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ELECTRON-ELECTRON SCATTERING IN CADMIUM

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Abstract.- Radio-frequency size effect measurements on cadmium indicate an electron-electron scattering frequency of \( \sim 2 \times 10^7 \text{s}^{-1} \text{K}^{-2} \), a factor of five larger than the theoretical value of Lawrence and Wilkins.

In recent years there has been renewed interest in estimating the magnitude of electron-electron (e-e) scattering and in searching for this characteristic \( T^2 \) contribution to the resistivity. Lawrence and Wilkins /1/ have calculated that it is of the same order of magnitude in the alkalis as in the other non-transition metals : the distorted Fermi surface (FS) of the latter metals enhances the number of "Umklapp" scattering processes. ("Normal" scattering processes do not contribute).

The smallness of the e-e scattering contribution explains why it has not yet been observed unambiguously except in the transition metals. Its observation requires a resolution of the order of \( 10^{-6} \) in resistivity measurements /2/. On the other hand radio-frequency size effect (RFSE) measurements /3/ have the advantages of : a) measuring both the normal and Umklapp e-e scattering frequency; b) being selective of the electron orbit investigated c) sufficiently sensitive : The RFSE signal varies typically by some 20% in the interval \( 1-2 \text{K} \). We present here the results of new tilted and parallel field RFSE measurements on different orbits in cadmium which confirm the presence of e-e scattering of the right order of magnitude. Our 13 mm diameter disc-shaped samples were spark-cut from 6\( \Omega \) single crystal bars and then polished mechanically and chemically to remove surface damage. The sample is placed in a loosely fitting coil that forms the inductive part of a tank circuit driven by a marginal oscillator optimized for RFSE measurements /4/. The temperature is measured by a calibrated Ge resistance clamped on the sample.

The amplitude of the RFSE signal is proportional to the probability that the electrons cross the sample without scattering : 

\[
A(T) = A(0) \exp \left( -\nu(T)t \right)
\]

where \( \nu(T) \) is the \( T \)-dependent scattering frequency and \( t \) is the time taken for an electron to cross the sample without scattering. The zero-temperature amplitude is determined by the impurity scattering frequency \( \nu_0 \), \( t \), and the sensitivity of the marginal oscillator. As \( \nu_0 > 1 \) in our samples we neglect the effect of multiple passes through the skin depth in analysing parallel field measurements. We do, however, use the modulus of the RFSE signals occurring in phase and in quadrature with the modulation magnetic field and we make the small corrections necessitated by the temperature dependence of the modulation magnetic field penetration depth /5/ to obtain an accuracy for \( A(T) \) of \( \pm 0.5\% \) at low \( T \).

We have analysed our data using the following simple expression :

\[
\nu(T) = \alpha T^2 + \beta T^1 + \delta T^n
\]

Theoretically the electron-phonon (e-p) scattering is expected to be proportional only to \( T^1 \). However the presence of strong intersheet scattering at points on the orbits where the electrons are close to the Brillouin zone boundary and the 2nd band FS sheet leads to temperature dependencies more rapid than \( T^1 /6/ \) and this effect is simulated by the \( \delta T^n \) term. Analysis with more complex formulae for e-p scattering do not alter the order of magnitude of the e-e scattering term.

The data for the circular and elliptic extremal orbits and the tilted field orbit near (0001) are shown in figure la. The results for the open orbit in the same sample are shown in figure lb.
Fig. 1 a: Scattering frequency $v(T)T^{-2}$ versus $T$ for electrons on the circular (0) and lenticular (0) extremal orbits, and the tilted field orbit (A) near <0001> on the 3rd band FS sheet of Cd. Sample thickness 0.527 mm. Equations (1) and (2) are fit to the data (solid curves) and the resulting values for the intercepts $\alpha$ are $(2.5, 2.1$ and $2.0 \pm 0.1) \times 10^{-7}$ s$^{-1}$ K$^{-2}$.

Fig. 1 b: Mean free path $\lambda(T)T^{-2}$ versus $T$ for electrons on the open orbit on the second band "monster" FS sheet of Cd. $B = 1.6$ T. Equations (1) and (2) are fit to the data with $s/\lambda(T)$ (s is path length across the sample) instead of $v(T)t$, as the Fermi velocity for electrons on this orbit is unknown, and the resulting value for $\alpha$ is $1.9 \times 10^{-7}$ mm$^{-1}$ K$^{-2}$.

Re-analysis of older parallel field measurements on a Cd sample 1.280 mm thick are shown in figure 2. In all cases a non-zero contribution to $v(T)$ proportional to $T^2$ is found. It is larger by about a factor of 5 than the value predicted by Lawrence and Wilkins/1/ for e-e scattering in cadmium, namely $4 \times 10^6$ s$^{-1}$K$^{-2}$ (including normal processes). The observed e-e scattering rate is quite isotropic in contrast to the large anisotropy found in the e-p scattering rate as can be seen in figures 1 and 2 /6/.

References

/1/ Lawrence, W.E. and Wilkins, J.W., Phys. Rev. B7 (1973) 2317-32