Observation of electrons localized over the surface of liquid ^{3}He

V. S. Édel'man

Institute of Physics Problems, USSR Academy of Sciences
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Cyclotron resonance of electrons localized over the surface of liquid ^{3}He was investigated. The measurements were made at a helium temperature 0.37 K at a frequency 18.76 GHz. A decrease of the electron relaxation time was observed with increasing clamping field. This is satisfactorily explained, for electrons localized above ^{3}He as well as ^{4}He, as being due to their interaction with the thermal oscillations of the helium surface.

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Electrons localized over the surface of liquid ^{4}He and forming a two-dimensional conducto were revealed in many studies[1] by thir electrostatic interaction with the dielectric. The mechanisn whereby such a system is produced is not connected with any peculiarities of liquid ^{4}He, and similar electron localization should take place over liquid ^{3}He, over liquid and solid Ne or H_2, an possibly over other dielectrics with relatively small dielectric constants ϵ.[2] We have therefor performed experiments aimed at observing cyclotron resonance for electrons localized over th surface of liquid ^{3}He.

The experimental setup is similar to that previously used in[3,4] A measured quantity of ^{3}He (c ^{4}He) was condensed in a vacuum-tight cylindrical resonator of 20 mm diameter and 9 mm heigh The electrons were extracted from the plasma produced when a discharge was initiated in the ga and were confined by a clamping electric field E applied between the insulated bottom of th resonator and its body. After turning on the discharge, a wave of frequency 18.76 GHz (TE_1 mode) was seen to pass through a resonator symmetrically coupled to two coaxial lines. A typic

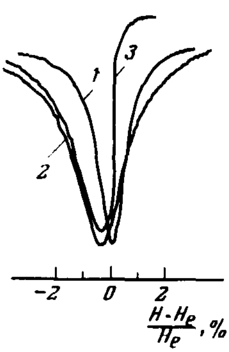
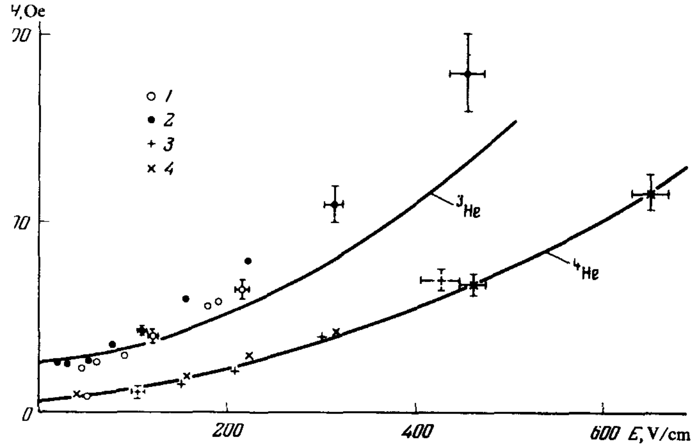


FIG. 1. Dependence of the amplitude of an 18.76-GHz signal passing through the resonator on tl magnetic field: 1—clamping field $E=90$; 2,3—$E=180$ V/cm. The jumplike change of the signal c plot 3 is due to the departure of the electrons from the ^{3}He surface. Temperature 0.37 K, depth ^{3}He layer 0.97 mm. The characteristic vertical scale represents the transmission coefficient ar decreases at resonance by an approximate factor of two. H_e is the cyclotron-resonance field of tl free electrons.



G. 2. Dependence of cyclotron-resonance line half-width ΔH on the clamping field E: 1,2—elec-
ɔns over a layer of ^{3}He 0.97 and 1.42 mm thick; 3,4—over ^{4}He 0.70 and 0.99 deep, respectively.
lid curves—calculation.

ot of the signal against a magnetic field applied normal to the helium surface is shown in Fig. 1 ıd demonstrates the absorption accompanying the cyclotron resonance.

In contrast to ^{4}He, where the electrons can remain over the surface of the liquid for a 'actically unlimited time after the discharge is turned off, in the case of ^{3}He we observed a mplike partial or total departure of the electrons after a random time interval that ranged from veral seconds to tens of minutes (Fig. 1). This phenomenon, in our opinion, is connected with e possibility of superheating and boiling of the ^{3}He, accompanied by bubble formation.

Just as for the electrons localized over ^{4}He,[3] a broadening and a shift of the resonance lines, rresponding to a decrease of the effective mass, were observed with increasing clamping field tensity E (Fig. 1). The dependence of the cyclotron-resonance line half-width ΔH on the ımping field is shown in Fig. 2.

To decrease the error of E due to the inhomogeneity of the electrostatic field in the resonator lume and the inhomogeneous charge density along the surface of the liquid, the measurements ːre performed at helium depths $d \sim 1$ mm. The experiments were performed in such a way that :er the surface became charged at the maximum value of E the successive plots were obtained th decreasing clamping field. The surface electron density n was the maintained at a value such ıt there was no electrostatic field over the liquid. In this case

$$n = V/4\pi de; \quad E = V/2d, \tag{1}$$

ıere V is the potential difference between the electrodes.

Owing to the small depth of the helium layer, even a slight inclination of the bottom of the ːonator relative to the horizon can lead to an appreciable inhomogeneity of E. It was possible to just the position of the instrument by observing the dependence, on the inclination angle θ, of : critical value E_{cr} at which the charged ^{4}He surface becomes unstable.[5] It turned out that when : discharge gap was continuously turned on, E_{cr} varied linearly with θ, decreasing by a factor ː–2 when θ changed from zero to $\sim 1°$. This has made it possible to mount the instrument in such way that the bottom of the resonator was parallel to the liquid surface accurate to $\sim 1'$, rresponding to possible variations ~ 0.01 mm in the depth of the helium; such variations are mparable with the deviations of the surface of the lower electrode from a plane. We note incidentally that the values of E_{cr} for ^{4}He were close to the predictions of the theory,[5], while fo ^{3}He they turned out to be smaller by a factor 2–4.

The width of the cyclotron resonance line as $E \to 0$, for the case of ^{3}He, was determined almos completely by the scattering of the electrons by the gas atoms. From the measured value $\Delta H = 2$ Oe calculation yields for the ^{3}He pressure in the resonator a value 0.015 Torr. (The pressure in th resonator was not measured by us directly; the ^{3}He pressure in the evaluated bath that cooled th resonator was 0.01 Torr. In analogy with the previously observed[4] appearance of a narro cyclotron-resonance line when the electron system localized over the liquid ^{4}He was superheate by a microwave field, this phenomenon was observed also for the ^{3}He case. The cyclotron resonance line for the free electrons had a width ~ 8 Oe, which is about one-third the width for th surface electrons. Calculations by means of the formulas of[6] yields for this ratio the close valu 2.3.

The value of ΔH calculated for ^{3}He at $E=0$ in accordance with[7],[1)] due to the electron-ripplo interaction, is 1.8 Oe. However, when E is increased the electron ripplon interaction increase rapidly (Fig. 2). To plot the theoretical curve of Fig. 2, the values of ΔH were calculated with th formulas of[7], to which was added a constant quantity corresponding to the scattering by the gas so as to reconcile the calculation with experiment as $E \to 0$.

At values $E \lesssim 200$ V/cm, the calculated dependence is close to the measured one, but at large E one notices a tendency of ΔH to increase more rapidly than predicted by the theory. In the cas of ^{4}He, good agreement with theory is observed up to fields ~ 600 V/cm. This difference for th cases ^{3}He and ^{4}He is quite natural. Indeed, the average value of the image-force field

$$\left\langle \frac{e(\epsilon-1)}{4(\epsilon+1)z^2}\psi^2(z) \right\rangle$$

(where $\psi(z)$ is the wave function of the ground state and depends on the coordinate z normal t the surface) amounts to 3.3×10^4 V/cm for ^{4}He and ~ 600 V/cm for ^{3}He. The perturbing action o the clamping field on the wave function of an electron localized over ^{4}He is therefore small, bu when the electron is localized over ^{3}He the average distance to the liquid surface is significantl decreased. The result should be an additional increases of the electron-ripplon interaction.

We note in conclusion that we have observed also electrons localized over the surface o ^{3}He+^{4}He solutions with ^{3}He concentrations from a fraction of one per cent to $\sim 10\%$.

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[1)]Formula (19) of[7] contains a numerical error that overestimates the mobility by a factor of 2

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