Electron mobility near the surface of liquid helium at temperatures down to 0.5 °K

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We measured the absorption of the energy of an electromagnetic field by surface electrons in the temperature interval 0.48–1.9°K at 2.98 and 14.65 MHz. The measurements have made it possible to determine the mobility of the surface electrons. It was observed that at $T < 1$°K the presence of the surface exerts a substantial influence on the character of the electron motion.

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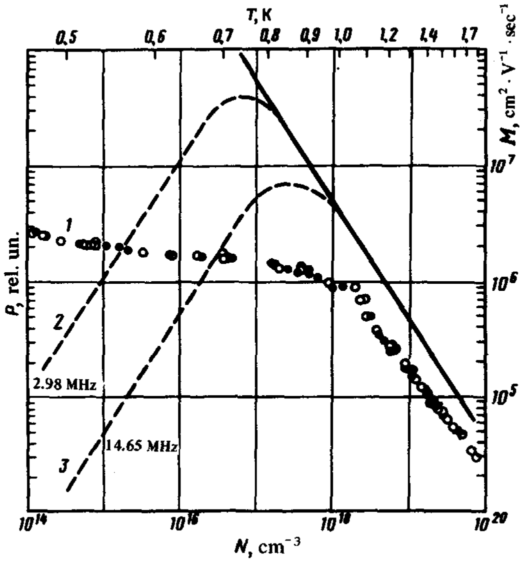
When electrons move along the boundary between liquid helium and its vapor (the surface electrons)[1] they should interact with the thermal excitations of the surface[2,3] and with the atoms of the gaseous helium. However, the data of[4–8] indicate that in the temperature region where the measurements were made (1–2 °K) it is impossible to observe the contribution of the surface oscillations to the electron scattering, and the electron mobility is determined by the collisions with the helium atoms in the vapor.

It was therefore deemed advisable to assess the influence of the surface on the electron motion at lower temperatures, where the vapor density becomes insignificant. To obtain information on the mobility of the surface electrons, we investigated in the present study the absorption of the energy of an electromagnetic field (2.98 and 14.65 MHz) by such electrons in the temperature interval 0.48–1.9 °K.

The absorption was determined from the change of the Q of a resonant circuit following admission of the surface electrons into the measurement space. The alternating electric field was parallel to the liquid-helium surface. The concentration of the surface electrons was set by means of a weak clamping field and ranged from 10^5 to 10^6 electrons/cm^2. The error in the determination of the absorption and concentration of the electrons was ~20%.

The experiments on the determination of the absorp-



Dependence of the relative specific absorption of the electromagnetic-field energy by surface electrons on the temperature: ●—2.98 MHz, ○—04.65 MHz, +—data on the electron mobility in gaseous helium.[7] Solid line—calculated values of μ_0.[10] *Curves 2 and 3—calculated from formulas (1).*

tion were first performed at relatively high temperatures, and served simultaneously for calibration purposes. As is well known, the power absorbed by charged particles in an alternating electric field of amplitude E and frequency ω is given by[1)]

$$p = eN\mu E^2 \qquad \mu = \frac{\mu_0}{1 + \omega^2\tau^2}. \tag{1}$$

Here N is the number of charges, $\mu_0 = (e/m)\tau$ is the mobility of the electrons in a constant electric field, e and m are the charge and mass of the electron, and τ is the relaxation time. At $\omega\tau \ll 1$ the absorption is directly proportional to μ_0 and does not depend on the frequency.

It was established experimentally in the present study that in the interval 1.3–1.9 °K the temperature dependence of the absorption coincides, for both frequencies, with the temperature dependence of the electron mobility in the gaseous helium. This is seen from the figure, which shows the dependence of the relative specific absorption P on the temperature, as measured in the present study (curve 1), and the electron-mobility data taken from[7]. The $P(T)$ curve was matched to the $\mu_0(T)$ dependence at 1.4 °K. The fact that both relations have the same character indicates that the absorption, as expected, is determined down to ~1.1 °K by the scattering of the electrons by the gaseous-helium atoms. A similar result was obtained in an earlier measurement[9] of the absorption in the interval 1.4–2.0 °K, with the alternating electric field perpendicular to the surface of the liquid helium.

In the temperature region 0.48–0.9 °K, however, the temperature dependence of the absorption begins to deviate from the expected value, and P varies approximately like T^{-1} at both frequencies. The figure shows for comparison the calculated plots of $P(T)$ described by relations (1) in the case when the electrons interact only with the helium atoms in the vapor (curves 2 and 3). The corresponding theoretical expression for τ was taken from[10]. It is seen that at low temperatures there are appreciable differences in the variations of the experimental and calculated absorption P, in its temperature dependence, and in its frequency dependence.

This disparity between the calculated and experimental dependences indicates that at low temperatures there appears a new electron-scattering mechanism, which is apparently connected with the existence of the interface between the vapor and the liquid and is due to the presence of thermal surface excitations in the liquid helium. The fact that the temperature dependence of $P(T)$ is the same at the two employed frequencies gives grounds for assuming that the condition $\omega\tau \ll 1$ holds in the entire investigated temperature region, and consequently $P \sim \mu_0$. Therefore the absorption data, when reconciled with the known value of μ_0 at high temperatures, yield information on the mobility of the surface electrons in the entire investigated temperature region.

It should be noted that the presented data were obtained at low values of E and N, where the relative specific absorption, and consequently also the mobility, do not depend on these values.

The results, unfortunately, cannot be compared with the theoretical estimates of[3], since the mobility was calculated there in the presence of a clamping electric field greatly exceeding that used in the present work. As to the results of Cole,[2] the value ~10^5 cm²/V-sec he obtained for the surface-electron mobility is lower than ours by one order of magnitude. Thus, we have observed here experimentally the influence of the surface of liquid helium on the motion of the electrons. The investigations of the observed regularities are being continued.

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[1)]These formulas are valid under the assumption that τ is independent of the momentum.

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