Specular reflection of slow atoms on solid surface

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The interaction of an atom with a solid surface at a distance larger than the atomic size is generally governed by attractive van der Waals potential or Casimir potential, which has a power dependence of $1/r^3$ or $1/r^4$, respectively. For an atom at room temperature this attractive potential pull the atom towards the surface within the distance to touch the repulsive wall of the surface. For a very cold atom the wave nature changes its trajectory. The atom can be reflected back even on the negative slope of the potential if the slope is sufficiently steep. A sizable reflection occurs when the change of the wavevector within the distance of $1/k$ is larger than the wavevector itself, $\phi = (dk/dr)/k^2 > 1$, where $k = \sqrt{k_r^2 - (2m/\hbar^2)U(r)}$ and the k_r is the wave vector of the atomic de Broglie wave perpendicular to the surface in free space. For the potential of $U(r) = -C_n/r^n$ with $n > 2$ the ϕ can take an arbitrarily large value as the wave vector k_r is reduced. Therefore, as the velocity decreases to zero, the reflectivity should approach unity. Since such reflection is the result of the wave nature of the atom, it is called quantum reflection. The quantum reflection was observed experimentally in the collision of He or H atoms on liquid He[1, 2]. For solids there were theoretical discussions[3, 4]. Kasevich et al[5] observed deviation from the classical result on the reflection of cold atoms on the glass surface illuminated by evanescent light wave.

We show in this paper the first clear observation of quantum reflection of atoms on a solid surface. The reflectivity of a laser-cooled metastable neon beam on a silicon or BK7 glass surface was measured in the velocity range between 35 mm/s to 1 mm/s. It was found to increase from 10^{-4} to the value larger than 30%.

The experiment was straight forward. The metastable neon atoms in the $1s_3$ metastable state were released from a small magneto-optical trap of neon atoms in the $1s_5$ atoms by optical pumping. The atoms passed through a 0.1 mm-diameter pin hole that was placed 30 cm below the trap and formed a well collimated slow atomic beam with the angular divergence less than 3×10^{-4} radians. The beam hit the silicon or the BK7 glass surface at a very small angle with the transverse velocity of 2.9 m/s, and the pattern of the reflected beam was imaged on a micro-channel plate detector. The imaging allowed us unambiguous counting of the number of specularly reflected atoms.

Figure 1 shows the reflectivity on the (1,0,0) silicon surface. The normal velocity was changed by changing the angle between the surface and beam. The qualitative feature was same for silicon and BK7 glass. We integrated numerically the wave equation with the potential $-C_3/r^3$ or $-C_4/r^4$ and compared the experimentally obtained velocity dependence with the theory. For the silicon the experimental curve fitted better with the Casimir potential $-C_4/r^4$, which is reasonable because the reflection should occur at a distance larger than 1μ. However, the polarizability α obtained from the formula given by Casimir[6] for a perfect conductive surface, $C_4 = (3\hbar c\alpha)/(8\pi)$ was approximately 3 times larger than that determined from the second order Stark effect[7].

Acknowledgments. The author would like to thank J. Fujita of NEC for supplying silicon wafers. This work was partly supported by the Grants in Aid for Scientific Research (11216202) from the Ministry of Education, Science, Sports and Culture.

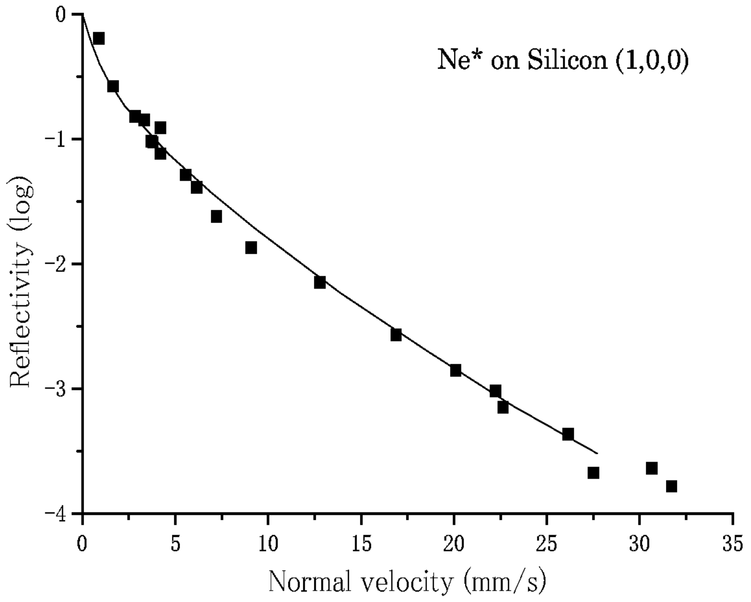

Figure 1: The reflectivity vs the normal velocity of colliding atoms. The solid line is the reflectivity calculated with the potential $-C_4/r^4$, where $C_4 = (3\hbar c\alpha)/(8\pi)$ with $\alpha = 8 \times 10^{-23}$(esu).

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