Ion "geysers" on the surface of superfluid helium

A. P. Volodin and M. S. Khaĭkin
Institute of Physics Problems, USSR Academy of Sciences

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A mechanism for disturbing the surface stability of superfluid helium charged by positive helium ions localized in the fluid near the surface is studied kinematographically and electrically. It is shown that the charge leaves the helium surface along with jets of liquid helium ejected by "geysers" arising on the crests of capillary waves.

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In Ref. 1 conditions have been studied for the breakdown of the surface stability of superfluid helium on which there is a two-dimensional layer of electrons localized in dielectric levels, and a mechanism for the loss of these electrons was given. Electrometric studies and high-speed cinematography showed that in the dips of the capillary waves arising during the breakdown of helium surface stability, there are bubbles charged by electrons, "bubblons," dipping into the helium and reaching the bottom which is the anode.

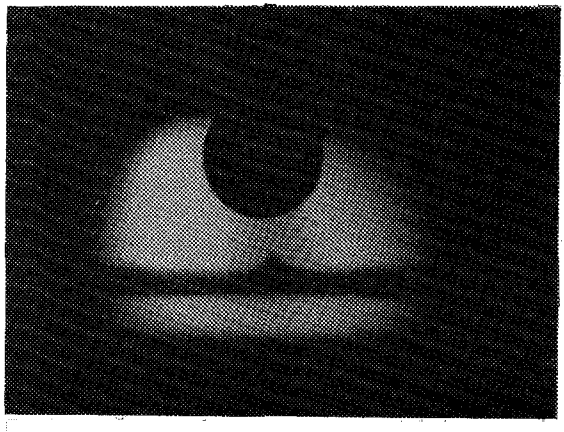

FIG. 1.

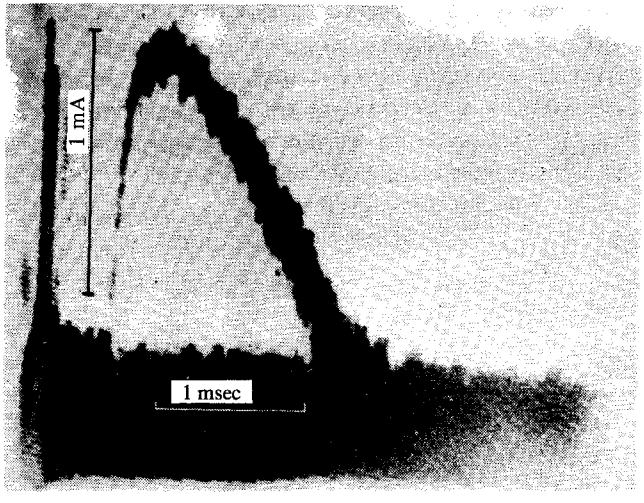

FIG. 2.

At the liquid helium surface from the liquid side[2] positive helium ions may also be localized. Results of electrical studies of the discharge of the charged surface by helium ions in the temperature range 3.24–5.13 K are given in Ref. 3. The pulsed nature of the discharge current is interpreted to mean that the discharge occurs by the formation of charged drops which escape upward from the liquid surface to the cathode.

In this work the mechanism for the surface discharge of superfluid helium by positively-charged helium ions was studied by means of high-speed cinematography in conjunction with a study of the discharge current. The studies were carried out in a cryostat with optical windows at a liquid helium temperature of 1.2 K. The helium surface was located between the capacitor electrodes; the upper electrode (cathode) was joined to a high-speed electrometer with a time resolution of $\sim 10^{-5}$ sec. The anode was a mesh through which the ions produced by the radioactive β-source below passed toward the capacitor. The ion current was controlled by the electrical potential of the source. The ions which penetrated to the capacitor gap were forced to the helium surface by the capacitor field.

During the experiment the state of the liquid helium surface was observed visually and was photographed by a high-speed movie camera. The surface discharge current was measured by a high-speed electrometer with an oscillograph at the output.

The appearance of the ion layer at the helium surface causes a rise in the helium level in the capacitor by tenths of a millimeter, similar to the lowering of the level for the case of surface charging by electrons.[1] When the electric field acting on the surface charge $n = 4.4 \times 10^8$ electrons/cm^2 reaches the critical value $E_{cr} = 1900$ V/cm, the surface stability is perturbed and it loses charge (the critical parameters for the system have been studied in Ref. 3).

The occurrence of instability leads to the excitation of electro-capillary waves at the helium surface. At their crests "geysers" are formed which eject liquid helium jets that reach the cathode. Figure 1 shows a movie film frame showing such a "geyser." In this experiment we used a cathode in the shape of a sphere with a diameter 2.5 mm which allowed us to localize the "geysers." The diameter of the helium jet at its upper part was $\sim 10^{-3}$ cm. The lifetime of an individual jet was $\sim 10^{-3}$ sec. During this time a charge of $\sim 10^8$ e (e is the electron charge) flows to the cathode. An oscillogram for the jet current pulse is shown in Fig. 2. The pulse width exceeds the resolution of the electrometer by about two orders of magnitude. Thus, the helium ion current moving with the jet is continuous.

The formation of charged jets of superfluid liquid helium is apparently explained by the fact that the helium ion flow traps neutral liquid with it. The high ion mobility in the superfluid helium ($\sim 10^2$ times larger than for 4.2 K) allows them to be drained to the jet from a rather large region of the helium surface (an area ~ 10 mm^2, judging by the magnitude of the charge) bounded by a random distribution of capillary waves and, thus, to continuously feed the jet for its entire lifetime.

Thus, it is shown that the two-dimensional layer of helium ions localized at the superfluid helium surface is lost as a consequence of the development of surface instability in relation to the electro-capillary waves.[4] During this process "geysers" occur on the helium surface which eject jects of charged fluid. The reason for this qualitatively new mechanism for the surface discharge of a fluid dielectric is high ion mobility in the superfluid helium.

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