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ONE ELECTRON DIMPLE ON A THIN HELIUM FILM

V.Shikin. Institute of Solid State Physics, Academy of Sciences,
142432 Chernogolovka, Moscow district, USSR

Conditions of existence of one-electron dimples on a thin helium film are discussed. It is shown that the dimples cannot exist if the helium film thickness goes to zero.

A problem concerning properties of one-dimensional dimples on a thin helium film has been considered theoretically in detail. We have in mind the first variational calculations for dimples provided by Monarkha [1] in the limit of zero temperature, introduction of temperature into the problem of dimples on a thin helium film [2],[3], the studies of the dynamic properties of these dimples [4] etc. Different approaches to construction of such a theory for 2-D dimples are in a good fit with each other and lead to a general qualitative conclusion that as a helium film d decreases, the coupling energy W increases monotonically and rather sharply (asymptotically $W(d) \sim d^{-4}$).

However the general conclusion about monotonic increase of the dimple energy with decrease of d is, in fact, incorrect. The aim of the given note is to formulate and to prove the fact that in the limit $d \rightarrow 0$ formation of one-electron dimples on a thin helium film becomes energetically unfavoured.

In order to formulate the problem about existence of a dimple we need to make some determinations. A variational calculation from [1] gives the following relations for the energy W and the localization length l

$$W = -\frac{F^2}{4\pi\alpha} \left(\ln \frac{1.3}{kl} - \frac{1}{2} \right), \quad \tilde{k}^2 = \frac{\tilde{\rho}\tilde{g}}{\alpha}, \quad \tilde{g} = \frac{3\Delta}{\rho d^4}, \quad kl \ll 1 \quad (1)$$

$$l^2 = 4\pi\alpha\hbar^2/(mF^2), \quad F = \Lambda_s/d^2, \quad \Lambda_s = \frac{e^2(\epsilon_s - 1)}{4(\epsilon_s + 1)} \quad (2)$$

Here α is the surface tension of liquid helium, ρ is its density, g is the effective acceleration due to Van der Waals force. Δ is the Van der Waals constant, F is the force pressing electrons against the free helium surface in the limit $d < \gamma_{\infty}^{-1}$ which is of interest for us, ϵ_s is the dielectric constant of the substrate, $\gamma_{\infty}^{-1} = 4(\epsilon+1)\hbar^2 / [me^2(\epsilon-1)]$ is the length on which the electron is localized due to its interaction with the substrate, ϵ is the dielectrical constant of liquid helium.

Using the definitions (1), (2) it is easy to understand the statement about a monotonic dependence of W on d . Indeed, the combination k_1 entering into the argument of logarithm in (1) with allowance for F from (2) turns out to be independent of d

$$\tilde{k}^2 l^2 = 12\pi \Delta \hbar^2 / (m_s^2) < 1 \quad (3)$$

Therefore the energy W is negative and increases monotonically as d decreases according to a law $W \sim d^{-4}$.

Now we note that the definition F (2) is not accurate. It is only valid in a region $\gamma_{\infty}^{-1} > d \gg \gamma_d^{-1}$, where γ_d^{-1} is the localization length for an electron above the helium film due to the action of the sublayer image force. In the case $d < \gamma_d^{-1}$ the law $F \sim d^{-2}$ ceases to be valid and the combination k_1 begins to depend on d . Schematically this effect can be presented as (first the effect of saturation dependent on $F(d)|_d$ was mentioned in [5])

$$F = \frac{\epsilon_s}{(d + \gamma_d^{-1})^2}, \quad \tilde{k}^2 l^2 \sim \frac{(d + \gamma_d^{-1})^4}{d^4} \begin{cases} 1 & d \gamma_d > 1 \\ \gg 1 & d \gamma_d < 1 \end{cases} \quad (4)$$

According to (4) the parameter k_1 in the range $d \gamma_d < 1$ begins to grow as $\tilde{k}^2 l^2 \sim d^{-4}$. If $k_1 > 1$ the localization energy W (1) becomes positive which corresponds to destruction of a dimple.

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