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SPIN-WAVE CONTRIBUTION TO THE HEAT CAPACITY OF NICKEL[1]

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The heat capacity of two high-purity nickel samples has been measured in the range from 1.8 K to 4.2 K. The existence and magnitude of a spin-wave contribution to the heat capacity of nickel has been established in both samples with a higher accuracy than in previously reported measurements.

ВЛИЯНИЕ СПИНОВЫХ ВОЛН НА ТЕПЛОЕМКОСТЬ НИКЕЛЯ

Измерена теплоемкость двух образцов никеля высокой чистоты в области температур от 1,8 К до 4,2 К. В обоих образцах более точно чем в предыдущих работах определен вклад спиновых волн в теплоемкость никеля.

I. INTRODUCTION

The total molar heat capacity of pure nickel can be written theoretically in the form

$$C = \gamma T + \beta T^3 + \alpha T^{3/2} F\left(\frac{T_g}{T}\right), \quad (1)$$

where γT is the electronic contribution, βT^3 is the lattice contribution, and the third term is the spin-wave contribution assuming the presence of spin-waves in ferromagnetic nickel. The coefficient γ is directly proportional to the density of states $D(\varepsilon_F)$ at the Fermi level ε_F

$$\gamma = \frac{\pi^2}{3} k_B^2 D(\varepsilon_F),$$

where k_B is the Boltzmann constant.

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The coefficient β is related to the Debye temperature T_D

$$\beta = \frac{12}{5}\pi^4 R \frac{1}{T_D^3},$$

where R is the molar gas constant.
The coefficient α is given by

$$\alpha = (0.113/z)R(k_B/2Js)^{3/2},$$

where $z = 4$ for nickel and 2 Js is a measure of the exchange interaction between neighbouring spins. The function $F(T_g/T)$ is the correction function which takes into account the energy gap $k_B T_g$ in the spin-wave spectrum. According to Argyle et al. [1] and Dixon et al. [2]

$$F\left(\frac{T_g}{T}\right) = 1 - 0.39\frac{T_g}{T} + 0.04\left(\frac{T_g}{T}\right)^2.$$

$T_g = a + cB$, where for Ni $a = 0.6$ K, $c = 1.3$ KT^{-1} and B is the magnetic induction corrected for demagnetization. Dixon et al. [2, 3] have found evidence for a spin-wave contribution to the heat capacity of iron, iron-nickel and copper-nickel alloys. However, their data for a spin-wave contribution to the heat capacity of nickel are ambigous. Because of the obvious importance to detect the spin-wave contribution to the heat capacity of nickel we decide to study the heat capacity of nickel in the temperature range from 1.8 K to 4.2 K, and also in the magnetic field

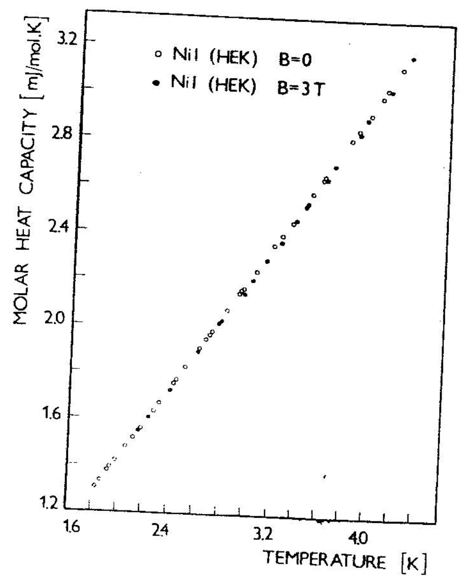

Fig. 1. The temperature and the magnetic field dependence of the molar heat capacity of Ni.

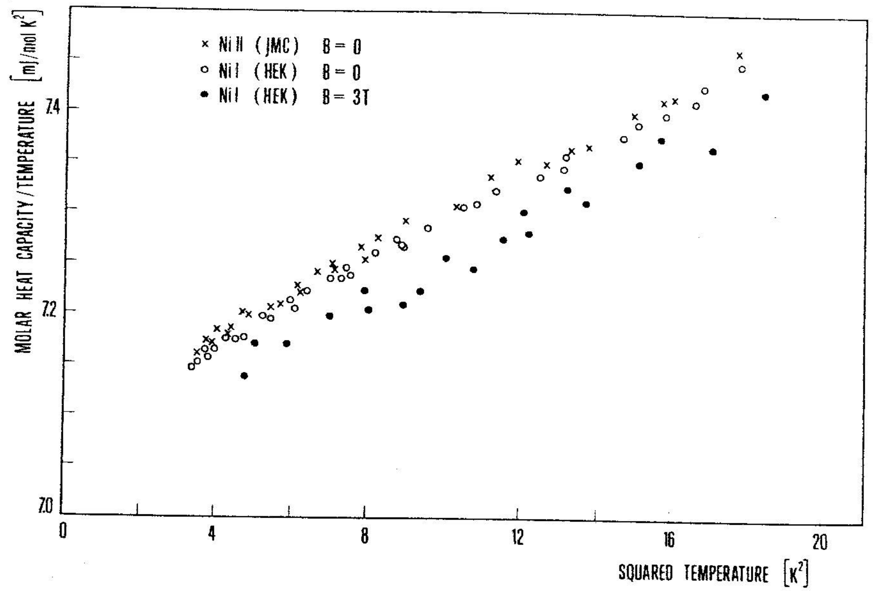

Fig. 2. The dependence of C/T vs. T^2.

3 T. The magnetic field quenches the spin-wave heat capacity by introducing a gap in the energy spectrum of the spin-waves.

II. EXPERIMENTAL DETAILS

The adiabatic pulse method was used. To calibrate the calorimeter, the heat capacity of a pure copper sample was determined. The essential features of the cryostat used in these investigations were published in [4]. The first nickel sample Ni I weighed 18.03352 g and was obtained from HEK, Lübeck, catalogue number M 11 250/64, with the following impurity contents: Fe (2 ppm), Cu (0.5 ppm), Al (1 ppm), Mg (0.5 ppm), Si (3 ppm), Ag (1 ppm). The second sample Ni II weighed 17.29873 g and was obtained from Johnson-Matthey Co., catalogue number JMC 890/8233/1 with the following impurity contents: Fe (10 ppm), Cu (2 ppm), Al (1 ppm), Si (1 ppm), Na (1 ppm, Ca (1 ppm), Ag (1 ppm). Both samples were annealed for 4 hours 40 minutes at 1033 K at a pressure 10^{-3} Pa.

III. EXPERIMENTAL RESULTS

Fig. 1 shows the data on the temperature dependence of the molar heat capacity of Ni I and the effect of the magnetic field. Three methods of analysis were used to determine the spin-wave contribution.

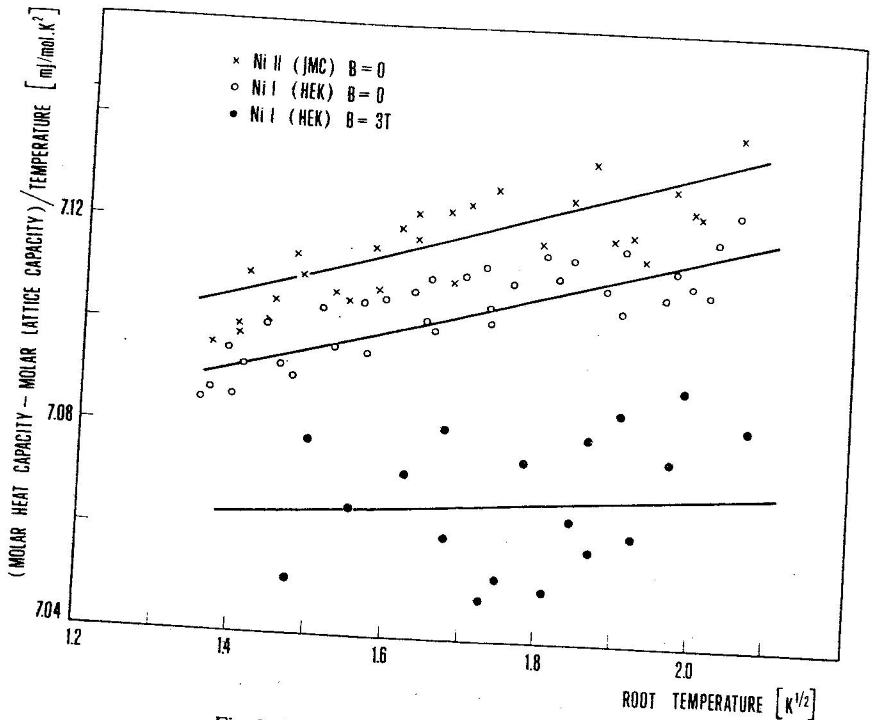

Fig. 3. The dependence of $(C/T-\beta T^2)$ vs. $\sqrt{T}$.

1. The results of measurements were plotted as C/T vs. T^2 and the effect of a spin-wave term is to cause the experimental curve to be slightly concave towards the T^2 axis because

$$\frac{d^2(C/T)}{d(T^2)^2}<0$$

for $T>T_g$. Fig. 2 shows the data protted in this way.

2. If we use the recommended value for the Debye temperature $T_D=473$ K [5] and the plot $(C/T-\beta T^2)$ vs. $\sqrt{T}$, the slope of such a line with $T_g=0$ is the coefficient α. If $T_g\neq 0$, then the slope of such a curve is slightly temperature dependent.

3. In the magnetic field 3 T the spin-waves are quenched and thus the spin-wave contribution is practically eliminated (Fig. 3).

Table 1 shows the result of fitting the experimental data to Eq. (1) with $T_g=0.6$ K using the recommended value for the Debye temperature $T_D=473$ K [5].

Table 1

	Ni I	Ni II
α [mJ/mol $K^{5/2}$]	0.036 ± 0.004	0.040 ± 0.006
T_D [K]	473.0	473.0
γ [mJ/mol K^2]	7.050 ± 0.006	7.056 ± 0.009

IV. CONCLUSION

The experimental results of the heat capacity of two high-purity nickel samples obtained from the different manufactures indicate unambiguously the presence of a spin-wave contribution. The magnitude of the spin-wave contribution in both samples was established with a higher accuracy than in previously reported measurements. The coefficient α is very close to the value of (0.033 ± 0.004) mJ/ /mol $K^{5/2}$ calculated from neutron scattering experiments [6].

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