

# Electron localization over the surface of crystalline hydrogen and neon

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(Submitted 20 February 1979)

*Pis'ma Zh. Eksp. Teor. Fiz.* **29**, No. 7, 421-425 (5 April 1979)

Electron localization in stationary dielectric energy levels near the surface of crystalline hydrogen and neon was observed. We measured the mobility of localized electrons in a two-dimensional layer which depends on vapor pressure and the quality of dielectric surface. The density of localized electrons remains unchanged for tens of minutes.

PACS numbers: 63.20.Pw

Electron localization near the dielectric surface in two-dimensional layers in stationary hydrogen-like levels has, heretofore, been observed for the case of cryogenic liquids: He<sup>4</sup>,<sup>4</sup> He<sup>3</sup>,<sup>2</sup> and H<sub>2</sub>.<sup>3</sup> However, similar dielectric levels may in principle also exist near the surface of a solid dielectric.<sup>4</sup> Investigation of this possibility is interesting primarily for two reasons: 1) electron transitions between dielectric levels that occur near cosmic dust particles may be the cause of cosmic radio emission in the submillimeter range<sup>5</sup> and 2) the electron density in a two-dimensional layer over the surface of a solid dielectric may be considerably higher than over the surface of a liquid where it is limited by surface instability.<sup>6</sup> We describe below experiments in which the possibility of electron localization in dielectric levels near crystalline hydrogen and neon was established under real experimental conditions, and the mobility of these electrons in two-dimensional layers produced by them was measured.

Figure 1 shows the layout of an instrument similar to one used in Ref. 3. The specimen liquid (H<sub>2</sub> or Ne) is condensed in Dewar 1 placed inside a helium cryostat in an amount such that its level 2 measured by a cathetometer lies between plane capacitor electrodes 3 and 4. The plate 4 inlet serves as a cold duct; the Dewar temperature  $T$  is regulated by its position in the cryostat. The liquid crystallizes by slow cooling in an hour at a rate  $\sim 3 \times 10^{-3}$  cm/min. The resultant crystals are transparent and have a specular surface. Electrons are emitted by a tungsten cathode 5 heated by a pulsed

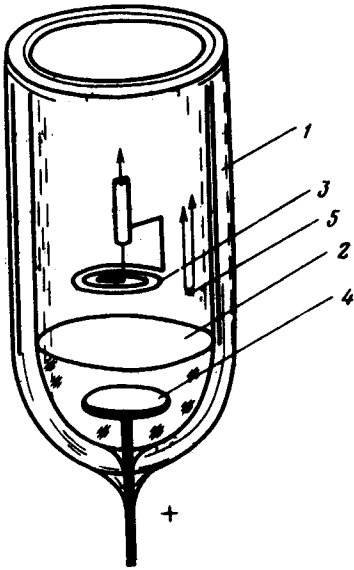


FIG. 1. Instrument layout.

electric source, and are maintained on the dielectric surface by the condenser field  $E \sim 0.3\text{--}1$  kV/cm. The presence of electrons and their mobility are determined from a reduction by  $\sim 5\%$  in the quality  $Q \sim 350$  of the measuring circuit (resonant frequency  $\sim 5.5$  MHz) in which a plane coil forms the upper electrode 3.

Under the influence of the capacitor field the emitted electrons diffuse in the gas toward the dielectric surface losing their energy in the process. This gives rise to an electron layer near the solid hydrogen surface at a temperature 12–14 K and a vapor pressure 14–50 tor. In the mobility measurements at low vapor pressures we used an electron layer obtained at a sufficiently high vapor density followed by a cooling of the instrument. At lower temperatures 10–11 K (pressure 3–10 tor) the emitted electrons fail to lose their energy, overcome the potential barrier near the solid hydrogen and charge the surface; the same occurs in experiments with Ne. To avoid this effect we used a “retarding gas”—He pressurized to 40 tor—which was admitted into the Dewar prior to electron emission and was pumped out after the two-dimensional electron layer had formed. Application of a clamping field  $E$  for a short time leads to the irreversible disappearance of localized electrons and quality restoration in the measuring circuit.

The foregoing methods were used to obtain stable layers of electrons localized on dielectric energy levels near crystalline hydrogen and neon surfaces at temperatures of 10–14 K and 16–20 K, respectively.

The quality of the measuring circuit depends on the mobility of the localized electrons  $\mu$ , their density  $n_e$  and on the geometry of the device; the latter condition requires that the device be calibrated. Calibration was carried out in a series of special experiments with liquid helium on the basis of data for the electron mobility near a  $\text{He}^4$  surface.<sup>7</sup> A surface electron density  $n_e \sim 10^8$  electron/cm<sup>2</sup> was calculated from the conditions of total screening of the electric field over them.

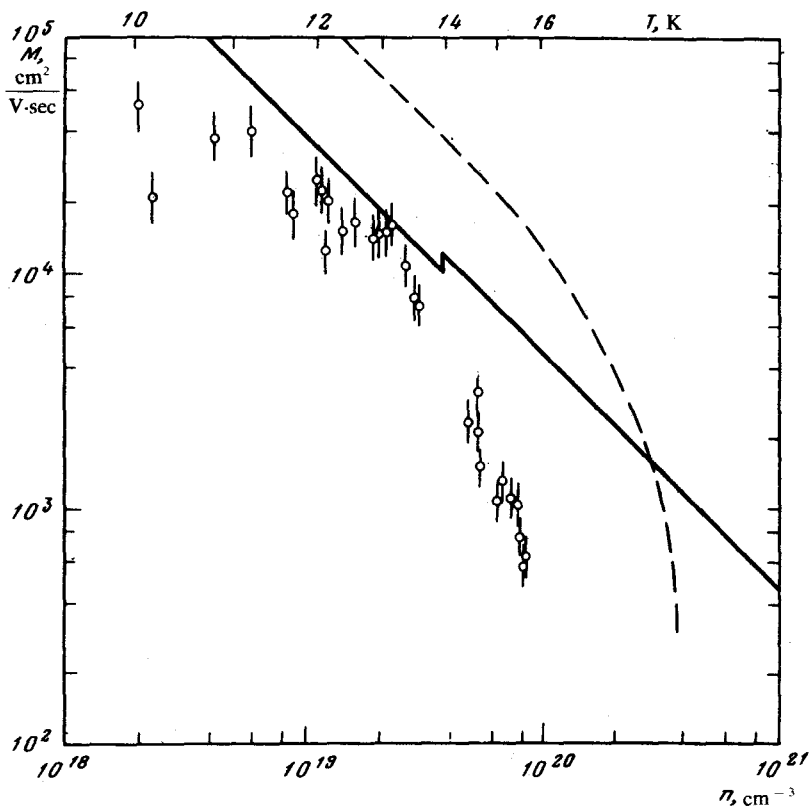


FIG. 2. Dependence of electron mobility in a two-dimensional layer over condensed hydrogen on the density of saturated vapors ( $T$  melting point = 13.9 K): broken line—theoretical calculation; dashed line—function  $\mu(n)$  for surface electrons over helium.

Figure 2 shows the results of measurements of the mobility  $\mu$  of electrons localized over a solid hydrogen surface, data points were obtained in several independent experiments. The broken line is the result of a kinetic calculation of mobility of a two-dimensional electron gas in hydrogen in accordance with Ref. 8 (the effective scattering cross-section was assumed to be  $5.7 \times 10^{-16} \text{ cm}^2$ ). The break divides the regions of the liquid and solid phases and corresponds to a permittivity jump. The dashed line shows for comparison the function  $\mu(n)$  for liquid  $\text{He}^4$  which was plotted from data in Ref. 7 ( $n$  is a number of atoms per  $\text{cm}^3$ ,  $T$  is the hydrogen temperature). The sharp reduction in the electron mobility at high helium vapor densities ( $n > 10^{20} \text{ cm}^{-3}$ ) is associated with production of negative ions—electron bubbles (bubblons) in a dense gas.<sup>9</sup> Clearly, the same mechanism determines the deviation of the function  $\mu(n)$  for hydrogen from the calculated linear path in the density region  $n \sim 10^{20} \text{ cm}^{-3}$ . At  $T \sim 12.5 \text{ K}$ , the resultant mobility function of the surface electrons over both liquid and crystalline hydrogen is determined by collisions between the electrons and molecules of the gas whose density at the above mentioned temperatures is sufficiently high. This follows from the similarity of the functions  $\mu(n)$  for He and  $\text{H}_2$  shown in

Fig. 2. At lower gas densities and  $T < 11$  K the function  $\mu(n)$  is nonexistent within experimental error and the electron density is defined by the quality of the crystal surface. This consideration is confirmed by the fact that electron mobility that was measured in experiments involving crystals of poorer quality which were grown at an increased rate of crystallization  $> 10^{-2}$  cm/min, is two to three-fold smaller.

The measured values of mobility of electrons localized over crystalline Ne are as follows:

$\mu \left( \frac{\text{cm}^2}{\text{V}\cdot\text{sec}} \right)$	$10^{-4}$	2.2	2.4	0.85 ( $\pm 15\%$ )
$n \text{ ( cm}^{-3} \text{ )} \cdot 10^{-18}$	1	4	12	

The effect of surface imperfection of the crystalline dielectric on mobility—measured in our experiments—may be explained in terms of two mechanisms: 1) scattering of electrons on the surface defects and 2) capture of electrons by the surface traps, which leads to a reduction in the density of traveling electrons. In order to determine the relative contribution of each of these processes to mobility, experiments are needed to measure  $\mu$  by other methods, for instance utilizing the resonant method or measurement of time-of-flight over a given path.

It should be noted that the density of electrons localized near the surface of crystalline hydrogen or neon remained unchanged during the entire helium experiment.

The authors thank P.L. Kapitza for attention to this work, V.S. Edel'man for useful discussions and F.S. Chernyshev for technical assistance.

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