The presented scheme is oversimplified, for actually both the conductivity of the semiconductor [9] and the electric characteristics of the inversion layer are altered when the intensity of the ESW is increased.

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FERRIMAGNETISM OF THE GARNET $Mn_3Cr_2Ge_3O_{12}$

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Measurements of the magnetic properties of garnets containing magnetic ions only in the c- and a-sublattices were first carried out by Bozorth and Geller [1, 2]. It was established there that the c-a exchange interactions cause ferrimagnetism to occur in the garnets $\{Gd^{3+}\}[Mn_2^{2+}](GaGe_2)O_{12}$ and $\{Gd_2^{3+}Ca\}[Mn_2^{2+}](Ge_3)O_{12}$ (with Curie points θ close to 8 and 6°K, respectively), whereas no spontaneous magnetic moment was observed in the garnets $\{Mn_3^{2+}\}[Fe_2^{3+}](Ge_3)O_{12}$, $\{Gd_3^{3+}\}[Co_2^{2+}](GaGe_2)O_{12}$, and $\{Gd_3^{3+}\}[Ni_2^{2+}](GaGe_2)O_{12}$ down to 1.5°K.

In the present study we have established the presence of ferrimagnetism in the garnet $\{Mn_3^{2+}\}[Cr_2^{3+}](Ge_3)O_{12}$, the Curie point of which is 3.68 ± 0.03°K. To obtain information on the values of the intrasublattice exchange interactions of the ions Mn^{2+} and Cr^{3+}, we measured also the magnetic properties of the "single-sublattice" garnets $\{Mn_3^{2+}\}[Ga_2](Ge_3)O_{12}$ and, earlier $\{Ca_3\}[Cr_2^{3+}](Ge_3)O_{12}$ [3].

The investigated polycrystalline samples were synthesized by a ceramic technology with double annealing in air at T = 1160°C; the phase composition was monitored by x-ray diffraction.

We present below the unit-cell parameters of the garnets investigated by us:

$$Mn_3Cr_2Ge_3O_{12},\ a_0 = 12.028 \pm 0.004\ \text{Å},$$
$$Mn_3Ga_2Ge_3O_{12},\ a_0 = 12.016 \pm 0.004\ \text{Å},$$
$$Ca_3Cr_2Ge_3O_{12},\ a_0 = 12.260 \pm 0.002\ \text{Å}.$$

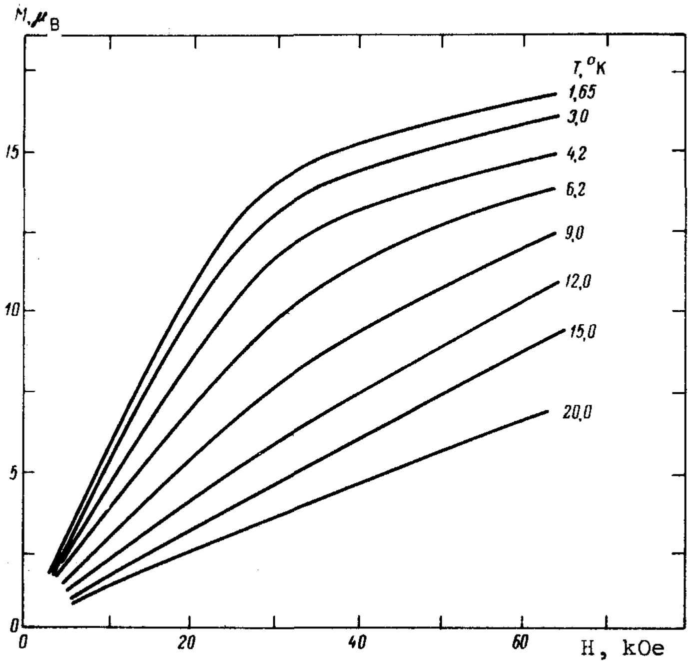

Fig. 1. Magnetization isotherms for a spherical sample (0.9 mm diameter) of the garnet $Mn_3Cr_2Ge_3O_{12}$.

The magnetic properties were measured with a vibration magnetometer [4] in the temperature interval 1.65 - 50°K and in magnetic fields up to 60 kOe. The temperature dependence of the specific heat of the garnet $Mn_3Cr_2Ge_3O_{12}$ was measured by the vacuum-calorimeter method [5] in the interval 2 - 15°K.

Figure 1 shows the magnetization isotherms of the $Mn_3Cr_2Ge_3O_{12}$ samples, produced with a x-y recorder. We see that even at the lowest temperatures there is no saturation on the M(H) curves, and the magnetic moment at T = 1.65°K in a feld of 60 kOe reaches a very large value, M = 16.5 μ_B. Were the c-a interaction to have a collinear antiferromagnetic character, as in iron garnets, then one should expect for $Mn_3Cr_2Ge_3O_{12}$ near T = 0°K a magnetic moment $M = (3M_{Mn^{2+}} - M_{Cr^{3+}})\mu_B = 9\mu_B$. The appearance of a value of M larger than $9\mu_B$ can obviously be attributed to rotation of the spin magnetic moments of the Cr^{3+} ions, which produce in a sufficiently strong external magnetic field a spin magnetic moment component that coincides in direction with the resultant spin moment of the Mn^{2+} ions. Unlike the iron garnets, where an effective magnetic field $H_{eff} \sim 2 \times 10^6$ Oe is produced at the a-sublattice ions by the d-sublattice, in the investigated garnet the Cr^{3+} ions are acted only by a field $H_{eff} \sim 2 \times 10^4$ Oe. This field, due to the c-a interaction, is comparable with the external magnetic field. It is also possible that the weak Mn^{2+}-O^{2-}-Cr^{3+} interaction gives rise to a noncollinear magnetic structure inside the sublattices c and a.

To determine the Curie temperature, we measured the specific heat of the $Mn_3Cr_2Ge_3O_{12}$ sample. The measured specific heat plotted in Fig. 2 demonstrates the existence at θ = 3.68°K of a narrow peak whose value is approximately 50 J/mole-deg. We relate its presence to the occurrence of ferrimagnetism of the $Mn_3Cr_2Ge_3O_{12}$ garnet as a result of the c-a interaction. The small maximum on the C(T) curve at 8.5°K could be attributed to the presence of a magnetic impurity. However, diffraction patterns of the sample do not show any impurity line (sensitivity ∿2% in terms of intensity).

Figure 2 shows also the temperature dependence of the spontaneous magnetization (M_S) of the $Mn_3Cr_2Ge_3O_{12}$ garnet, calculated by the method of

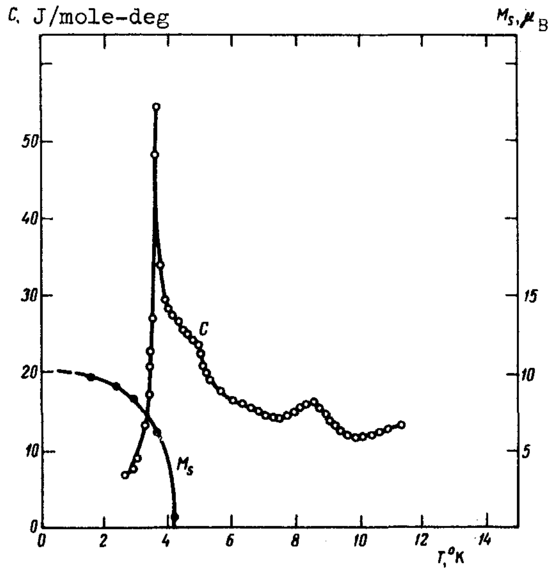

Fig. 2. Temperature dependence of the specific heat and of the spontaneous magnetic moment of the garnet $Mn_3Cr_2Ge_3O_{12}$.

thermodynamic coefficients from the dependences of H/M on M^2 [6]. Extrapolation of this curve to the value $M_S = 0$ yields $\Theta \approx 4.1$°K, and extrapolation to T = 0°K yields a magnetic moment $(M_S)_0 = 10.2\ \mu_B$.

It should be noted that the antiferromagnetic intrasublattice c-c and a-a interaction are small in the case of the ions Mn^{2+} and Cr^{3+}, and we estimate them at $J/k \leq 0.1$°K. These values of the exchange-interaction parameters were obtained by us for the c and a sublattices by measuring the susceptibility of the "single-sublattice" garnets $Mn_3Ga_2Ge_3O_{12}$ and $Ca_3Cr_2Ge_3O_{12}$, in which no antiferromagnetic ordering is observed down to 1.5°K. The weak intrasublattice interactions of the Mn^{2+} and Cr^{3+} ions in the c and a sublattices of the garnet are apparently the main cause for the appearance of ferrimagnetism in the garnet $Mn_3Cr_2Ge_3O_{12}$.

We can explain from the same point of view also the absence of ferrimagnetism in the garnets $Gd_3Co_2GaGe_2O_{12}$ and $Gd_3Ni_2GaGe_2O_{12}$ [1]. In fact, although the c-c interactions of the gadolinium ions are small ($T_N < 0.3$°K for $Gd_3Ga_5O_{12}$), the exchange a-a interactions of the Co^{2+} and Ni^{2+} ions exceed by one order of magnitude, according to [5], the corresponding values of J_{aa}/k for the Cr^{3+} ions. For the Fe^{3+} ions in the a sublattice, according to the data of [5], $J_{aa}/k \approx 0.4$°K, which is probably also too large for the onset of ferrimagnetism in the garnet $Mn_3Fe_2Ge_3O_{12}$. Lind and Geller explained the absence of ferrimagnetism in this sample as being due to the unfavorable geometry of the exchange interactions [7]. Owing to the close values of a_0 in $Mn_3Fe_2Ge_3O_{12}$ (12.087 Å) and in $Mn_3Cr_2Ge_3O_{12}$ (12.028 Å), their structures should differ quite insignificantly. Therefore the decisive factor for the occurrence of ferrimagnetism in such compounds, in our opinion, is the presence of a definite ratio of the intra- and intersublattice exchange interactions.

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