ELECTRON MOBILITY VARIATION IN DENSE ^{4}He GAS *

H. R. HARRISON and B. E. SPRINGETT
H.M. Randall Laboratory of Physics, The University of Michigan, Ann Arbor, Michigan, 48104, USA

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We present electron mobility measurements in ^{4}He gas for $10^{19} < \rho < 10^{22}$ cm^{-3} and $3 < T < 300$ K. The results are discussed in terms of current theories and a new model for the electron bubble is proposed.

We have used a single-gate velocity spectrometer to measure electron mobility in the gas phase of ^{4}He. The gas number density was obtained using pressure and temperature measurements and the equation of state. The mobility is accurate to roughly ± 10% absolute accuracy. Smoothed values are presented in fig. 1 (density variation) and fig. 2 (temperature variation). The internal accuracy of each curve is greater than that already quoted. For fig. 2, the density along a given curve remains only approximately constant due to a finite volume at room temperature. Agreement with previous values at 4.2 K [1] and 300 K [2] is excellent. The curves show clearly the transition from free electron to localized electron behavior.

To elaborate, the low density and/or high temperature variation of the mobility, μ, is characteristic of a free electron both with respect to magnitude and to variation with the independent variable; the high density and low temperature limit of μ has a variation characteristic of a large object moving in a viscous medium. In these two limits agreement with calculated values of μ is good. It is the transition region between the two which is poorly understood. Recent attempts [3-5] at explaining the dramatic drop in μ are in poor agreement with our data. In the case of [3] and [4], the problem is tackled from the free electron point of view assuming static random scattering centers. No attempt is made to take account of atom-atom correlations or gas deformations by the electron. The value of these treatments is that they are first attempts to properly include multiple scattering and the statistics of the scattering centers. The shortcoming of [1] and [5] and similar calculations [6,7] is that they assume a particular model for the localized electron - the bubble model - and, in analogy with the problem of an insulator with fixed traps, take for μ a weighted average of localized and free mobilities. This approach is invalid on three counts at the lower densities: (i) the current bubble model uses a square-well potential which is obviously incorrect as the atomic separation becomes large; (ii) the bubble only exists for $\rho > \rho_c$ $T < T_c$, where ρ_c, T_c are deter-

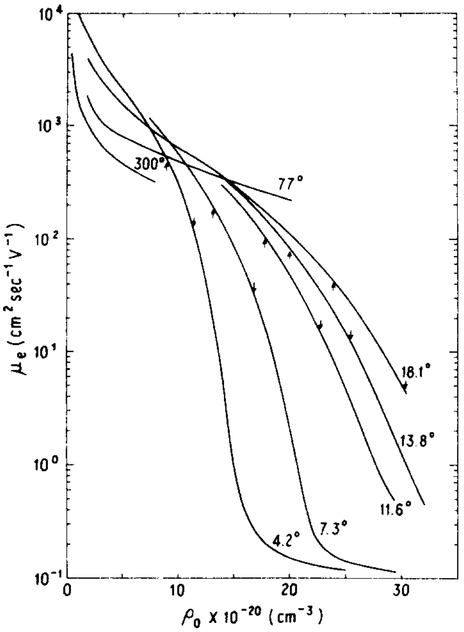

Fig. 1. Measured electron mobility versus number density at temperatures as marked. The ↑ arrows show where the state corresponding to eq. (1) first becomes stable: the ↓ arrows indicate the same point for a square-well bubble.

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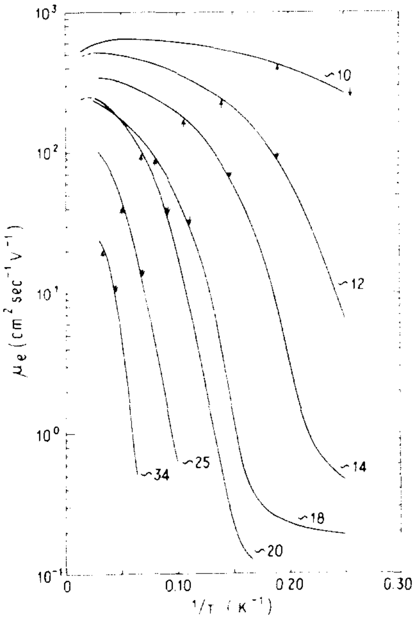

Fig. 2. Mobility versus inverse temperature at almost constant density as marked in units of 10^{20} cm^{-3}. The arrows have the same meaning as in fig. 1.

mined by the total free energy of the system; (iii) the electron is self-trapped and hence its lifetime in the localized state depends on density fluctuations interfering with the formation of a stable state.

In interpreting our data we ignored (iii) because this boils down to trying to improve on the static theories [3, 4], and concentrated on improving the situation as regards (i) and (ii). We adopted a rounded trapping potential,

$$V(r) = -U_0 \cosh^{-2}\{\alpha(\rho, T)r\} \tag{1}$$

which is algebraically tractable, and contains only a single parameter like the square-well. U_0 is the Wigner-Seitz value and we performed essentially the same algebra as in [8] to find the value of α which minimizes the free energy of the system. We find that the localized state sets in at significantly lower values of ρ (or higher T) than is the case for the square-well. The figures show that we now have respectable quantitative agreement with the values of ρ and T at which the drop in μ occurs. However, we still cannot fit the shape of the curves very well using this model (our fits drop too steeply).

In conclusion, our data are compatible with a transition from free electron to localized electron behavior and can be explained quantitatively in the high and low density limits. The model we adopted for the localized state is more realistic than previous models and gives good agreement with the data for the values of ρ and T at which the mobility collapse occurs. Details will be published at a later date. We suspect that better overall fits will be obtained if the theory of [4] can be improved, and if measurements of the electric field dependence of the drift velocity are incorporated into the theory [1, 5].

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