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Specific Heat of SnTe-MnTe System from 2 to 25°K*

Abstract: The low-temperature specific heat of a series of semiconductor alloys of the SnTe-MnTe system, for Mn to Sn ratios of 0 to 0.1 has been measured in the temperature range 2 to 25°K. Large anomalies are observed due, presumably, to the ordering of the Mn⁺⁺ spin system. The temperature region over which these anomalies occur is roughly the region in which ferromagnetism is observed.

Introduction

The semiconducting system (Sn_{1-x}Mn_x)_y Te, where y is slightly less than unity, provides an interesting system for the study of indirect exchange mechanisms since the carrier density and the concentration of the magnetic ions can be varied independently over a wide range within the primary phase field of the B1 structure based on SnTe. As reported earlier,^{1,2,3} the Mn ions couple ferromagnetically with each other in the SnTe matrix and the paramagnetic Curie temperature θ varies linearly with the magnetic ion concentration. For a constant magnetic ion concentration, θ varies with the carrier concentration as is expected in a typical indirect exchange. Since the change in energy that occurs when the spontaneous magnetization of the ferromagnetic system is changed gives rise to thermal effects, we have measured the specific heats of the pure material and its alloys for y approximately equal to 0.97.

The heat capacity measurements were performed in a modified pulsed type calorimeter described previously.⁴ The accuracy of the calorimeter was checked by measuring the heat capacity of pure copper. The electronic and lattice terms both lay within 0.5% of the previously determined values as noted in a previous paper.⁵

Results and discussion

The low-temperature heat capacity was measured from 1.8°K to 25°K, which is well above the temperature range where superconductivity occurs (0.20°K for Sn_{0.97}Te). The observed specific heat of Sn_{0.97}Te (see Fig. 1) at the lowest temperatures ($< \theta_D/20$) can be fitted to the expression

$$C = \gamma T + \alpha T^3, \quad (1)$$

where γT is the electronic contribution to the specific heat and αT^3 is the lattice contribution. The values of γ and θ_D , derived from α in the usual way, are 1.1 mJ mole⁻¹ deg⁻² and 135°K respectively. Our data on pure Sn_{0.97}Te, shown in Fig. 1, are in good agreement ($\gamma = 1.15$, $\theta_D = 144^\circ\text{K}$) with similar measurements made down to 0.3°K by Phillips et al.⁶ on samples prepared in a different manner. Also shown in the same figure are the raw data for Sn_{0.97}Te when 3, 5, 7 and 10 atomic percent of Mn is introduced. The additional contribution to C must be attributed to the presence of Mn ions, which at low temperatures dominates the specific heat, due, presumably, to magnetic effects.

Assuming that the total heat capacity C_A of the alloy is the sum of the heat capacity C of pure Sn_{0.97}Te and a magnetic term C_M due to the presence of Mn ions, we have for the alloys

$$C_A = C + C_M. \quad (2)$$

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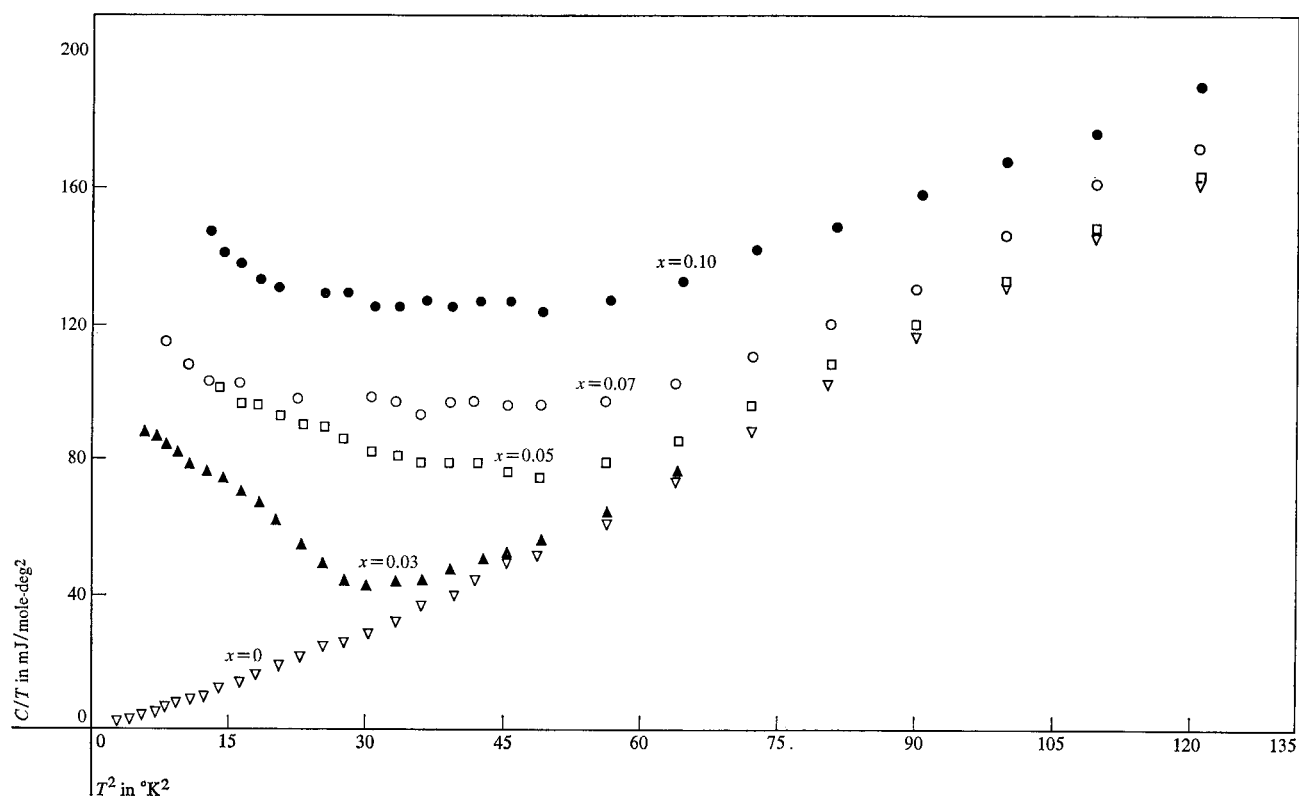


Figure 1 C/T vs T^2 for pure $\text{Sn}_{0.97}\text{Te}$ and its Mn alloys.

Figure 2 C_M/T vs T for alloys.

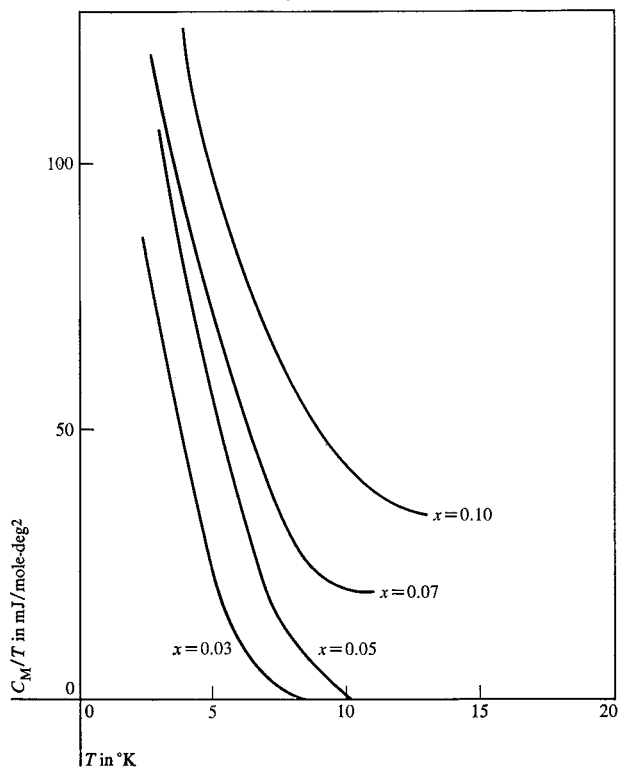
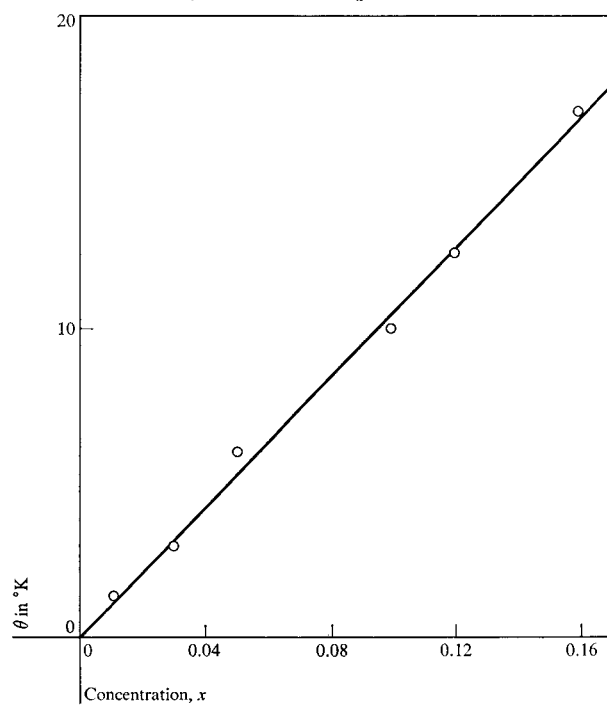


Figure 3 Paramagnetic Curie temperature θ vs x .



In Fig. 2, C_M/T is plotted against T . It should be noted by comparison with Fig. 3, where θ has been determined from susceptibility measurements, that the temperature region in which C_M/T has the large negative slope is roughly the region in which these alloys are ferromagnetic. The heat capacity itself in this region rises to a peak between absolute zero and the paramagnetic Curie temperature and then falls with increasing temperature. Preliminary results indicate that the curves may flatten out above the Curie temperature instead of approaching zero. The fact that the peak is broad is probably a consequence of the variation in molecular field at the various sites of the Mn ions.⁷

The extra entropy due to the Mn ions is given by $\int (C_M/T)dT$. A rough estimate of this integral, as given by Fig. 2, shows it to be approximately proportional to the concentration x , and the proper order of magnitude to be accounted for by the magnetic term $k \ln(2s + 1)$

per Mn ion, where k is the Boltzmann constant and s the spin (5/2 in our case).

References

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