

Fast Atom Diffraction from crystalline surfaces at femtometer wavelengths: where is the quantum limit?

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Since the physical intuition by Louis de Broglie in 1923, diffraction has been the most direct demonstration of the wave nature of matter. Electrons in 1927, light atoms and molecules in 1930, neutrons in 1934, all these exhibited diffraction by scattering from crystalline materials. Incidentally, each of these diffraction regimes have produced a standard technique or a commercial instrument for material structure analysis. In practice, these particles are characterized by a de Broglie wavelength from a few Å (electrons at energies below 100 eV, thermal neutrons) to few pm (electrons at 100-200 keV in transmission mode). Diffraction of atoms (H, rare gases) and molecules (H₂) was typically performed at thermal energies, i.e. with de Broglie wavelengths close to 1 Å. The diffraction signal typically vanishes at energies above 200 to 400 meV, depending on experimental conditions (surface material and temperature), due to thermal decoherence. Nowadays, observations tend to push the limits of diffraction to ever-smaller wavelengths. This can be done by increasing the mass or the

velocity of the diffracting object. The former case leads to the study of macromolecules diffraction, where energy stored in the internal degrees of freedom eventually lead to decoherence [1]. We will rather focus on the latter case, where high energy (up to 10 keV) light atoms are scattered from crystalline surfaces. Here, decoherence proceeds by entanglement with the surface through inelastic processes. As an illustration, Figure 1 shows the diffraction pattern from the quantum scattering of 5 keV He from LiF(100) at the grazing incidence angle of 0.72°. This new regime of diffraction [2,3], called GIFAD for *Grazing Incidence Fast Atom Diffraction*, appears to be well suited for observing matter waves at the smallest wavelengths, with values down to 160 fm [4]. The level of inelasticity in the He-surface interaction, and thus the coherent fraction, can be adjusted through the incidence angle. GIFAD has essentially been operated for surface structure analysis and interaction potential refinement. Alternatively, the crystalline surface can also only be used as (i) a reflection grating for the production of wave packets whose subsequent decoherence can be explored by e.g. interaction with a surrounding gas; (ii) a beam splitter for fast atom interferometry but also (iii) as a source of entangled atomic pairs.

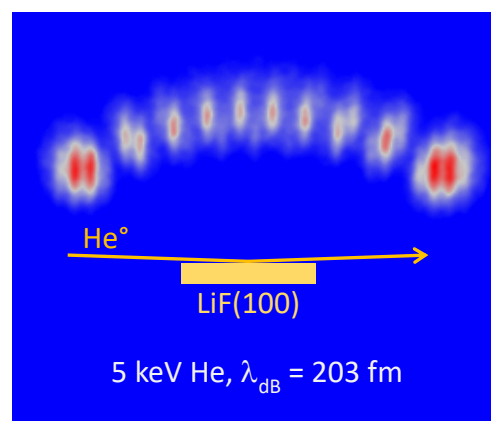


Figure 1. Diffraction pattern from 5 keV He[°] scattering from a LiF(100) surface at a grazing angle of 0.72°.

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