# Sticking coefficients of atoms on solid surfaces at low temperatures

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It is shown that the polarization effect, discussed by Knowles and Suhl [Phys. Rev. Lett. **39**, (1977) 1417], is unnecessary to explain why sticking (adsorption) probabilities of atoms on surfaces remain nonzero down to zero energies. The earlier explanation, in terms of the long-range nature of the atom-surface interaction potential, is sufficient.

Recently, Knowles and Suhl[1] addressed themselves to "a long-standing puzzle in the interpretation of data on the sticking probability of atoms on solid surfaces at low temperatures." The "puzzle" referred to is, essentially, as follows. The earlier (quantum-mechanical) theories[2-4] of the scattering of low-energy atoms by solid surfaces predict that the sticking (adsorption) probability $S$ of an atom on a surface at zero temperature ($T_s = 0$) tends to zero as the incident energy $E_i$ of the atom tends to zero, that is,

$$S(0,0) \equiv \lim_{E_i \to 0} S(E_i, T_s = 0) = 0 . \tag{1}$$

The result (1) implies in turn that the energy accommodation coefficient, $\alpha(T)$, of a gas-surface system at temperature $T_s = T_g = T$ obeys $\alpha(0) = 0$, whereas both intuition and experimental trends[5,6] indicate that $\alpha(0) > 0$; the classical-mechanical theories[7-9] of $\alpha(T)$ are successful at essentially all experimental energies (although no one knows why), predicting $\alpha(0) = 1$ for all systems with long-range attractive forces (this result is discussed in particular detail in Ref. 7).

The earlier theories[2-4] referred to above were based on the first-order distorted-wave Born approximation, and Knowles and Suhl[1] contend that the "puzzle" in question may be resolved by considering an effect not considered in this approximation. We need not consider their effect in detail here, but essentially it is a polarization effect which leads to an enhanced "effective mass" of the scattering atom, and/or renormalization of the static potential due to phonons.[10] To illustrate their results, they use a square-well potential (their Fig. 1) to model the atom-surface interaction.

The purpose of this note is to point out that a resolution of the "puzzle" was first given much earlier by Goodman,[11,12] and later by García and Ibañez,[13] and it will be useful to repeat briefly the main points here. The essential point is that $S(0,0)$, defined by (1), depends in a remarkably crucial way on the form of the long-range (attractive) part, $V_A(z)$, of the atom-surface interaction potential, $V(z)$, where $z$ is the distance of the atom from the surface. Goodman first[11] considered the cases

$$V_A(z) = -Az^{-r} , \tag{2}$$

with $A > 0$ and $r = 2$ and

$$V_A(z) = -Be^{-az} , \tag{3}$$

with $B > 0$ and $a =$ constant, and then[12] the more general case (2) with arbitrary $r$; García and Ibañez[13] considered the case (2) with $r = 2$ and 3 and the case (3). Readers are referred to the original papers[11-13] for details, but the outcome of the analyses is as follows: (a) the "puzzle" (1) occurs for $V_A(z)$ of range not longer than the exponential case (3); (b) it does not occur for $V_A(z)$ of range longer than the exponential case, for example, for $V_A(z)$ of the form (2).

The above earlier theories[2-4] all used Morse potentials for $V(z)$, in which $V_A(z)$ is of the exponential form (3), and this fact is the origin of the "puzzle" under discussion. The square-well potential of Knowles and Suhl[1] is of range shorter than the exponential potential, and so the "puzzle" occurs for their case also. It is well known that the "correct" $V_A(z)$ is of the form (2), with $r = 3$ if the relativistic retardation correction[14-16] is ignored and with $r = 4$ if this correction is included; with these "correct" longer-range $V_A(z)$, the "puzzle" does not occur, that is, $S(0,0) > 0$ and $\alpha(0) > 0$, although the numerical result obtained in Sec. VII of Ref. 12 should not be taken too seriously.

Although we have shown in this note that the Knowles and Suhl effect[1] is not necessary to resolve the "puzzle," the question still remains as to just how large it is. The result of the effect is the appearance of a longer range of the initial static potential because of the renormalization due to phonons; it is this longer-range potential which leads to a nonzero value of $S(0,0)$ when a short-range static potential is used. The size of the effect is a problem for future study, but, in the present authors' opinion, the effect will be negligible when a realistic, longer-range, static potential [for example, (2) with $r=3$] is used. It may be possible that the effect is important for chemisorption processes, but it is not so for the sticking probabilities of atoms on solid surfaces at low temperatures.

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