TRAPPING AND ESCAPE OF NEGATIVE IONS FROM THE SURFACE OF LIQUID ^{4}He

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The lifetime of negative ions in the image-potential induced energy well below the free surface of liquid ^{4}He has been measured. The excape from the well is discussed in terms of a thermal diffusion over a barrier of 43.8°K.

The transmission of negative ions through the free surface of liquid ^{4}He has been studied by Bruschi et al. [1] and more recently by Schoepe and Probst [2]. These authors studied the steady state negative ion current from a radioactive source in the liquid through the free surface as a function of temperature when a uniform electric field is applied across the surface. The application of an electric field across the surface in combination with the image potential leads to a potential well which traps the negative ions for extended periods of time. This letter reports the first measurements of the trapping time τ of the negative ions in this potential well near the free surface. It is found that the negative ions are trapped for times up to 100 seconds in the potential well and escape only by thermal diffusion [3] (Brownian Motion) over a barrier which is electric field dependent.

The form of the potential (fig. 1) seen by ions near the free surface of liquid ^{4}He with an applied field $\mathcal{E}$ is $V(x) = (A/x + e\mathcal{E}x)$ where x is the distance into the liquid measured from the surface and A/x is the image potential of the ion near the surface $[A = e^2(\epsilon-1)/4\epsilon(\epsilon+1)]$. The barrier height seen by ions trapped in the minimum of the potential is $\phi_b - 2\sqrt{Ae\mathcal{E}}$ where ϕ_b is a constant to be determined by experiment. An analysis of thermal diffusion in an external field based on the Smoluchowski equation [3] gives the trapping time τ for particles in the well. We find:

$$1/\tau = \alpha(\mathcal{E})\,\mu(T)\,\exp-[(\phi_b - 2\sqrt{Ae\mathcal{E}})/T]\ \mathrm{sec}^{-1} \qquad (1)$$

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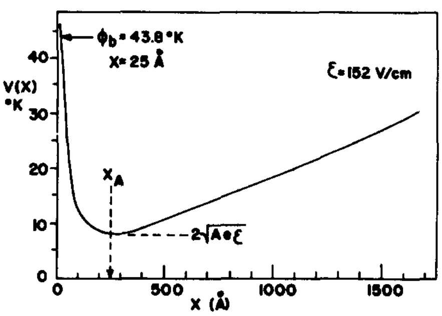

Fig. 1. The image-induced potential $V(x)$ near the free surface of liquid ^{4}He is shown as a function of distance into the liquid.

where $\alpha(\mathcal{E}) = 3.21 \times 10^7 \mathcal{E}^{3/4}\sqrt{V_c''}$ depends on the curvature V_c'' at the top of the well. $\mu(T)$ is the negative ion mobility measured in cm^2/volt sec. $\mathcal{E}$ is measured in volt/cm, ϕ_b in °K and V_c'' in erg/cm^2. ϕ_b and V_c'' depend on the physical process by which the negative ion (or electron) escapes over the barrier at $(x = x_c)$ and are determined from a best fit to the experimentally measured values of τ.

A diagram of the experimental cell is shown in fig. 2. Trapping times were measured by the following method. First the well near the liquid surface is filled with negative charge by suitable electric fields applied between the radioactive source S(^{241}Am) and collector Co. After a steady state is reached (i.e. the charge ρ trapped in the well becomes time independent) the source current is switched off by means of the grid G. The electric field across the liquid vapor interface is held constant. A guard ring at the grid potential prevents the trapped charge from leaking to the walls of the cell. The rate of charge

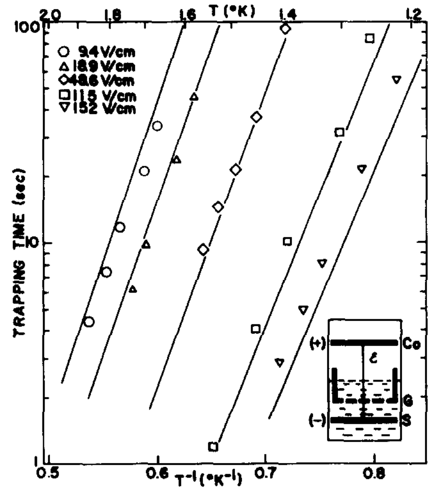

Fig. 2. Measured and calculated trapping times of negative ions in the image-induced potential well below the free surface of liquid ^{4}He for various electric fields across the surface are shown versus $1/T$. The insert shows a schematic of the grid arrangement inside the low temperature cell.

escape from the surface (I_S), measured by a fast rise electrometer, is observed to decay exponentially with time $I_S(t) = I_S(0)\exp - (t/\tau)$. The decay occurs because the number of charges in the well decays exponentially $I_S(t) = \rho(t)/\tau = [\rho(0)\exp - (t/\tau)]/\tau$ where τ is a constant for fixed $\mathcal{E}$ and T.

Fig. 2 shows a plot of the experimentally determined τ versus $1/T$ for different values of $\mathcal{E}$. Eq. (1) is also plotted in the diagram (full lines) with $\phi_b = 43.8^oK$ and $V_c'' = 3.10 \times 10^3$ ergs/cm^2 (2.23×10^3 $^oK/Å^2$).

At the top of the well, with a bubble radius of 20Å, only 5Å of liquid exist between the wall of the bubble and the surface of the liquid. The escape of the electron from the bubble through the surface can thus occur quite easily. For example, the free surface of the liquid and the surface of the bubble may merge and open up allowing the electron to escape. Electron tunneling might also occur. These processes would be consistent with the large value of V_c'' which is measured.

The trapping of ions at the free surface of ^{3}He as well as the phase boundary of ^{3}He-^{4}He mixtures [4] can be examined by the methods presented in this letter. The posssibility of such measurements is presently being considered.

A more complete and detailed account of this work will be published elsewhere [5]. The Deutsche Forschungsgemeinschaft supported this work and a visit to the Physik-Department der Technischen Universität München by one of us (GWR).

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