

Spectrum of electrons localized above liquid ^3He

A. P. Volodin and V. S. Édel'man

Institute of Physical Problems, USSR Academy of Sciences

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The spectrum of electrons localized above ^3He was measured. The difference between the natural frequencies and those given by the hydrogen-like model, as in ^4He , is shown to be small and does not exceed 3–4%. The similarity between the spectra of electrons above ^3He and those above ^4He indicates that the structure of the liquid-vapor interface is identical.

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As is well known, electrons localized above the surface of liquid helium have a spectrum that differs little from the hydrogen-like spectrum

$$E_l^o = - \frac{mZ^2 e^2}{2\hbar^2 l^2}, \quad l = 1, 2, \dots, \quad (1)$$

where $Z = (\epsilon - 1)/4(\epsilon + 1)$ and ϵ is the dielectric constant of the medium.^(1,2) The spectrum of such electrons localized above ^4He ⁽³⁾ was investigated experimentally earlier. Since the small differences between the measured frequencies of the resonance transitions and those given by Eq. (1) give information on the properties of the surface of the liquid, it is of interest to determine the spectrum of electrons above ^3He in order to have input data for comparison of the model of the liquid ^3He surface with that of liquid ^4He .

The variation of conductivity of an electron system due to excitation of resonance transitions in it was observed in Ref. 4. This gave us a convenient method for the spectroscopy of surface electrons. The experiment was performed in the following way. A specified amount of ^3He was condensed into a 45-mm-diam, airtight chamber whose bottom was insulated from the body. The surface of the helium was charged by electrons emitted from a tungsten heater cathode (by switching it on briefly for ~ 0.1 sec) to the surface density

$$n = U/4\pi e d, \quad (2)$$

where U is the potential difference between the bottom and the chamber walls and d is the thickness of the helium layer. The appearance of charges reduced the Q of the ~ 25 -mm-o.d. plane spiral coil, which was placed above the surface of the helium. The coil was an element of the resonant circuit tuned to the frequency of 7 MHz.

SHF radiation from a backward-wave tube was introduced into the chamber at the frequency F in the range of 70 to 100 GHz. The frequency of the F_{1l} resonance transition also decreases with decreasing U , because of the Stark effect induced by the forcing field $E_1 = U/2d$, and coincides with the frequency F at a certain value of U . At

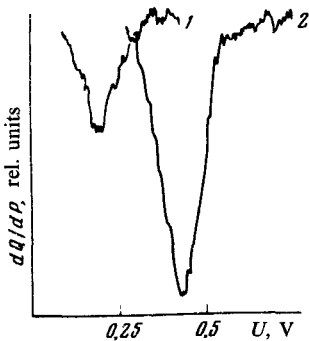


FIG. 1. Dependence on the holding potential of the losses contributed by the electrons localized above ^3He to the rf circuit as a result of their irradiation at the frequency of 70.72 GHz (1) and 71.67 GHz (2). $T = 0.38$ K and the depth of the liquid layer is 1.39 mm.

resonance the SHF radiation, after interaction with the electrons, changes their mobility and contribution to the losses of the rf circuit. The variation of Q of the circuit was recorded by measuring the amplitude of the 7-MHz signal it received. The SHF radiation was modulated at the frequency of ~ 1 kHz, and the signal at the modulation frequency, which appeared during the resonance, was separated by a narrow-band amplifier with a synchronous detector (Fig. 1).

The purpose of the experiment was to measure the E_1 dependences of the frequencies of the F_{1l} transition from the ground state to the l excited state. Since U was a directly measured value, the exact value of d had to be known and the contact potential differences between the electrodes had to be eliminated in order to determine F_1 . We had to perform the measurements twice in order to determine d at the same frequency F : at $d_1 \sim 1$ mm and at $d_2 = d_1 + \Delta d \approx 3$ mm, where Δd was calculated with an accuracy of $\sim 0.4\%$ from the diameter of the chamber, from the density of the liquid ^3He ,⁽⁵⁾ and from the amount of the additionally condensed gas. We are able to calculate d_2 with an accuracy of $\sim 0.5\%$ from the voltages U_1 and U_2 , at which the resonance was observed, and from Δd . To eliminate the contact potential differences between the electrodes, we covered all the components inside the chamber with a platinum film. The absence of parasitic potentials was established from the coincidence (on the E_1 scale) of the resonance lines at different d and at values of E_1 corresponding to $U \leq 1$ V.

Figure 2 shows the $F_{12}(E_1)$ and $F_{13}(E_1)$ dependences. The derivative $(dF_{12}/dE_1)_{E_1 \rightarrow 0}$ almost coincides with the predicted Stark shift $\Delta F_{12}/E_1 = (e/2\pi\hbar)(\langle x \rangle_2 - \langle x \rangle_1) = 1.10$ GHz-cm/V, where the average values of the coordinates were calculated for the hydrogen-like model (Fig. 2). For the $1 \rightarrow 3$ transition the $\sim 10\%$ difference between these values, which is not great, is apparently attributable to the fact that the deviation from linear dependence in this case occurs at much lower fields than those for the $1 \rightarrow 2$ transition. Note that in Ref. 3 the value of dF_{12}/dE_1 measured for the electrons above ^4He is 10% smaller than the predicted value. This is apparently connected with the fact that in Ref. 3 the resonances were observed only at $E_1 \geq 6$ V/cm, where even in our case dF_{12}/dE_1 is noticeably smaller than at $E_1 \rightarrow 0$ (Fig. 2).

A linear extrapolation to $E_1 = 0$ gives $F_{12}(0) = 69.9 \pm 0.1$ and $F_{13}(0) = 83.3 \pm 0.2$ GHz. According to the mass-spectroscopic analysis, the ^3He used

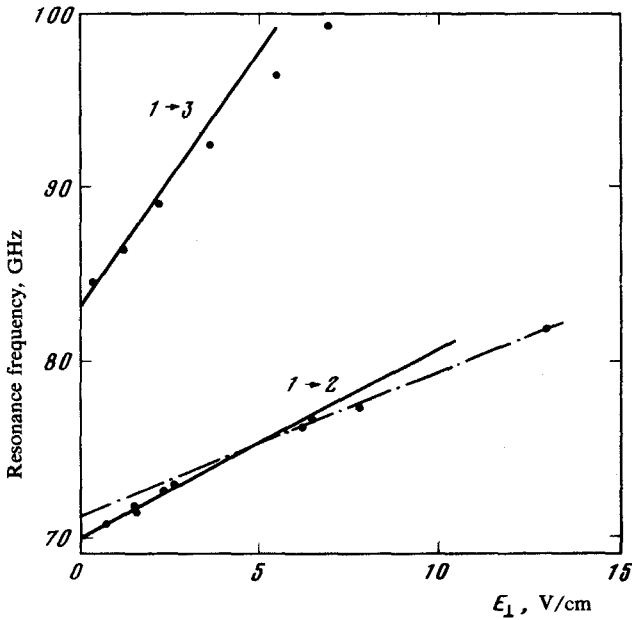


FIG. 2. Dependence of the transition frequencies F_{12} and F_{13} on the holding field E_1 for electrons localized above the liquid ${}^3\text{He}$. The solid lines represent the calculated Stark shift equal to 1.10 and 2.93 GHz/(V/cm) for the $1 \rightarrow 2$ and $1 \rightarrow 3$ transitions, respectively. The dot-dashed line is drawn through the experimental points measured at $E_1 \geq 6$ V/cm.

by us had $(0.3 \pm 0.1)\%$ ${}^4\text{He}$ impurities. Introducing the correction for variation of ϵ , which was calculated from the data of Refs. 5 and 6, we obtain for pure ${}^3\text{He}$ the transition frequencies 69.8 ± 0.15 and 83.15 ± 0.25 GHz. As in the case of the electrons above ${}^4\text{He}$, the observed transition frequencies are slightly higher than the theoretical values of 67.6 and 80.1 GHz, which were determined from Eq. (1) with $\epsilon({}^3\text{He}) = 1.042764$.⁽¹⁶⁾

To account for the shift of the transition frequencies, which were measured for electrons localized above ${}^4\text{He}$, Grimes *et al.*⁽³⁾ used a model potential that contained two parameters: $V(x) = -Ze/(x + \beta)$ at $x > 0$, i.e., above the liquid, and $V(x) = V_0$ at $x < 0$. In this model the shift of the natural frequencies is given by

$$\delta F_l = \frac{\hbar}{\pi m} \left\{ \beta - \left(\frac{\hbar^2}{2mV_0} \right)^{1/2} \right\} [\psi_l^{\circ \prime}(0)]^2, \quad (3)$$

where $\psi_l^{\circ}(x)$ is a hydrogen-like wave function (i.e., at $V_0 = \infty$ $\beta = 0$). According to Eq. (3), the ratio $\delta F_{13}/\delta F_{12} = 208/189 = 1.10$. The value measured experimentally is equal to 1.4 ± 0.2 . Thus, model (3) does not describe the experiment sufficiently well. However, since it was used earlier by Grimes *et al.*,⁽³⁾ we determine the parameter β for ${}^3\text{He}$ by using the frequency shift averaged for the levels with $l = 2$ and 3. Following this procedure, we determine for the expression in the braces $\{ \} = -0.8 \text{ \AA}$. Using the theoretical value $V_0 = 0.9 \text{ eV}$,⁽¹¹⁾ we obtain $\beta_3 = 1.25 \pm 0.15 \text{ \AA}$, a value close to $\beta_4 = 1.04 \text{ \AA}$ for ${}^4\text{He}$.⁽³⁾

As seen from a comparison of the results obtained by us and those of Grimes *et al.*,⁽³⁾ we do not expect the structure of the surface of liquid ${}^3\text{He}$ to be substantially different from that of liquid ${}^4\text{He}$ or the presence of a transition region with greater

Distribution in the Treiman-Yang angle for the reaction ${}^4\text{He}(\gamma, pn){}^2\text{H}$

Yu. M. Arkatov, P. I. Vatsset, V. I. Voloshchuk, V. A. Zolenko, and I. M. Prokhorets

Physicotechnical Institute, Ukrainian Academy of Sciences

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Experimental distributions in the Treiman-Yang angle were determined in the investigated process for the purpose of completing the program of identification of the pole mechanism in the ${}^4\text{He}(\gamma, pn){}^2\text{H}$ reaction.

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In studying the problem of identification of the pole mechanism in three-particle reaction (Fig. 1), it is important to verify the Treiman-Yang criterion. By defining the Treiman-Yang angle as the angle between the (a, b) and (II, c) planes in the antilaboratory system (particle I is at rest),¹⁾ we obtain an isotropic distribution in it, if the spin i of the particle is equal to zero. There are several papers on Treiman-Yang angle distributions known at this time (see, for example, Ref. 2). There are no papers avail-

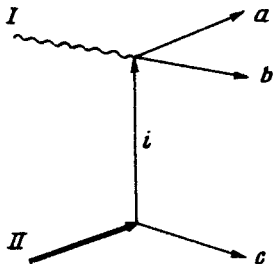


FIG. 1. Pole diagram for a three-particle reaction.