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Realization of the Feynman-Young thought experiment – controlled electron interference in Fraunhofer and image space

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Some of the key features of quantum mechanics are illustrated by the Feynman-Young double-slit thought experiment, whose second part discusses the electron distribution that is recorded when one of two illuminated slits is partially or totally closed by an aperture and whose analysis leads to the idea of the probability amplitude. Although this experiment has been attempted previously [1,2], the presence of diffraction phenomena in the Fresnel regime meant that these studies were only approximations to an ideal experiment. Here, we show how such shortcomings can be overcome in a modern microscope. We achieve an ideal Feynman-Young experiment, both in diffraction (Fraunhofer) space and in image space, by precisely tuning the microscope lenses to make use of conjugate plane(s) to the double slit plane.

Figure 1 shows the realisation of the controlled double slit experiment. The slits are in the object plane of an electron microscope, while a beam blocker (here, a Mollenstedt biprism) is placed exactly in a conjugate plane of the slits. The biprism is located in the image plane of an extra lens, which is just above the diffraction lens of the microscope. When the biprism covers one of the slits completely, the interference phenomena in the double slit regime transform into the diffraction envelope of a single slit. This experiment was carried out at 60 kV, in order to ensure that no electron could pass through the covered part of the slits or the beam blocker.

Figure 2 shows a controlled electron interference experiment performed in image space using two electron biprisms, with the lower biprism located close to the image plane of the diffraction lens. The upper biprism is tilted with respect to the slits, but is still in a conjugate plane. The lower biprism is slightly above the second conjugate plane and can be used to interfere the beams by applying a voltage to it. Changes in the spacing and direction of the interference fringes, which were observed when voltages were applied to one or both biprisms, will be discussed.

References:
[1] G. Matteucci and G. Pozzi. Two further experiments on electron interference. Am. J. Phys., 46(6):619{623, 1978.
[2] R. Bach, D. Pope, S.-H. Liou and H. Batelaan. Controlled double-slit electron diffraction. New J. Phys., 15(3):033018, 2013.

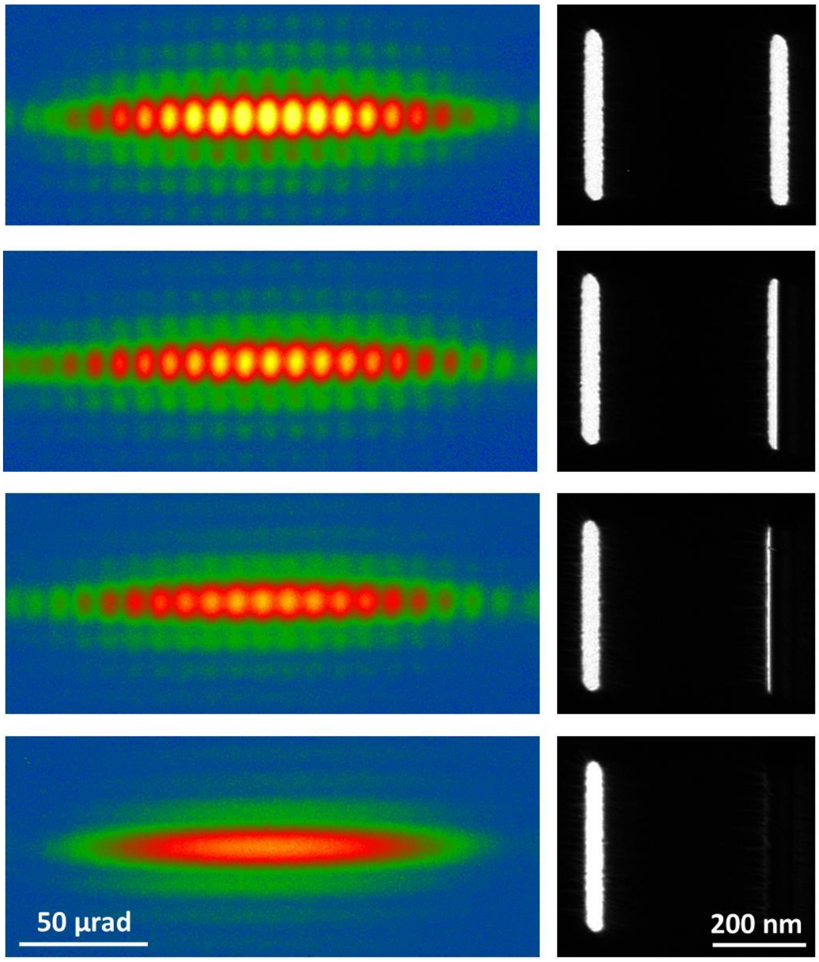

Figure 1. Double slit controlled electron beam experiment with a mask in a conjugate plane of the slits (right) and its effect on the corresponding Fraunhofer diffraction image (left).

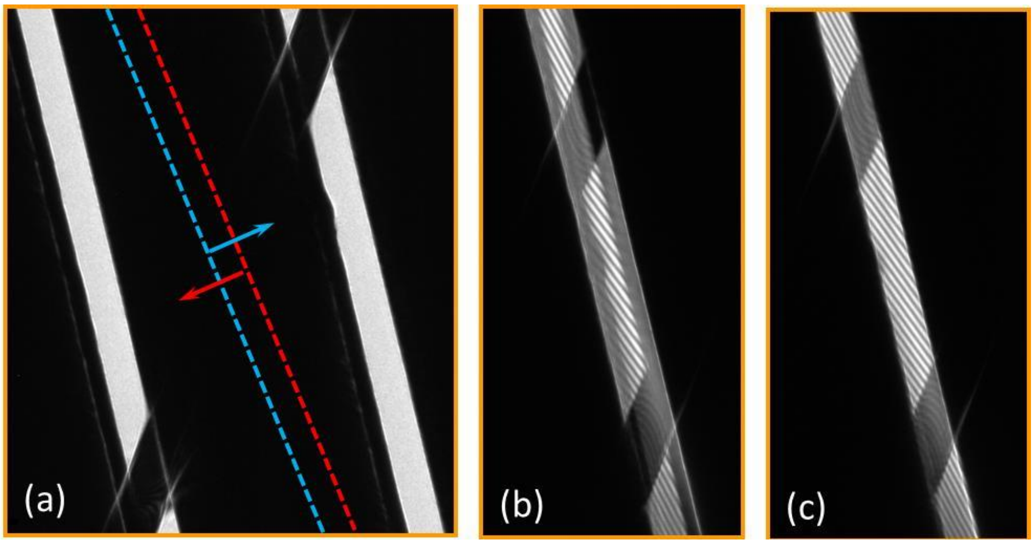

Figure 2. (a) Controlled electron interference experiments in image space performed using two electron biprisms. The lower biprism is located in the dark region between the two slits (and is positioned some distance above a conjugate image plane). Its edges are marked by dashed lines. The upper biprism is visible crossing the slits at an angle and is in a conjugate image plane. (b) Partial and (c) total overlap of the two slits was achieved when the bias applied to the lower biprism was increased, resulting in the formation of two-beam interference fringes.