

# One electron dimple on a thin helium film

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## ONE ELECTRON DIMPLE ON A THIN HELIUM FILM

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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  $l$

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

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

Here  $\alpha$  is the surface tension of liquid helium,  $\rho$  is its density,  $g$  is the effective acceleration due to Van der Waals force.  $\Delta$  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,  $\epsilon_s$  is the dielectric constant of the substrate,  $\gamma_{\infty}^{-1} = 4(\epsilon+1)h^2 / [me^2(\epsilon-1)]$  is the length on which the electron is localized due to its interaction with the substrate,  $\epsilon$  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  $d$

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

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  $\gamma_d^{-1}$  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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