CRITICAL BEHAVIOUR OF THERMAL RESISTIVITY OF Ni

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Accurate data are presented on the behaviour of the thermal conductivity $K$ as a function of temperature for a pure Ni sample near its Curie point. Previous results on the electrical resistivity ($\rho$, $d\rho/dT$) are used to explain the temperature-dependence of $K(T)$. The results are analysed in terms of electron-phonon and $s-d$ exchange interactions. The critical behaviour of the thermal resistivity $W (= K^{-1})$ has also been investigated.

Study of the transport properties of magnetic phase transitions provides a sensitive and often rather simple means of investigation details of the microscopic interactions. The electrical resistivity $\rho$ in particular has received a good deal of attention [1–7]. The scanty experimental information available on the thermal conductivity $K$ of magnetic materials and on the complex behaviour which occurs in the transition region earlier precluded any discussion on such matters as the values of the critical exponents. Accordingly, only general features were considered [8–12]. The critical exponents are of interest because many different kinds of physical systems behave in a similar way near the critical point $T_c$. This work reports for the first time the critical exponents of the thermal resistivity of pure Ni both below and above $T_c$. The universality concept [4, 5, 13] is also tested.

In ferromagnetic metals and alloys, the most characteristic interaction is the $s-d$ interaction, i.e. the spin exchange interaction between the conduction (s) and unfilled shell (d) electrons. According to Kasuya [1], this exchange interaction depends on the relative orientation of the spins of both electrons. Therefore, at $T=0$ all the spins of $d$-electrons being in order, there is no electrical resistance, while at a finite temperature this order is disturbed and thus a resistance appears and increases with temperature. Above $T_c$, the directions of the $d$-electron spins become perfectly random, and the electrical resistance remains constant. The resistivity caused by such a process is called the spin-fluctuation [3] or spin-disorder contribution [10].

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In the present work, we present accurate data on the thermal conductivity of pure Ni near its Curie point. The results show a well-defined anomaly in $K(T)$, precisely located at $T_c$ and in good agreement with the electrical resistivity data ($\rho$, $d\rho/dT$) obtained for the same sample [7]. The results are discussed in terms of electronic, phonon and $s-d$ exchange interactions. The critical exponents of the thermal resistivity are calculated and compared with the unique rough estimate reported for Ni by Graig et al. [14], who analysed the thermal diffusivity data measured by Kirichenko [15].

Experimental

A nickel rod 2.34 mm in diameter and 5.5 cm in length was supplied by the National Physics Laboratory, Budapest, Hungary. It was stated to be of high spectrographic purity. The electrical resistivity $\rho$ of the same sample was previously measured by using a standard four-probe technique [7].

The thermal conductivity $K$ was measured by using an apparatus described in detail earlier [11, 12]. It is mainly based on the electrical and thermal potential distributions along a thin rod that is heated by passing a direct electric current through it. The quantity $K\rho$ was calculated by using the measured voltage vs. temperature ($V$ vs. $\theta$) relation. The estimated uncertainty in $K$ is about 3%.

Results and discussion

1 Electrical resistivity

It was shown previously that the electrical resistivity $\rho$ of ferromagnetic metals and alloys displays anomalous behaviour during transition from the ferromagnetic to the paramagnetic state. This anomaly results from the exchange interaction between the $s$ and $d$-electrons [1, 3]. In a previous paper [7] on the electrical resistivity of Ni, particular emphasis was put on analysis of the critical behaviour related to the nature and the type of the singularities in the temperature coefficient of resistivity (TCER) in the immediate vicinity of $T_c$.

In this work, we are interested only in decomposing the electrical resistivity into its different contributions according to the corresponding scattering mechanisms, and in using the results in the analysis of the thermal resistivity. If Mattheissen's rule is assumed provide an adequate approximation, the total electrical resistivity $\rho(T)$ is the sum of a spin-fluctuation component $\rho_s(T)$, a component due to electron-phonon scattering $\rho_{ph}(T)$, and a contribution due to the scattering of electrons by