1' - 6J_1'' + 6J_2).$$

If it is assumed that the exchange interaction is indirect [2 - 4] and that the role of the ligands is assumed by pairs of oxygen ions located between the magnetic cations, then J_1', J_1'', and J_2 characterize the couplings realized by three, two, and one pair, respectively. The distances between the oxygen ions forming these pairs differ by approximately 10%. To estimate the exchange integrals we can put

$$(1/3) J_1' \approx (1/2) J_1'' \approx J_2.$$

Using the data of Mamsurova and Sokolov [6], we obtain $J_2 \simeq -0.5°K$ for the nickel garnet and $J_2 \simeq -1.1°K$ for the cobalt garnet.

Habbard and Marshall [7] have discussed effects that the presence of covalent spin density on the ligands produces in magnetic Bragg scattering of neutrons. One such effect is a peak on the plot of the magnetic form factor in the region of small momentum transfers. The investigated compounds are ideal objects for the observation of this peak. First, the magnetic structure has been determined from the very fact of appearance of magnetic reflections, and not from their intensities, i.e., independently of the form factor. Second, since the nearest neighbors are antiferromagnetically ordered, the spin density at the center of the distance between them is equal to zero. Thus, the form factor is affected only by the spin density on six identical ligands binding the ferromagnetically-ordered second neighbors. Owing to the large distance between the second neighbors (6.2 Å), the expected peak should become particularly clearly manifest.
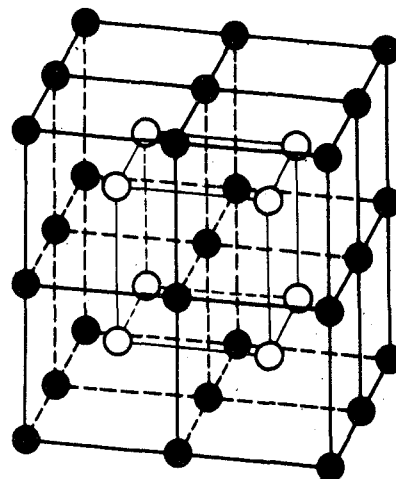
Fig. 2. Magnetic structure of nickel and cobalt garnets.

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DYNAMIC NEGATIVE CONDUCTIVITY DUE TO NONLINEARITY OF THE CURRENT VOLTAGE CHARACTERISTIC AND TO THE FINITE ELECTRIC-CONDUCTIVITY RELAXATION TIME

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Owing to the finite relaxation time (τ) of the conductivity in a certain interval of frequencies (ω), when $\omega\tau \sim 1$, a phase difference is produced between the current and the voltage. If the conductor has a nonlinear stationary current-voltage characteristic, then the dynamic dependence of the current on the voltage becomes multiple-valued and forms a loop that can have descending sections. As will be shown below, under certain conditions the phase difference between the current and the voltage may exceed $\pi/2$, and such a conductor, if connected in an oscillating circuit or a resonator, can be used for the amplification and generation of oscillations. The conductor need not necessarily have stationary negative differential conductivity in this case.

This effect can occur, in particular, in semiconductors. To illustrate this possibility, let us consider the simple case of a semiconductor whose stationary current voltage characteristic has a section close to current saturation, and the time of establishment of the conductivity does not depend on the voltage U. We put

$$i = \sigma_0(U)\,U = \frac{i_s v}{1 + v}\ , \qquad \frac{d\sigma}{dt} = \frac{\sigma_0 - \sigma}{\tau}\ , \tag{1}$$

where i_s is the saturation current, $v = U/U_c$, and U_c is a certain characteristic voltage. Putting $v = v_0 + v_1 \cos \omega t$ and representing i and $\sigma_0(v)$ in the form of Fourier expansions, we can find the ac conductivity G of the specimen. Calculation yields

$$\frac{G}{G_0} \equiv \frac{2 < i\,v_1 \cos\omega t>}{G_0 v_1^2} = \frac{8\,F(z^2)}{(1 + z^2)(1 + 4z^2)\sqrt{(1 + v_0)^2 - v_1^2}} \tag{2}$$

where G_0 is the conductivity in a weak field, $z = \omega\tau$, and F is given by

$$F = 2z^4 - z^2 \left[\frac{3v_0 - 1}{v_1^2} \left(1 + v_0 - \sqrt{(1 + v_0)^2 - v_1^2}\right) - 2 \right] + \\ + \frac{1 + v_0 - \sqrt{(1 + v_0)^2 - v_1^2}}{v_1^2}\ . \tag{3}$$

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