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Autor(en): **Shikin, V.**

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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 $d \to 0$ 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

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

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

Here α is the surface tension of liquid helium, ρ is its density, $\tilde{g}$ 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, $\gamma_\infty^{-1} = 4(\varepsilon+1)\hbar^2/\left[me_s^2(\varepsilon-1)\right]$ 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 $\tilde{k}l$ entering into the argument of logarithm in (1) with allowance for F from (2) turns out to be independent of d

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

Therefore the energy W is negative and increases monotonically as d decreases according to a law W 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 $\tilde{k}l$ begins to depend on d. Schematically this effect can be presented as (first the effect of saturation dependent on $F(d)|_{d\to 0}$ was mentioned in [5])

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

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

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