ELECTRICAL RESISTIVITY AND THERMOELECTRIC POWER OF Ni NEAR THE CURIE POINT

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It is shown that the thermoelectric power of Ni as a function of temperature exhibits a minimum followed by a maximum in the same temperature interval in which a deviation from the logarithmic temperature dependence of the $\alpha(T)=d\rho(T)/dT$ curve was observed. In other samples of the same purity the $\alpha(T)$ curve did not show any deviation from the logarithmic temperature dependence and the thermoelectric power is a monotonic function of the temperature.

In the last few years there has been a growing interest in the critical behavior of the transport properties of matter.[1] The primary aim of the research has been to study the appearance and character of the singularities in transport coefficients. In this paper some new results of high-precision electrical resistivity and thermoelectric power measurements on high-purity nickel in the vicinity of its Curie point will be reported.

It was noticed a long time ago[2] that the temperature coefficient of the resistivity $[\alpha(T)=d\rho(T)/dT$, where $\rho(T)$ is the resistivity$]$ of various d metals has a sharp maximum at T_c, although this fact has only recently attracted greater attention.[3] Three years ago Craig et al.[4] measured directly $\alpha(T)$ in five-9's purity Ni and found a logarithmic divergence for $T>T_c$ and for $\epsilon=|T-T_c|/T_c>5\times10^{-3}$. Closer to the Curie point they observed a stronger than logarithmic divergence. It was suggested by Craig et al. that the change in the strength of the divergence is related to the fact that the range of the critical fluctuations equals the mean free path of the electrons at a temperature near the Curie point.

These observations stimulated Fisher and Langer[5] to improve the existing theoretical treatments of the resistivity anomaly such as that of de Gennes and Friedel.[6] It was clearly shown that the main contribution to the resistivity anomaly in magnetic metals near the Curie point is due to the short-range spin fluctuations and hence $\alpha(T)$ should have the same temperature dependence as that of the magnetic specific heat above but near the Curie temperature. The measured values of $\alpha(T)$ on Ni are consistent with this conclusion in the temperature region of logarithmic divergence, but the change in the order of the divergence observed by Craig et al. cannot be explained by the Fisher-Langer theory.

In order to obtain more precise data and to study the most sensitive electronic transport property of metals it was decided to perform careful electrical resistivity and thermoelectric power measurements in the vicinity of the Curie point on nickel samples of 99.999% purity produced by Johnson and Matthey.

For the measurements three samples were prepared from the same Ni. Each of the samples was a 50-cm-long Ni wire of 0.1 cm diam wound as a small sphere which was inserted into the middle of a precisely shielded spherical vacuum furnace. The temperature inhomogeneity in the sample was less than 0.01°K.

The resistivity measurements were carried out using dc and a manual potentiometer with a photogalvanometer amplifier of high stability. During the measurement the current in the sample was kept constant within 10^{-6}. The voltage on the specimen was almost exactly compensated by the potentiometer and only the noncompensated part of the voltage was fed after a suitable amplification into the y input of an x-y recorder. A Pt-PtRh thermocouple welded on the sample measured the temperature. The amplified noncompensated voltage of the thermocouple was fed into the x input of the recorder which directly recorded the $\rho(T)$ curve in arbitrary units.

The thermoelectric power was measured on the same samples as the resistivity. In order to produce a small temperature difference between the ends of the Ni wire, direct current of 0.2 A was applied to the sample through the current leads for a short period (5-10 sec). The generated Peltier heat resulted in a temperature difference of a few tenths centigrade on the sample. After the switching off of the current the temperature difference begins to decrease immediately and disappears in about 2 min. By measuring the decreasing voltages of the Pt-Ni-Pt and PtRh-Ni-PtRh differential thermocouples the thermoelectric power of Ni can be determined.

The voltage of one of the differential thermocouples versus that of the other was recorded after a suitable amplification by an x-y recorder. If the parasitic voltages do not change during the measurement a straight line can be expected,

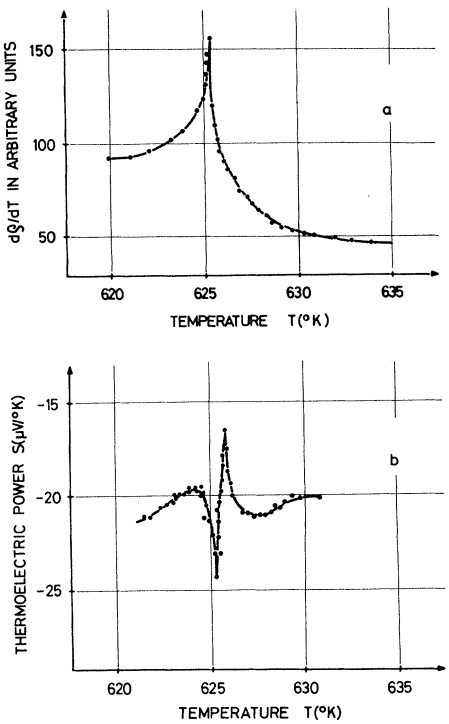

FIG. 1. (a) $\alpha(T) = d\rho/dT$, the temperature coefficient of resistivity of Ni sample No. 1, versus temperature in the vicinity of the Curie point. (b) Variation of the absolute thermoelectric power with temperature of Ni sample No. 1 in the immediate neighborhood of the Curie point.

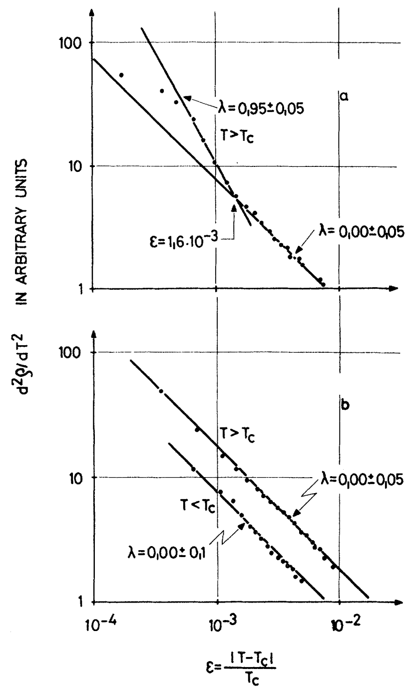

FIG. 2. (a) The log-log plot of $d\alpha/dT$ vs $\epsilon = |T-T_c|/T_c$ for sample No. 1. (b) The log-log plot of $d\alpha/dT$ vs $\epsilon = |T-T_c|/T_c$ for sample No. 2. λ is the critical exponent describing the divergence of $\alpha(T)$.

from the slope of which it is easy to calculate the thermoelectric power of Ni. Since the temperature difference on the sample was not larger than 0.2° even at temperatures near the Curie point, the just-described method allowed us to determine the absolute thermoelectric power of Ni to an accuracy of better than 5%.

In order to determine the divergence of the temperature coefficient of the resistivity in the vicinity of the Curie point, $\alpha(T)$ was represented in a manner proposed by Fisher for other divergent quantities:

$$\alpha(T) = A(\epsilon^{-\lambda} - 1)/\lambda + B,$$

where $\epsilon = |T-T_c|/T_c$ and A, λ, and B are temperature-independent constants. From the measured $\rho(T)$ curve, the curve of $\alpha(T) = d\rho(T)/dT$ was calculated by graphical differentiation using intervals $\Delta T = 0.1°$. In Fig. 1(a) the temperature dependence of $\alpha(T)$ for sample No. 1 is shown.

Calculating the second derivative of $\rho(T)$ for $T > T_c$ we used the log-log plot of the curve

$$\frac{d\alpha(T)}{dT} = -A\epsilon^{-(\lambda+1)}$$

for the evaluation of the parameter λ. The log-log plot of $d\alpha/dT$ can be seen in Fig. 2(a). The agreement with Craig's curve is quite satisfactory. The only difference is that the break point at which the strength of the divergence is changing lies nearer the Curie point than in Craig's curve which gives $\epsilon \sim 5\times10^{-3}$ as compared with our $\epsilon \sim 1.6\times10^{-3}$. Below the Curie point the strength of the divergence could not be clearly determined.

The thermoelectric power measurements on sample No. 1 resulted in a very unexpected anomaly. It can be seen in Fig. 1(b) that the curve of thermoelectric power versus temperature has a sharp minimum followed by a sharp maximum in the same very narrow temperature interval in which the deviation from the logarithmic divergence of the $\alpha(T)$ curve was observed. Far from the Curie point the temperature dependence of the thermoelectric power does not differ from the results of other measurements.[7]

In our experiment, however, the most important result is the disappearance of the break point on the $\alpha(T)$ curves measured on the other two samples. Fig. 3(a) shows the $\alpha(T)$ curve for sample No. 2. Precisely the same curve was found in the case of sample No. 3. In Fig. 2(b) the log-log plot of $d\alpha(T)/dT$ clearly demonstrates

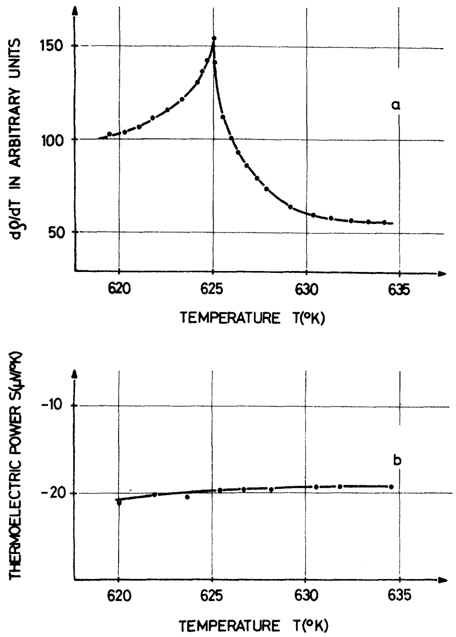

FIG. 3. (a) The temperature coefficient of resistivity of Ni sample No. 2 versus temperature. (b) The temperature dependence of the absolute thermoelectric power of sample No. 2.

that the logarithmic divergence is conserved on both sides of the Curie temperature at temperatures very near the critical point, too. More exactly, it was found that the temperature coefficient of the resistivity in Ni has a logarithmic divergence in the immediate neighborhood of the Curie temperature ($|T-T_c| \geq 0.2$°K).

The temperature dependence of the thermoelectric power on these samples (No. 2 and No. 3) is completely different from that measured on the sample (No. 1) with a break point on the $\alpha(T)$ curve. In samples No. 2 and No. 3 the curves of thermoelectric power versus temperature do not show any surprising anomaly in the vicinity of the Curie point. As can be seen in Fig. 3(b), the curve for sample No. 2 is quite similar to that reported earlier.[7]

In the light of these results a few comments can be made concerning the Fisher-Langer theory and the Craig experiment. First, Fisher's conclusion that $\alpha(T)$ should vary as the magnetic specific heat above the Curie point is consistent with the experiment covering the immediate neighborhood of the Curie point ($|T-T_c| \geq 0.2$°K). Second, the prediction that $\alpha(T)$ should have a critical exponent of $2\beta-1$ below the Curie point (β is the critical exponent for the magnetization) seems to be not true because the experiment suggests a logarithmic divergence. Third, Craig et al.'s suggestion that the crossover between the two types of singular behavior occurs when the correlation length equals the electronic mean free path is rather questionable since the onset of the crossover may depend on several factors the nature of which is not yet understood. The only thing which can be regarded as a real physical consequence of the short electronic mean free path is that which was pointed out by Fisher, and this is the importance of the short-range part of the spin-correlation function in the critical behavior of the resistivity of magnetic metals.

Finally, one has to note here that the critical behavior of the thermoelectric power unfortunately cannot be analyzed theoretically because of the lack of any theory in this field.

[1]P. P. Craig and W. I. Goldburg, J. Appl. Phys. 40, 964 (1969).

[2]W. Gerlach, Physik Z. 24, 953 (1932); H. Bittel and W. Gerlach, Ann. Physik 33, 661 (1938).

[3]Ya. A. Kraftmakher, Fiz. Tverd. Tela 9, 1528 (1967) [Soviet Phys. Solid State 9, 1197 (1967)].

[4]P. P. Craig, W. I. Goldburg, T. A. Kitchens, and I. I. Budnick, Phys. Rev. Letters 19, 1334 (1967).

[5]M. E. Fisher and J. S. Langer, Phys. Rev. Letters 20, 665 (1968).

[6]P. G. de Gennes and J. Friedel, J. Phys. Chem. Solids 4, 71 (1958).

[7]M. V. Vedernikov and N. V. Kolomoets, Fiz. Tverd. Tela 2, 2718 (1960) [Soviet Phys. Solid State 2, 2420 (1961).