Temperature Dependence of the Neutral Current in Liquid Helium*

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We compute the energies of the bound state of an excited helium atom on the surface of liquid helium in a simple model. The consequent temperature dependence of the neutral current is in qualitative agreement with experiment.

Studies of the neutral current in liquid helium, discovered by Surko and Reif, have not yet fully established its origin. A model proposed by Halley and Giese and by others interprets the current as arising from the trapping of excitons (He*) at the liquid surface, followed by neutral destruction of the excitons via the process He* + He* → He^+ + e^- + He. The model accounts for several features of the experiments. In the present note we report a calculation indicating that the model can qualitatively account for the observed temperature dependence of the current. To do this we have (1) extracted a He*-He potential from the literature, (2) integrated this over a He distribution \( \rho_0 \delta(z) \) to give a potential \( V(z) \) for He* as a function of the distance \( z \) from the surface of the liquid, (3) integrated the wave equation to find the number of bound states (there are four), (4) solved the equation for the eigenvalues of these bound states, and (5) used a simple kinetic argument to give the effect on the lifetime of the He* at the surface and hence on the neutral current.

The He*-He potential is (assuming He* is a triplet \( s \) state)

\[
V(r) = \alpha r^2 e^{-\kappa r} - \left( \Sigma/r^6 \right) + \frac{1}{\gamma} e^{-\eta r}
\]

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where
\[ a = 0.3, \quad n = 1.4, \quad \gamma = 1.54, \quad \tau = 1.43, \quad \Sigma = 20.0 \]

Everything is in atomic units. Integrating the potential gives
\[
V(z) = \rho_0 \int_{-L}^{L} dx' \int_{-L}^{L} dy' \int_{-\ell}^{0} dz' \times \left\{ \frac{1}{2} \left( x'^2 + y'^2 + \left( z - \ell \right)^2 \right) \right\}^{1/2} = 2\pi \rho_0 \left\{ -\frac{\Sigma}{12z^3} + \frac{\gamma}{2} e^{-\frac{a}{z^2}} \left[ \frac{1}{\tau^2} + \frac{1}{\tau^3} \right] \right\} + \alpha e^{-n^2z^2} \left( \frac{z^3}{n^2} + \frac{6z^2}{n^3} + \frac{18z^2}{n^4} + \frac{24}{n^5} \right) \]

The potential is shown in Fig. 1. Next we solved the wave equation. The eigenvalues were at energies \(-5.85, -1.28, -0.17,\) and \(-0.007\) K.

Some comments are in order about how accurate these numbers are. First, \(V(z) \to \infty\) as \(z \to 0\). We cut the potential off at 0.02 eV (the Hickman and Lane value of the energy for \(\text{He}^*\) in the bulk liquid). This should have negligible effect on the results. Second, the potential is probably too large as \(z \to 0\) since the liquid surface can readjust to lower the energy. We believe...