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D. K. Lambert and P. L. Richards

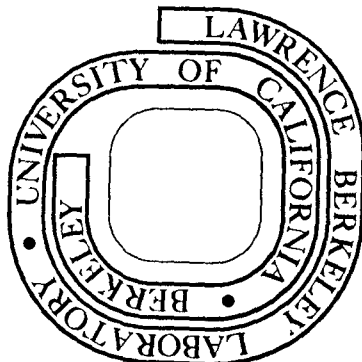
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D. K. Lambert and P. L. Richards

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Infrared Measurements of Electrons Trapped on the Surface of Superfluid Helium

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It is known¹ that free electrons which approach the surface of superfluid liquid helium from the gas can populate bound states at the gas-liquid interface. Electrons in the gas are attracted to the surface by an electrostatic image potential arising from the polarization of the liquid helium. Since a large amount of energy is required to force a free electron into the liquid, the liquid surface can be approximately represented by an infinite potential. The spectrum of bound states is that of a one-dimensional hydrogen atom with an ionization energy corresponding to 159 GHz.

Experiments on this system are conventionally carried out in a cylindrical metal cell with a vertical axis of symmetry, which is half filled with liquid helium. The planar top and bottom of the cell are electrically isolated so that an electric field can be applied which is predominately normal to the helium surface. The applied field is shaped by the cell walls so as to confine the electrons to the central region of the helium surface. In this region the net normal field is nearly uniform. A field of several hundred volts per centimeter will increase the depth of the potential well and shift the frequencies of transitions between the bound states into the far infrared.

We have used a CO₂ pumped methyl alcohol laser, an electric field modulation technique, and an InSb hot electron bolometer to measure the spectrum of transitions from the ground state to various excited states as a function of the electric field. The laser light is introduced into the cavity through a Winston light concentrator. It bounces around randomly, and is sampled through a second Winston concentrator which conveys it to the detector. The electric field is swept linearly in time and modulated at 20 KHz. The resonances observed in the 20 KHz detector signal are shown in Fig. 1. The laser light is also chopped at 90 Hz and the 90 Hz detector output is used to normalize fluctuations in the laser power.

The line frequencies measured as a function of electric field are in good agreement with calculations done by O'Connell² using the model described above and the WKB approximation. In order to extract quantitative information from the absorption line shapes, we have developed a numerical model of the electrostatic field in our absorption cell. From this model we find that the electrons cover only the central region of the helium surface. The electron density varies linearly as a function of radius near the edge of the charged region. We find

from the calculation that we can deduce the total charge on the surface from measurements of the AC capacitance between electrodes above and below the helium surface. The measured dependence of capacitance on electric field is in good agreement with our calculations. Capacitance measurements have shown that under unfavorable circumstances substantial charge densities can collect on the superfluid film covering the metal walls of the cavity. When very large surface charge densities are used it is found that the simple derivative line shapes shown in Fig. 1 are strongly distorted. We interpret this effect as arising from distortions in the helium surface.

We are planning to explore a number of different physical situations with this apparatus. The bound-state energies are expected to increase if the depth of the helium pool is reduced sufficiently that the electrostatic contribution of the bottom of the cell becomes important. Larger binding energies are also expected for electrons on hydrogen or neon. If a magnetic field is applied parallel to the helium surface, the optical transitions are coupled to the in-plane motion of the electrons. It should then be possible to observe effects on the optical line shapes arising from correlated excitations in the electron liquid or solid.

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1. C. C. Grimes, Surface Sci. 73, 379 (1978).
2. R. F. O'Connell, Phys. Letters A60, 481 (1977).

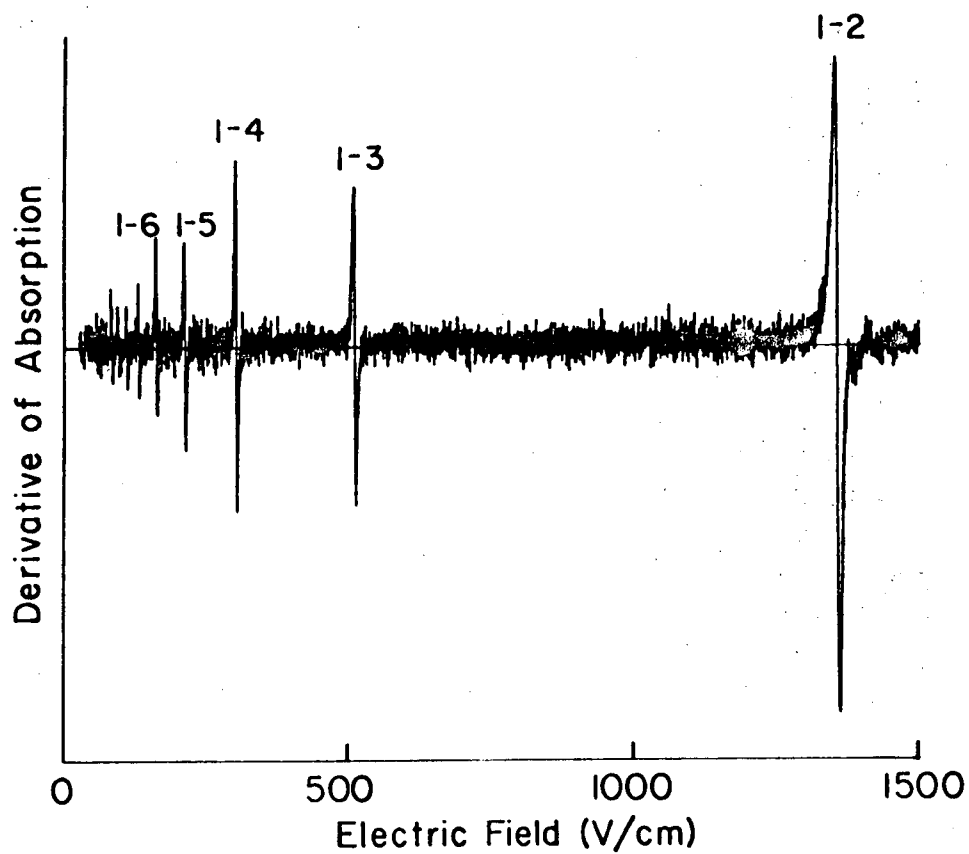


Fig. 1. Derivative of the absorption of 525.5 GHz laser light as a function of the applied electric field. The electronic surface charge density varies from 2.6×10^7 to 9.2×10^7 electron/cm² as the field is increased. The transitions are identified by the changes in the quantum number.

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