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MAGNETIC SUSCEPTIBILITY OF PbTe AND PbSe*,**

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The magnetic susceptibility of Bridgman-grown single crystals of PbTe and PbSe has been examined. The measurements were carried out using a SQUID detection system over a temperature range from 2 to 100 K in magnetic fields up to 1 T. Both systems were diamagnetic at 100 K with a susceptibility of about -3.6×10^{-7} emu/g for PbSe and -3.1×10^{-7} emu/g for PbTe. With decreasing temperature the magnitude of the susceptibility increased slightly; below 10 K there was a rapid decrease, an order of magnitude for PbTe and about 10% for PbSe.

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1. Introduction

Recently, we have measured magnetic properties of IV–VI diluted magnetic semiconductors, such as $Pb_{1-x}Mn_xTe$, $Pb_{1-x}Gd_xTe$, and $Pb_{1-x}Mn_xSe$ [1–3]. In order to interpret the magnetization and susceptibility measurements it was necessary to know the diamagnetic contribution of the host material. Therefore, we have measured the magnetic susceptibility of PbTe from 1.8 K to 250 K and of PbSe from 2.2 K to 100 K at fields from 0.1 to 1 T.

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2. *Experiment*

The PbTe and PbSe samples were cut out from larger boules grown by the Bridg technique. Transport parameters at liquid helium temperature are shown in Table

We had two different types of PbTe samples. In samples of PbTe 2 the carrier co centration, determined by assuming one-carrier transport, had an unrealistic, low val at 4.2 K. This, together with the low mobility value, suggested a strong compensation b unknown defects. The samples of PbTe 1 and PbSe were typical pure lead chalcogeni crystals.

The susceptibility of single crystals of PbTe and PbSe was measured using a SQU detection system. Our experimental set-up is described elsewhere [1–3]. The measurem

TABLE

Sample	Type	Carrier concentration [cm^{-3}]	Hall mobility [$cm^2/V \cdot s$]
PbTe 1	p	4.78×10^{18}	1.01×10^5
PbTe 2	n	4.69×10^{15}	5.60×10^3
PbSe	n	3.06×10^{18}	1.29×10^5

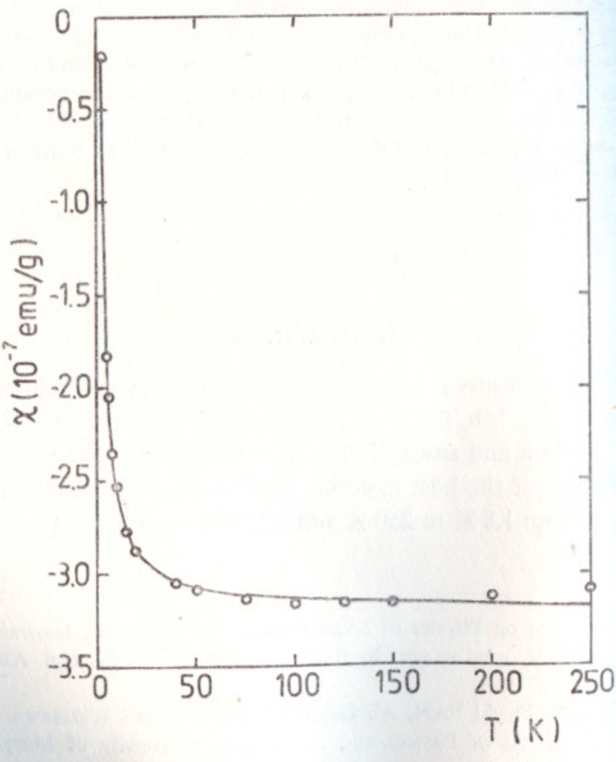

Fig. 1. Magnetic susceptibility vs temperature for PbTe 1. Solid line is a fit of the Curie law

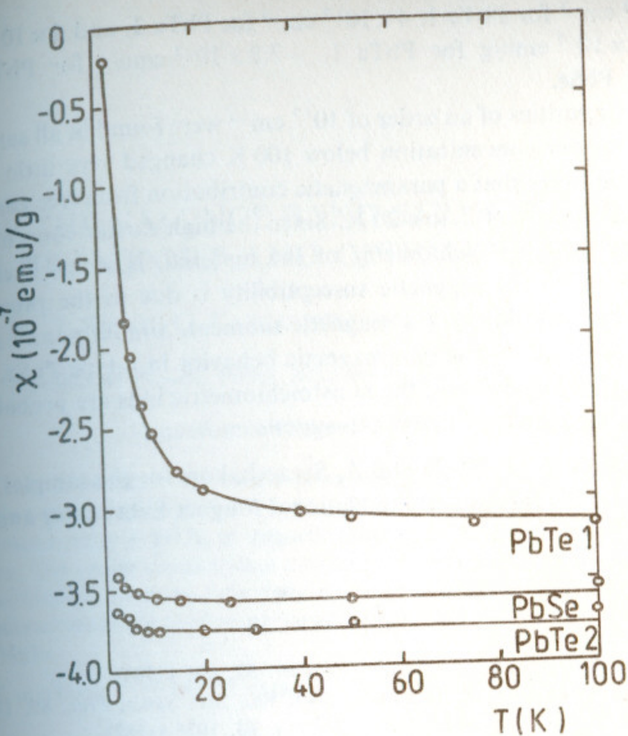

Fig. 2. Magnetic susceptibility vs temperature for PbTe and PbSe. Solid lines are fits of the Curie law

were made on samples of PbTe 1 from 1.8 K to 250 K, of PbTe 2 from 2 K to 100 K, and of PbSe from 2.2 K to 100 K. The magnetization was measured at each temperature at three fields, usually 0.1, 0.5, and 1 T. The magnetic susceptibility was determined by a linear least squares fit with an accuracy of about 2%.

The magnetic susceptibility vs temperature for samples PbTe 1 is shown in Fig. 1, and for PbTe 1, PbTe 2, and PbSe in Fig. 2. All materials were diamagnetic, but there was a strong evidence of paramagnetic contribution below 20 K.

3. *Discussion*

The susceptibility data have been fitted to the Curie law:

$$\chi = \frac{N_S g^2 \mu_B^2 S(S+1)}{3k_B T} + \chi_{dia}, \tag{1}$$

where N_S is a number of spins, $S = 1/2$ is the assumed spin, $g = 2$ is the assumed spin-splitting factor, μ_B is the Bohr magneton, k_B is the Boltzmann constant, T is the absolute temperature and χ_{dia} is the lattice diamagnetic susceptibility, assumed to be constant. The results of fits are shown in Figs 1 and 2 as solid lines. The fitting parameters were:

N_S about 8×10^{18} cm^{-3} for PbTe 1, 4×10^{17} cm^{-3} for PbTe 2, and 6×10^{17} cm^{-3} for PbSe; χ_{dia} about -3.2×10^{-7} emu/g for PbTe 1, -3.8×10^{-7} emu/g for PbTe 2, and -3.65×10^{-7} emu/g for PbSe.

No magnetic impurities of an order of 10^{17} cm^{-3} were found in all samples by an X-ray fluorescence. The carrier concentration below 100 K changed very little with temperature and it does not seem likely that a paramagnetic contribution from free carriers can account for the paramagnetic behavior below 20 K. Since the high carrier concentration in PbTe 1 is probably due to the nonstoichiometry of the material, it seems likely that the paramagnetic contribution to the magnetic susceptibility is due to the presence of Te^- ions or Pb vacancies which would carry a magnetic moment. Similarly, an excess of Pb^+ ions or Te vacancies would lead to the paramagnetic behavior in n-type PbSe. Samples PbTe 2 seemed to be strongly compensated, the nonstoichiometric ions are probably either neutral or doubly ionized, and do not carry a magnetic moment.

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