THE EXTRAORDINARY PHENOMENA OF WEAK ADSORPTION

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A summary is provided of a variety of intriguing phenomena involving particles weakly bound to surfaces. One kind of problem involves wetting and prewetting transitions (for H₂, He and Ne on alkali metals) and thus far mysterious behavior of He on an H₂ substrate. A second kind involves the adsorption of atoms on the surfaces of liquid ⁴He or ³He.

1. Introduction

Physicists often go to extreme measures in their quest to understand nature. Examples are the pursuit of ever higher energy physics, ever colder condensed matter physics, and ever more distant astrophysics. There is a common rationale: that new behavior may occur when a new regime is explored. This article describes a variety of phenomena which have been seen in the case of ultraweak adsorption.

The term “ultraweak” is a relative expression, since no connection to W bosons is intended here. The benchmark instead is a “natural” energy scale for a given problem. In the case of ⁴He, this could be either the bulk cohesive energy (≈ 7 K per atom) or the well depth (ε ≈ 11 K) of the pair potential. We shall see that quite distinct behavior occurs for the adsorption of He on surfaces having binding energy small or large compared to this energy scale.

This paper divides naturally into two parts. One is the wetting behavior of inert gases on ultraweakly adsorbing surfaces. The other part is the equilibrium or dynamical properties of a weakly adsorbed species (or film) on quantum fluids. Not surprisingly, there arise some common features of

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the two kinds of problem. We are struck by the richness of the diverse physics arising within this relatively small domain of physical system. This exemplifies how quantum fluids are paradigms for condensed matter physics.

2. Transitions in weakly bound films

Consider the problem of He adsorption on substrates having a well depth $D$. Until a few years ago, there was observed a generic behavior: because of the He inertness, a prototypical substrate provided a strong attraction ($D > \varepsilon$), resulting in solidification of at least one helium layer which did not contribute to the superfluid properties. It was pointed out, however, that some substrates should be exceptions because of very small $D$ values; a liquid monolayer was predicted for $^4$He on hydrogen and alkali metal substrates.\(^1\) Subsequently, a density functional calculation\(^2\) predicted that $^4$He ought to exhibit wetting and prewetting transitions on the alkalis, neither of which had been observed previously for any substrate. Several low temperature experimentalists\(^3\)–\(^7\) were sufficiently audacious to proceed without the "high-tech" tools of modern surface science. There has ensued a set of exciting discoveries, which have been reviewed recently\(^8\)–\(^10\) are discussed in other articles in this symposium. It should suffice to summarize the situation: $^4$He exhibits prewetting transitions on Rb, oxidized Rb, and Cs. This means that the film undergoes a thin-to-thick transition analogous to 3d condensation. The wetting temperatures are considerably lower than had been predicted.\(^2\) Hypothetical sources of this discrepancy involve energetics of the solid-liquid interface\(^11\),\(^12\) or the possibility that the theoretical potential significantly underestimates the true potential.\(^13\) This transition is "tunable" by varying the thickness of the alkali layer deposited on another material, due to the change in the substrate potential.\(^14\),\(^15\)

$^3$He, in contrast, is believed to wet all surfaces at $T = 0$\(^16\). Perhaps this is paradoxical since a single $^4$He atom is bound more strongly to Cs, but $^4$He does not wet this surface. This is explained in terms of either the smaller surface tension (relative to the density) of $^3$He relative to $^4$He or the smaller (bulk) cohesive energy (which is the reference energy arising in the wetting problem).\(^2\) $^3$He - $^4$He mixture films exhibit reentrant wetting as a function of $T$.\(^17\) This was predicted on the basis of the $T$ dependence of the surface tension, which is anomalous because of the role of the $^3$He surface state.\(^18\) A recent discovery (again unprecedented) is the apparent presence of $^3$He bound states at the Cs interface with the mixture.\(^13\),\(^19\) The explanation is that the Cs plays the role of the vacuum because it depresses the $^4$He density.

$H_2$ and $D_2$ films on Rb exhibit prewetting behavior which is qualitatively similar to that found for $^4$He on Rb and Cs; the observed properties in this