Quantum reflection of helium atom beams from solid surfaces

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Abstract

We have identified quantum reflection as a mechanism of coherent reflection from microscopically rough surfaces like, e.g., glass [1]. In quantum reflection a wave packet is reflected at the attractive branch of the atom-surface potential. In contrast to classical mechanics there is no classical turning point resulting from a repulsive potential branch. As quantum reflection takes place tens of nanometers above the surface where the equi-potential surfaces are flat, the coherent reflection probability is hardly diminished by the roughness of the actual surface.

In a first experiment we have observed high-resolution diffraction patterns of a thermal-energy helium atom beam reflected from a microstructured surface grating at near grazing incidence. The grating consists of 10-μm-wide Cr strips patterned on a quartz substrate and has a periodicity of 20 μm. Fully resolved diffraction peaks up to the seventh order have been observed at grazing angles up to 20 mrad. With changes in de Broglie wavelength or grazing angle the relative diffraction intensities show significant variations which shed light on the nature of the atom-surface interaction potential. The observations are explained in terms of quantum reflection at the long-range attractive Casimir-van der Waals potential [1].

In another experiment we have demonstrated 1-dimensional focusing of a thermal helium atom beam by quantum reflection from a cylindrical concave quartz mirror at near grazing incidence. Three effects have been observed to contribute to the finite focal width; (i) the finite size of the atom beam source; (ii) diffraction at the beam-collimating aperture; and (iii) spherical aberration. The smallest width of the focus that has been achieved is 1.8 μm, essentially limited by spherical aberration. We propose to apply near-grazing reflection from two concave elliptical mirrors in a Kirkpatrick-Baez arrangement for 2-dimensional focusing of a helium atom beam, paving the way for a helium atom microprobe with a lateral resolution on the order of 100 nm [2].

Furthermore, we have investigated the transition from quantum to classical reflection with thermal helium atom beams scattered off various microscopically-rough flat surfaces at near grazing incidence. For a sufficiently small normal component k_z of the incident wave-vector of the atom the reflection probability is found to be a function of k_z only, and is explained by quantum-reflection as described above. For larger values of k_z, however, the overall reflection probability is found to also depend on the parallel component k_x of the wave-vector. The k_x dependence for this, presumably, classical reflection from the repulsive branch of the potential is material dependent and depends also on the actual surface roughness as it is probed under grazing incidence conditions.

Keywords: quantum reflection, atom optics, diffraction, grating

References

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