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# WETTING TEMPERATURE SHIFT OF HELIUM ON A LAYERED SUBSTRATE

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We calculate the shift in wetting temperature $T_w$ of a He film on a layered substrate. The latter consists of an alkali metal layer film of thickness d, deposited on a semi-infinite medium. $T_W$ can change from nonzero to zero (Cs) or vice versa (Na) as d changes. The shift is an extremely sensitive probe of long range van der Waals potentials.

## 1. INTRODUCTION

Until recently, $^4$He was perceived to be a universal wetting agent. It was then discovered that Cs and perhaps Rb are nonwetting surfaces due to their weak adsorption potentials.[1-3] This paper addresses a very specific question. Given that the wetting temperature on Cs is $T_W \cong 1.95$K, by how much ($\delta T_W$) does this value change in the case of a Cs film, of thickness d, deposited on another surface? We specialize to the case of "large" alkali thickness d, such that van der Waals (VDW) interactions predominate.[4] The wetting condition satisfies,

$$O = \sigma_{s\ell}(T_w) + \sigma_{\ell v}(T_w) - \sigma_{sv}(T_w) \qquad (1)$$

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For the layered substrate, an analogous condition obtains at temperature $T_W' = T_W + \delta T_W$. By subtracting

$$O = \Delta\sigma + \sigma_{\ell v}(T_w') - \sigma_{\ell v}(T_w) \tag{2}$$

$$\Delta\sigma(d) \equiv \sigma_{s\ell}'(T_w + \delta T_w) - \sigma_{s\ell}(T_w) - \left[\sigma_{sv}'(T_w + \delta T_w) - \sigma_{sv}(T_w)\right] \tag{3}$$

where the primed variables refer to the compound substrate. As argued previously[1], we expect the temperature dependences in Eq. (3) to be much smaller than those of the liquid-vapor surface tension; this leads to the low temperature approximation

$$\Delta\sigma \cong \left[\sigma_{s\ell}' - \sigma_{sv}'\right]_{T=0} - \left[\sigma_{s\ell} - \sigma_{sv}\right]_{T=0} \tag{4}$$

The preceding equations are the basis of our discussion. The next section obtains results for $\Delta\sigma$. Section 3 summarizes our results and reaches some intriguing conclusions.

## 2. RESULTS FOR $\Delta\sigma$.

We could estimate the right side of Eq. (5) as follows. A He atom at distance z above Cs experiences a potential $-C_3\ z^{-3}$, where $C_3$ depends on the He polarizability $\alpha$ and substrate dielectric function $\varepsilon$, evaluated at imaginary argument iE. Above the layered substrate, the He potential is shifted; the perturbation is then $\Delta V \cong -\Delta C_3\ (z+d)^{-3}$. By integrating over the film, we obtain the energy shift:

$$\Delta\sigma = -n\int_o^\infty \frac{dz\,\Delta C_3}{(z+d)^3} = -\frac{n\Delta C_3}{2d^2} \tag{5}$$

$$\Delta C_3 = \int_o^\infty \frac{dE\,\alpha(\varepsilon_x - \varepsilon)}{2\pi(\varepsilon_x + 1)(\varepsilon + 1)} \tag{6}$$

where $\varepsilon_X$ is the semi-infinite substrate's dielectric function and n is the He density. Eqs. (5) and (6) implicitly assume additivity of the potential contributions of the two components of the layered substrate and negligible retardation. Nonadditivity (many body) effects can easily be included as follows. The "exact" VDW energy shift per unit area (relative to d=∞ ) is[5]

$$\Delta E / A = \frac{-1}{16\pi^2 d^2}\int_o^\infty \frac{dE\left(\varepsilon-\varepsilon_{He}\right)\left(\varepsilon-\varepsilon_x\right)}{\left(\varepsilon+\varepsilon_{He}\right)\left(\varepsilon+\varepsilon_x\right)} \qquad (7)$$

We expand this in n by using $\varepsilon_{He} \equiv 1+4\pi n\alpha$. The leading term is that of the vacuum-solid interface. Hence the next term is

$$\Delta\sigma = -n\Delta C^{many\ body} / \left(2d^2\right) \qquad (8)$$

$$\Delta C^{many\ body} = \int_o^\infty \frac{dE\left(\varepsilon_x-\varepsilon\right)\alpha}{\pi\left(\varepsilon_x+\varepsilon\right)\left(1+\varepsilon\right)^2} \qquad (9)$$

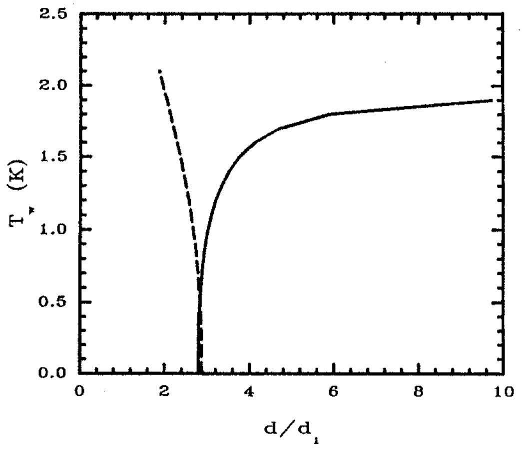

Figure 1. Full curve depicts results for a Cs film using Eq. (10). The dashed curve is obtained for Na from Eq. (12). The characteristic thickness $d_1$ is defined in Eq. (15), with ΔC positive (negative) in the two examples shown here.

We observe that Eq. (5) coincides with this result if ε is not very different from unity; this is expected for weak screening.

## 3. RESULTS FOR WETTING TEMPERATURE

Eqs. (2a) and (8) yield an expression for the wetting temperature $T_W'$ on the layered substrate in terms of a characteristic thickness $d_1$:

$$(d_1/d)^2 = \left[\sigma_{\ell v}(T_w') - \sigma_{\ell v}(T_w)\right]/\sigma_{\ell v}(0) \qquad (10)$$

$$d_1^2 = n|\Delta C^{manybody}|/\left[2\sigma_{\ell v}(0)\right] \qquad (11)$$

Figure 1 shows numerical results[5]; one observes a precipitous drop near $d=2.79\ d_1$. For graphite (Au), $d_1=7.1\ (9.8)\mathrm{\mathring{A}}$. We note that a layered substrate can produce the reverse effect (increased wetting temperature, as d decreases) if $\Delta C<0$. An interesting case is Na, predicted to be wetting at T=0. The wetting condition (2a) becomes

$$\sigma_{\ell v}(0) - \sigma_{\ell v}(T_w') - \Delta\sigma(d) = \sigma_{\ell v}(0) + \sigma_{S\ell}(0) - \sigma_{Sv}(0) \qquad (12)$$

Figure 1 shows results obtained with a value $-0.033\mathrm{K}/\mathrm{\mathring{A}}^2$ on the right side.[1] $T_W'$ rises from zero when $d/d_1 \cong 2.88$. For the case of Na on Cs, many body effects provide a factor of two (!) screening due to their comparable values of the plasma frequency, $\omega_p$, yielding $d_1 \cong 2.7\ \mathrm{\mathring{A}}$.

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