V. S. Édel'man. *Investigation of the Resonance properties of electrons above the surface of liquid helium*. The most effective and direct way to study the dynamics of electrons localized over the surface of liquid helium and their interaction with the surrounding medium is to investigate resonance effects in electric and magnetic fields. Resonant transitions between quantum levels and cyclotron resonance in a magnetic field H perpendicular to the helium surface were observed by Grimes *et al.*[1,2] at temperatures $T \gtrsim 1.3$ °K. Under these conditions, the main interaction determining the relaxation time is collisions between electrons and helium atoms, whose density in the vapor is 10^{19} cm^{-3}. Lowering the temperature below ~1°K results in a rapid drop in the density of the vapor, and the interaction with thermal vibrations of the liquid surface (ripplons) becomes dominant[3,4].

Our studies of cyclotron resonance at ~18 GHz showed that the electron relaxation time τ increases at small restraining fields $E_\perp$ from ~10^{-10} sec at $T = 1.3$ °K to 10^{-8} sec at $T = 0.4$ °K. Since the relative width of the resonance line was $\Delta H/H_e \approx 10^{-3}$, it was possible to establish that the effective mass of the electrons with **H**||**N** (**N** is the normal to the helium surface) and $E_\perp \lesssim 50$ V/cm is within $\sim 3 \cdot 10^{-5}$ of the mass of the free electron.

As $E_\perp$ increases, the interaction of the electrons with the ripplons becomes stronger, and this broadens the cyclotron resonance line in strong fields approximately in proportion to $E_\perp^2$ at a rate $\sim (1.5 \pm 20\%) \cdot 10^{-4}$ $(\text{eV/cm})^2$ at $E_\perp \lesssim 1$ kV/cm. Further increases in $E_\perp$ were limited by stability loss in the system of electrons over the surface of ^{4}He.[5] Similar effects have also been observed for electrons localized over the surface of ^{3}He.[6]

Increasing $E_\perp$ also lowers the effective mass.[7] The resonance shift δH in the magnetic field is proportional to $\sim E_\perp^2$ and (for ^{4}He) amounts to $(6 \pm 30\%)\ 10^{-5}$ Oe/(V/cm)^2. Experiments performed at 37.8 GHz showed that δH does not depend on frequency. A theory of the effect that agrees qualitatively with experiment (quantitative agreement has not yet been obtained) was presented in Ref. 8, according to which the effective mass decreased because the electron, localized in the plane of the liquid by the strong magnetic field, presses on its surface with a force $eE_\perp$ and forms a well whose parameters are determined by this force and by the surface tension of helium. This changes the intrinsic energy of the electron and with it the effective mass as well.

The large relaxation times make it possible to observe a whole series of nonlinear effects even at low microwave power levels. A peculiarity of the system under discussion is that the times corresponding to a mean free path are much larger for excited states than for the ground state. This is because the average distance from the helium surface to the electron increases when the latter is excited, and τ should reach $\tau_{\max} \approx 3 \cdot 10^{-4}$ sec on transition to the continuous spectrum at $T \approx 0.4$ °K. This value is determined by the frequency of collisions with vapor atoms.

Heating of electrons in cyclotron resonance has been observed in Ref. 9 (see Fig. 1). An additional narrow resonance line appears when the microwave-signal power is increased. Its position does not depend on the angle between **H** and **N**, while for surface electrons the resonance shifts in accordance with the law $H_{\text{res}} \propto 1/\cos(\widehat{\mathbf{HN}})$ (see Fig. 1). Thus, the narrow peak is associated with cyclotron resonance of free electrons. The

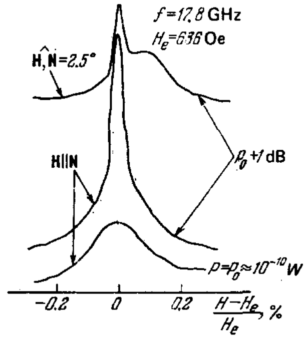

FIG. 1.

smallest linewidth that was observed was $\Delta H \approx 0.15$ Oe and corresponded to $\tau \approx 4 \cdot 10^{-7} \ll \tau_{\max}$. This was due to strong overheating of the excited electrons, something that it is fundamentally impossible to avoid in this excitation method.

It would appear promising to excite the electrons by applying a secondary electromagnetic field with a frequency corresponding to the energy of the transition between the quantized levels or their transition to the continuous spectrum. Observation of these transitions would broaden the capabilities of low-temperature spectroscopy. Among other things, we might expect to be able to observe cyclotron resonance of free electrons with a relative linewidth $\Delta H/H < 10^{-7}$, which would make it possible to work on improvement of the values of the universal constants.

The materials of the paper have been published.[6,7,9]

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