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Low-energy Electron Holograms and Diffraction Patterns of Individual Biomolecules

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The ultimate goal of developing novel microscopy techniques is associated with the visualization of the atomic arrangement of individual molecules, in particular the complex structures of proteins. This goal can be realized when using radiation with very short wavelengths of the order of one Ångstrom or less, such as X-rays or electrons. However, when imaging biological specimens, the obtainable resolution is mainly determined by the radiation damage threshold. Low-energy electrons (50-250 eV) have been proven to be the best known radiation for imaging individual biological molecules at high resolution, as they have a sufficiently short wavelength (0.7-1.7 Å) and inflict the least radiation damage. Two dedicated low-energy electron microscopes for imaging individual biomolecules are operated in our group: using either holographic or coherent diffractive imaging (CDI). In both microscopes, a coherent divergent spherical electron wave is generated by field emission from a sharp tungsten tip. In the holographic microscope, part of the divergent wave is scattered by an individual molecule placed about 1um distant from the tip. The scattered and unscattered wave form an interference pattern - the hologram. In the CDI microscope, the divergent electron wave is collimated by a microlens and the parallel plane wave incidents onto the individual molecule. The far-field diffraction pattern is recorded at a 68 mm distant detector. Holograms and diffraction patterns of individual biomolecules are then subject to numerical reconstruction. Images of individual molecules reconstructed from their holograms, such as DNA and bacteriophages at sub-nanometer resolution will be presented. The intrinsic properties of CDI and holography, in particular, the achievable resolution with low-energy electrons will be addressed. We will also show how holography and CDI can be merged into one superior technique: holographic coherent diffraction imaging (HCDI). In HCDI, two images of the same sample, a hologram and a diffraction pattern, are used. In the reconstruction, HCDI employs an iterative phase retrieval algorithm where the initial phase distribution is not random as in conventional methods, but directly obtained from the hologram. Such well-defined initial phase distribution provides a stable convergence of the iterative procedure towards a unique solution. Thus, reconstructions obtained by HCDI combine the highest possible resolution and uniqueness of the solution. Reconstructions of experimental low-energy electron diffraction patterns of carbon nanotubes and of free-standing graphene at 2.13 Å resolution will also be presented.