A detailed description of studies of the photomagnetic effect in p-n junctions will be published later.

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SPIN-WAVE HEAT CAPACITY IN ANTIFERROMAGNETIC MnCO$_3$

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INVESTIGATION of the temperature dependence of the heat capacity of antiferromagnetics gives the possibility of verifying the predictions of the theoretical law of dispersion of spin waves. However, up until the present time such investigations have not been carried out. In large part this is connected with the fact that in the usual antiferromagnets, because of the presence of a significant gap in the energy spectrum, the magnetic heat capacity should change exponentially, and in the low temperature region it is found to be small compared with the lattice heat capacity. One of the authors[1] has shown that in the case of the antiferromagnetic carbonates, in which the spins lie in the plane perpendicular to the three-fold axis, the spin-wave spectrum divides into two branches, one of which has practically no gaps. The result is that the magnetic heat capacity, beginning at very low temperatures, should vary according to a cubic law.

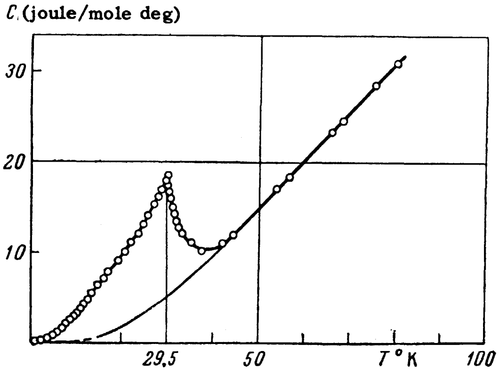

FIG. 1. Temperature dependence of the molar heat capacity of MnCO$_3$ (points and heavy curve) and CaCO$_3$[7] (light curve) extrapolated to 0°K (dashes).

In the present work the temperature dependence of the heat capacity of MnCO$_3$ was studied from 1.6 to 80° K. The MnCO$_3$ compound in the form of tiny crystals was obtained by a hydrothermal method by N. Yu. Ikornikova of the Institute of Crystallography of the U.S.S.R. Academy of Sciences.[2] The measurements were carried out in a vacuum calorimeter similar to that used in[3,4] in the region 1.5—14° K and in an adiabatic calorimeter[5] from 14 to 80° K. The temperature was measured with a bronze thermometer below 4° K, a carbon thermometer between 4° and 14° K[6], and a platinum thermometer above 14° K. Figure 1 shows the general behavior of the heat capacity. The characteristic maximum corresponding to the transition of manganese carbonate from the antiferromagnetic to the paramagnetic state can be seen here. The heat capacity maximum is found at 29.5° K, which is 2.9° lower than $T_N = 32.4°$ K, as determined from magnetic data.[1]

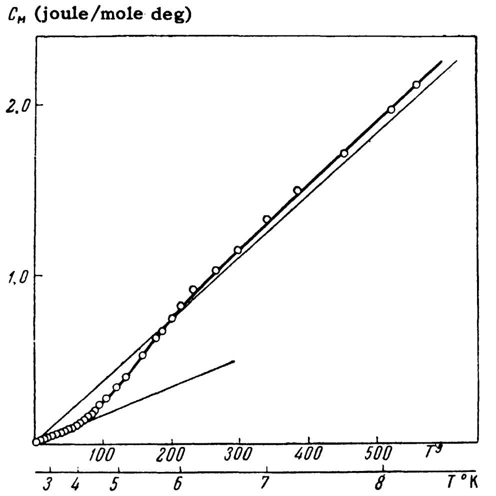

FIG. 2. Temperature dependence of the magnetic heat capacity of MnCO$_3$. (The light lines are according to the spin wave theory from the magnetic data.[1])

In order to separate out the magnetic heat capacity it was necessary to subtract the lattice and nuclear heat capacities from the data obtained. In order to estimate the specific heat of the lattice we made use of the results of Simon and Swain,[7] who investigated the temperature dependence of the heat capacity of diamagnetic CaCO$_3$, isomorphous with $MnCO_3$, above 14° K. From Fig. 1 it can be seen that above the transition temperature the heat capacities of $MnCO_3$ and $CaCO_3$ vary according to the same law and do not differ by more than 4%. Since the heat capacity of $CaCO_3$ already follows a T^3 law below 25°K, we considered it possible to extrapolate these results to helium temperatures and took for the lattice heat capacity the following formula obtained from the data of Simon and Swain[7]: $C_{lat} = 2.08 \times 10^{-4} T^3$ joule/deg mole. It is to be noted that this amount of heat capacity does not exceed 10% of the total heat capacity of $MnCO_3$ at low temperatures. As is known,[8] ordering of the nuclear moments begins already at helium temperatures in antiferromagnets, leading to an additional contribution to the heat capacity of the form $C_{nuc} = b/T^2$. From our data at low temperatures we find $b = (2.7 \pm 0.5) \times 10^{-2}$ joule/deg mole, which agrees within the limits of error with the value of b for MnF_2.[8]

The magnetic heat capacity C_M obtained from our data after introducing the corrections indicated is plotted in Fig. 2 vs. T^3. We see that up to 3.7° K the heat capacity varies according to the cubic law, agreeing with the formula obtained in [1]:

$$C_M = (4\pi^2 k^2 / 5\mu_B)\, \chi_\perp^0 \eta T_N (T/T_N)^3 = aT^3.$$

Substituting in this formula the values $\chi_\perp = 43 \times 10^{-3}$, $\eta = 0.24$, $T_N = 32.4$° K from [1], we obtain $a = 17.5 \times 10^{-4}$ joule/mole $\deg^4$. The experimental value is $a = 18 \pm 0.7 \times 10^{-4}$ joule/mole $\deg^4$. Such good quantitative agreement between the temperature dependences of the spontaneous magnetization and heat capacity of $MnCO_3$ is an important experimental confirmation of the spin wave theory. From 3.7 to 6° K C_M increases sharply and thereafter up to 8.5° K follows the cubic law anew. The coefficient in this new cubic law equals (2.1 ± 0.1) a. This result is also found to be in agreement with the prediction of spin wave theory, according to which the magnetic heat capacity should increase with a doubled coefficient after excitation of the second branch (which has a gap kT_{AE}). An approximate estimate of the size of the gap from a consideration of the transition region gives $T_{AE} = 15$° K.

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