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MOBILITY OF ELECTRONS IN LIQUID He^3 AT THE CRITICAL POINT

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In this Letter we report some experimental results on the mobility of electrons in liquid He^3 at the critical point. Considerable interest[1-3] has been raised recently about the behavior of the transport properties at the critical point. However, as far as diffusion is concerned, very few experimental results[4-6] are available and these are strongly conflicting.

In fact, some authors[4] claim that at the critical liquid-gas point the diffusion coefficient D goes practically to 0, whereas others[6] do not find any peculiar behavior. We chose to measure the mobility of electrons in He^3 since, as is well known, electrons in dense He become practically a rigid bubble[7] of about 14-Å radius, and therefore, they are very useful probes for studying hydrodynamics.[8,9] Moreover, the mobility μ and the diffusion coefficient are related by the Einstein relationship. He^3 is a very convenient substance since it is available at high purity,[10] and very good PVT experimental data are available.[11] On the other hand, quantum effects do not seem to modify qualitatively the critical behavior as has been shown for equilibrium properties.[12] The experimental apparatus is shown in Fig. 1. With the He^4 bath at a temperature of 0.05°K lower than the He^3 temperature, the exchange gas provides any necessary cooling to the He^3 cell, while heating is provided by the resistance heater ⑤ wound around the He^3 cell ④. The heater current is electronically controlled by the two

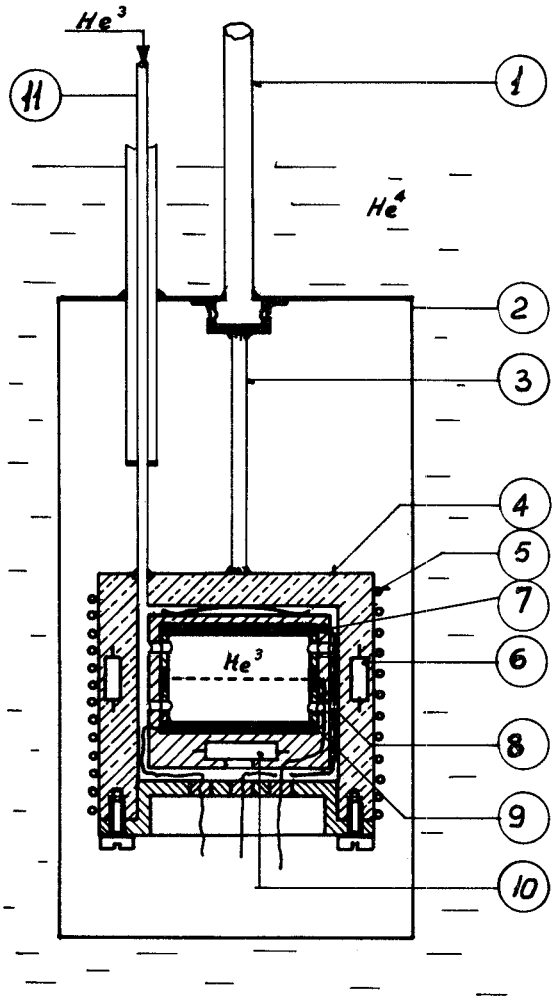

FIG. 1. Schematic view of the experimental assembly. ① Inlet tube for exchange He^4 gas, ② stainless-steel container, ③ supporting tube, ④ copper block containing the He^3 cell, ⑤ heater, ⑥ two carbon resistors incorporated within the walls of the copper block. ⑦, ⑧, and ⑨ form a triode for mobility measurement as follows: ⑦ Source electrode coated with P^{210}, ⑧ grid, ⑨ collector electrode. ⑩ carbon resistor for measurement of the temperature of He^3, ⑪ vacuum-jacketed He^3 filling tube.

carbon resistors ⑥ imbedded in the wall of the cell. The He^3 temperature is read by the carbon resistor ⑩, immersed in the liquid He^3, which was repeatedly calibrated against the He^4 vapor pressure using the T_{58} temperature scale. The accuracy of the calibration was $\pm 2\times 10^{-3}$ °K. The stability of the temperature of the He^4 bath, achieved through a bellows manostat, was ±0.005°K, whereas that of the He^3 cell was ±0.0002°K. The pressure of the He^3 in the cell was read by a Texas-Instrument quartz bourdon gauge (sensitivity ±0.02 Torr) and corrected for the hydrostatic head (however, this correction was always very small). To measure the mobility we used a time-of-flight method[13,14] which measures essentially the time of flight between the grid ⑧ and the collector ⑨. The distance from the grid to the collector was 4 mm; so the gravitational effect on the critical point was negligible. The electric field between grid and collector (zero-to-peak voltage of the square wave) was either 150 or 75 V/cm; no difference was observed. For thermodynamical states around the critical point the time of flight result ≥ 0.1 sec. The error on the μ measurement was ±3%.

The measurements were performed at constant temperature varying the He^3 pressure in both senses (decreasing and increasing pressure). Around the critical point the pressure increments were ≤ 0.3 mm Hg between successive points. In each step we waited more than 1 h after equilibrium was reached before performing the mobility measurement. At the critical point we repeated the measurement at 1-h intervals in the same thermodynamic conditions without observing any difference.

The experimental results are shown in Fig. 2, where the PVT data[11] were used to transform $\mu(T,p)$ into $\mu(T,\rho)$. The curves a, b, c, and d are smooth curves through the experimental isotherms. It is evident from Fig. 2 that approaching the critical isotherm we have a clear decrease of the mobility in the density region $0.7 \leq \rho/\rho_c \leq 1.3$. (The critical values were taken from Ref. 11.)

In Fig. 3(a) we report the mobility versus $(T-T_c)/T_c$ at $\rho=\rho_c$.

In Fig. 3(b) we report the critical effect on the mobility at $T=T_c$ as a function of ρ measured by the difference between the critical isotherm and the one at $T=3.448$°K which, from the previous figures, seems to be slightly affected by critical effects. From these figures the critical region, as far as mobility is concerned, appears to be quite wide mainly on the ρ/ρ_c axis. The effect is peaked for $\rho \simeq \rho_c$ but it is slightly unsymmetrical. One possible explanation, excluding critical effects, for the mobility defect at the critical point would be a modification of the bubble radius. However, this effect would seem to us quite unlikely, on the basis of the theoretical model[7] for the bubble, since an increase of 27% of the bubble radius would be needed to explain the over-all decrease.

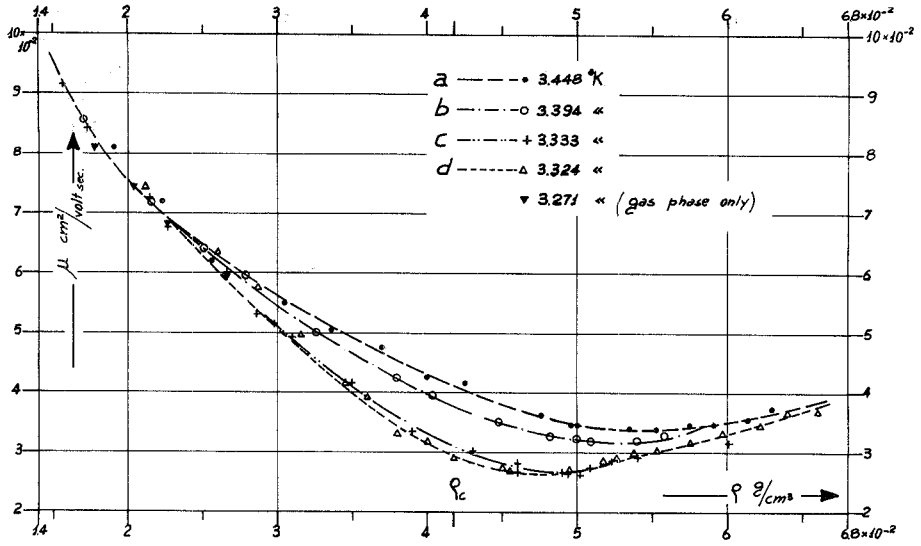

FIG. 2. Experimental results: $\mu = f(\rho)$ for various isotherms. Curves a, b, c, and d are smooth curves through the experimental points for each isotherm.

We conclude from our measurements that the mobility, and therefore the diffusion coefficient, undergoes a small decrease (~30%) in the critical region but does not seen to go to 0 as Krichevskii, Khazanova, and Linshitz[4] reported. Our results seem to confirm the Noble and Bloom experiments,[5] although these authors analyze their data in a different way, mixing possible effects on the diffusion coefficient with the density behavior. With regard to the Trappeniers and Oosting experiments[6] we would like to point out that, keeping in mind our knowlegde of the width of the critical region, they have just one point ($\rho = 235$ Amagat; $T = 190.48$°K) useful for the investigation of the critical effect.

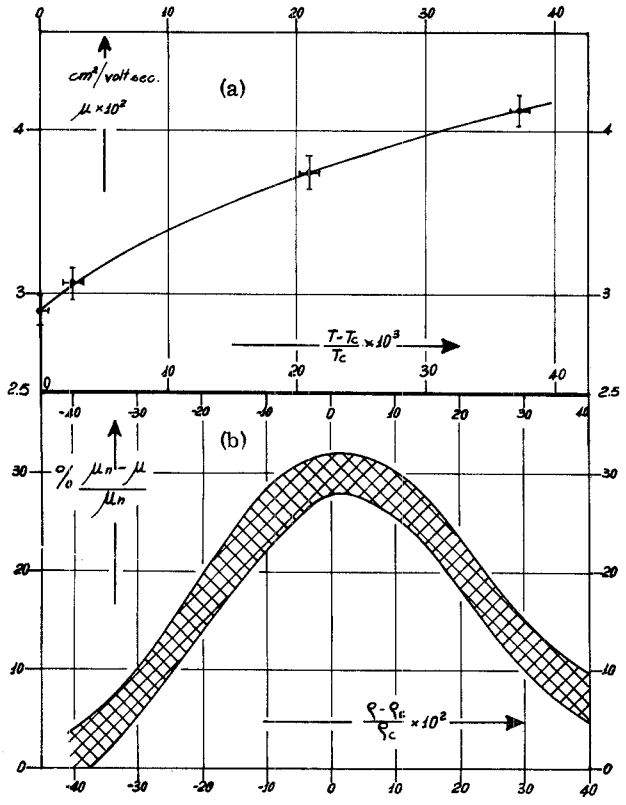

FIG. 3. (a) Mobility versus temperature at $\rho = \rho_c$. (b) $[\mu_n(T = 3.448°K) - \mu(T = 3.324°K)]/\mu_n(T = 3.448°K)$ as a function of density. The width of the curve represents the experimental uncertainty.

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