# Direct observation of optical absorption by excess electrons in liquid helium

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Experiments described here have resulted in the direct observation of a $1s$–$1p$ absorption line corresponding to absorption by electrons self-trapped in microscopic bubbles in liquid helium. The position of the absorption line corresponds to the theoretical prediction, while its width is several times greater than the theoretical prediction.

The model in which an excess electron in liquid helium undergoes a self-trapping in a microscopic bubble with a radius of 10–20 Å, depending on the pressure, is now generally accepted. An important consequence of this model is that an electron can undergo a transition from its ground state to an excited state when excited by light. Direct spectroscopic data might be of assistance in refining the microscopic model of such a bubble.

The experimental data of Northby and Sanders are closest to the spectroscopic data.[1,2] At temperatures below 1.3 K, and in sufficiently strong electric fields, electron bubbles create vortex rings in superfluid helium and move along with these rings. A slight increase in the electron mobility at certain wavelengths of the exciting light has been observed under these conditions. These wavelengths were interpreted in Ref. 5 as corresponding to photoionization and to a $1s$–$2p$ transition. The mobility increase was explained on the basis that the energy released in the course of the relaxation accompanying the electron transition was sufficient to liberate a bubble from the core of a vortex ring; until a new ring was produced, the ion would have a high mobility. Our intention in the present study was to detect the $1s$–$1p$ transition in a corresponding way. For this transition, the photoabsorption cross section is estimated to be two orders of magnitude greater than that for a $1s$–$2p$ transition. An experiment of this sort was carried out just recently by Grimes and Adams.[6]

In the present study we attempted to directly observe the absorption of light upon $1s$–$1p$ transitions of an electron in a bubble.

In the present experiments, semiconductor lasers with fixed wavelengths were used. These lasers operated at liquid-helium temperature and were mounted directly in the cryostat in the vacuum chamber. The laser light was incident along a short length (60 mm) of a AgCl optical waveguide in KRS-13 cladding in the test chamber with the liquid helium. Inside the test chamber (Fig. 1), this waveguide passed through a gap 1 mm wide between two plane electrodes, one of which was coated with a layer of $TiT_2$ (a standard $\beta$ source with a saturation current of $1.5\times 10^{-8}$ $A/cm^2$). As the light propagated between the electrodes, it struck a photoresistor (boron-doped sili-

  

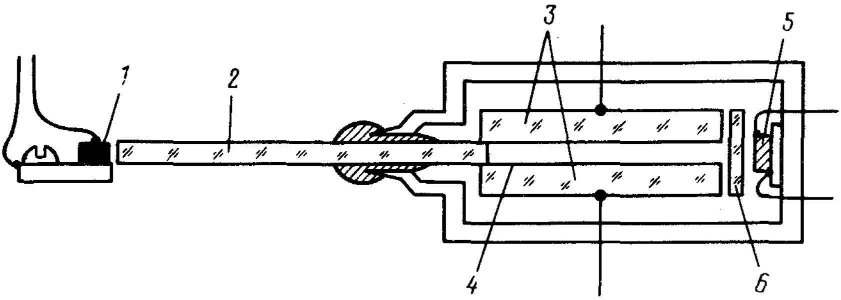


FIG. 1. Schematic diagram of the test chamber. *1*—Laser crystal; *2*—AgCl optical waveguide in a KRS-13 cladding; *3*—electrodes (stainless steel); *4*—$TiT_2$ layer (the tritium source); *5*—SiB photoresistor; *6*—NaCl plate.

con). The path length over which the light was absorbed was 40 mm and was determined by the geometry of the $\beta$ source.

It was a simple matter to achieve average electron densities on the order of $10^8$ $cm^{-3}$ in the gap between the electrodes. For this purpose, electrons were extracted from a thin insulated layer near the electric field source. Efforts to achieve substantially higher electron densities ran into difficulties, tentatively due to a recombination of ions and electrons close to each other on the tracks of the original $\beta$ particles. As the external electric field is increased, the recombination rate decreases, but there is a simultaneous decrease in the transit time of the electrons through the gap between the electrodes. There is essentially no change in the average electron density in the gap. It is possible, on the other hand, to make the ionized layer more uniform (spatially), by using a strong rf electric field to move the charged particles. By applying an alternating voltage with a frequency of $2\times10^5$ Hz and an amplitude of $10^3$ V to the electrodes, we were thus able, with a drift voltage of 25 V, to achieve an average electron density of $2\times10^9$ $cm^{-3}$ and to modulate it at an essentially 100% level. The time required for the electrons to traverse the gap under our conditions was 15 ms. The modulation period was chosen to be 36 ms. The electron density could be monitored easily on the basis of the static current-voltage characteristics.

The signal from the photoresistor was detected in a synchronous manner along with the drift voltage, with a time constant of 100 s. It was fed to the "$y$" input of a chart recorder. A signal proportional to the helium pressure in the test chamber (with a Sapfir converter) was fed to the "$x$" input. By slowly varying the pressure we were able to observe a resonant absorption of light when the frequency of the electron transition in the bubble was equal to the fixed laser frequency. Working from theoretical estimates of the photoabsorption cross section and the linewidth,[3,4,6] we expected an absorption $\Delta I/I \sim 10^{-5}$ under our conditions, with a linewidth (in pressure) on the order of several atmospheres.

Figure 2 shows some illustrative experimental records at various temperatures. The laser wavelength for these curves was 6.7 $\mu$m, and the emission linewidth was less than 10 $cm^{-1}$.

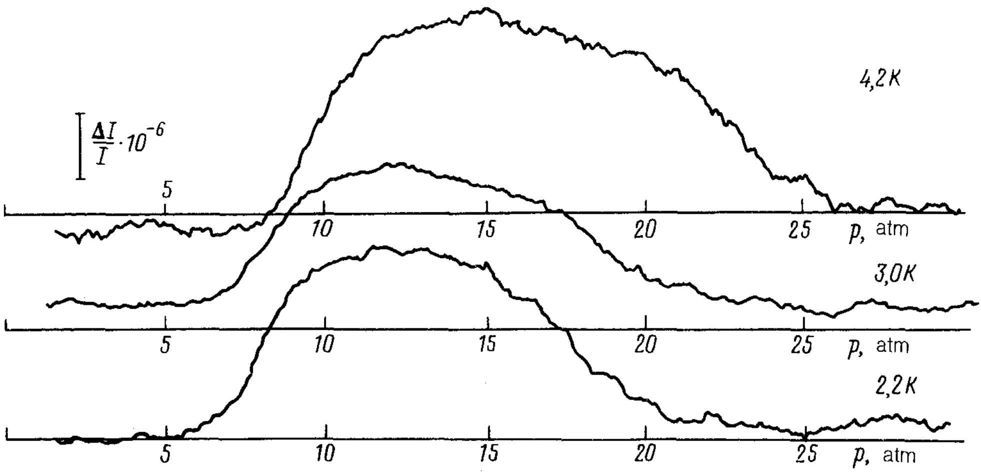


FIG. 2. Illustrative experimental records of the absorption lines at various temperatures. The laser wavelength is 6.7 $\mu$m.

The observed temperature shift of the absorption line is probably due to an increase in the equilibrium radius of a bubble as the effective surface tension $\sigma$ decreases with increasing temperature. Our data can be explained by assuming a decrease in $\sigma$ of about 0.15 dyn/cm as the temperature is raised from 2.2 K to 4.2 K. This result is in reasonable agreement with both the theory[3–5] and the results of Ref. 6.

The linewidth is about 0.04 eV in energy units, or several times the theoretical estimates of Refs. 3 and 4. In experiments with a mobility,[6] the linewidth was about 0.02 eV at the same wavelength as in our experiments. We note in this connection that the line detected in these experiments may differ from the actual absorption line, since it incorporates the energy dependence of the probability for the detachment of an electron bubble from the core of a vortex ring.

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