

# Neutron diffraction investigation of magnetic semiconductors of the system $^{114}\text{Cd}_{1-x}\text{Zn}_x\text{Cr}_2\text{Se}_4$

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Results are presented of magnetic and neutron-diffraction investigations of the system  $^{114}\text{Cd}_{1-x}\text{Zn}_x\text{Cr}_2\text{Se}_4$  of magnetic semiconductors with spinel structure. It is shown that with decreasing zinc concentration in the system the period of the magnetic helix increases. It follows from the obtained neutron diffraction patterns that the transition from the magnetic helix into the ferromagnetic state proceeds via a disordered magnetic phase.

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Compounds of the system  $\text{Cd}_{1-x}\text{Zn}_x\text{Cr}_2\text{Se}_4$  are magnetic semiconductors with normal spinel structure. This system of compounds is of interest because it undergoes an abrupt transition from the ferromagnetic state into the anti-ferromagnetic state when Cd is replaced by Zn near the concentration  $x = 0.4$ .<sup>1</sup>

It is known from neutron-diffraction data<sup>2,3</sup> that  $\text{ZnCr}_2\text{Se}_4$  has at  $T < 20$  K a helical magnetic structure with a propagation vector along the [100] direction in the crystal and with a spin rotation angle  $42^\circ$  from plane to plane. However, an investigation of the magnetic structure of the entire system  $\text{Cd}_{1-x}\text{Zn}_x\text{Cr}_2\text{Se}_4$  at  $x < 1$  is made difficult by the large cross section for absorption of thermal neutrons by natural cadmium (2500 b).

We have carried out, for the first time ever, a neutron-diffraction investigation of the magnetic structure of this system. To decrease absorption of the thermal neutrons we used for the samples the isotope  $^{114}\text{Cd}$ , which has an absorption cross section  $\sim 7$  b. The single crystals of the system were grown by spontaneous crystallization from the solution in the melt. The crystal-growth method is described in detail in Ref. 4. The dependence of the crystal-cell parameter on  $x$  is linear, and the parameter changes from 10.755 Å at  $x = 0$  to 10.440 Å at  $x = 1.0$ .<sup>5</sup>

A vibration magnetometer was used to obtain for these samples the dependence of

the temperature of the phase transition on the Zn concentration, which is shown in Fig. 1. This dependence is close to that obtained earlier in Ref. 1.

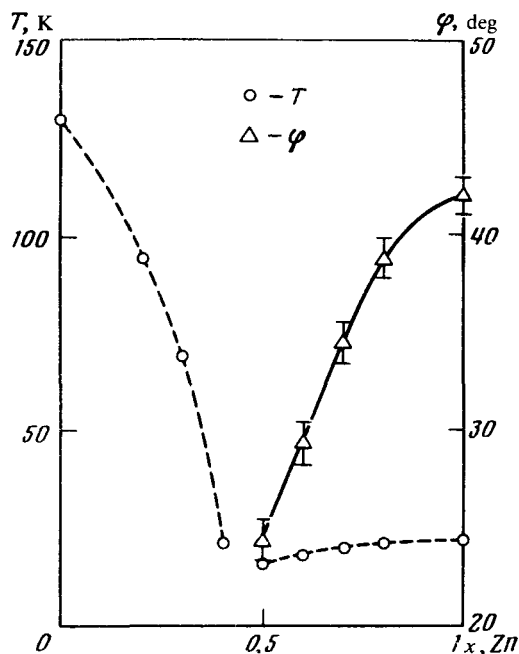


FIG. 1. Dependence of the temperature of the phase transition  $T$  and of the rotation angle  $\phi$  of the magnetic moment on the composition.

The Curie temperature was determined by the magnetization "kink" method.<sup>6,7</sup> The Néel temperature was determined from the maximum of the temperature dependence of the magnetization. It follows from the obtained data that at  $x > 0.4$  the samples are antiferromagnetic.

To ascertain the magnetic structure of these compounds, investigations were made with the IRT neutron-diffraction installation of our Institute, with neutron wavelength  $1.05 \text{ \AA}$ . We measured the neutron diffraction patterns of powdered samples obtained by pulverizing single crystals, and packed in vanadium cassettes. The measurements were performed at liquid-helium and at room temperatures.

The neutron diffraction patterns obtained at room temperature have, for all compositions, only reflections corresponding to the structure of the normal cubic spinel.

In analogy with Refs. 2 and 3, at  $T = 4.2 \text{ K}$  we observed on the neutron diffraction pattern of  $\text{ZnCr}_2\text{Se}_4$ , magnetic satellites of the spiral structure near the nuclear-reflection peaks. The angle of rotation of the magnetic moment was also found to be  $42^\circ$ .

The diffraction patterns of compositions with zinc contents  $x = 0.8, 0.7, 0.6,$  and  $0.5$  also show at  $T = 4.2 \text{ K}$  magnetic satellites whose positions change noticeably as functions of  $x$ . The obtained dependence of the angle of rotation of the magnetic moment on  $x$  is shown in Fig. 1. This result confirms the previous calculation<sup>1</sup> of the dependence of the rotation angle on the composition.

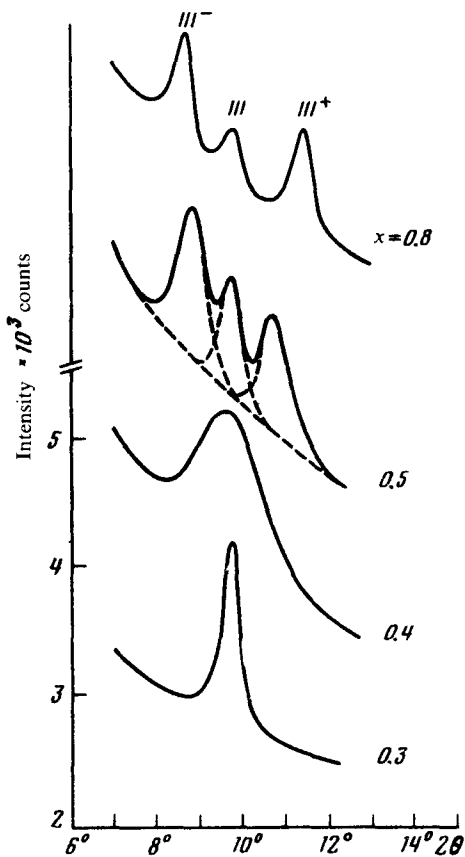


FIG. 2. Neutron diffraction patterns of powders of  $^{114}\text{Cd}_{1-x}\text{Zn}_x\text{Cr}_2\text{Se}_4$  at  $T = 4.2$  K.

Figure 2 shows neutron diffraction patterns of spinels with zinc concentrations  $x = 0.8, 0.5, 0.4$ , and  $0.3$  at  $T = 4.2$  K. For the compositions with  $x = 0.6$  and  $0.5$ , the magnetic satellites  $111^-$  and  $111^+$  are considerably broadened compared with the nuclear reflections  $111$ , while on the neutron diffraction pattern of  $^{114}\text{Cd}_{0.6}\text{Zn}_{0.4}\text{Cr}_2\text{Se}_4$  the place of the reflection  $111$  is occupied by a broad diffuse maximum. Only ferromagnetic-ordering peaks are observed on the neutron diffraction patterns of the compositions with  $x = 0.3, 0.2$ , and  $0$ . The foregoing shows that when the concentration of the zinc decreases the period of the helix increases, and starting with  $x = 0.6$  the magnetic system begins to break up into regions with different helix periods. At a concentration  $x = 0.4$  there is no definite magnetic structure in the entire crystal, and apparently there exist regions with both ferromagnetic and with helical ordering.

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