A short history of aberration-corrected electron optics and the realization of atomic-resolution electron microscopy

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Only a few years after the invention of the conventional transmission electron microscope by Ernst Ruska (1931) and the scanning transmission electron microscope by Manfred von Ardenne (1937), the first theoretical considerations were made about the resolution limit of these instruments. Otto Scherzer showed in 1936 that this limit is restricted by the aberrations of the electromagnetic lenses. The most important one is the spherical aberration, according to which the focal length of a lens is shorter in the peripheral region than in the central region. If one cuts out the peripheral area in order to get a better image, this leads to a reduced resolution. In particular, this limits the path toward atomic resolution, which Ruska already knew was in principle within the range of the electron microscope because of the short wavelength. Therefore, ways to minimize these aberrations were sought early on. A critical point here was that due to Gauss' law of magnetism, one of Maxwell's equations, it is fundamentally impossible to construct diverging lenses from round magnetic fields. This blocked the path that Ernst Abbe had taken in light optics, namely to compensate for the spherical aberration of a converging lens by combining it with a suitable diverging lens. By its very nature, circumventing a law of nature is a formidable task. It therefore took more than sixty years until we (M. Haider, H. Rose, K. Urban et al., Nature 392, 768, 1998) succeeded in realizing aberration-corrected electron optics with the aid of unround diverging lenses consisting of multipoles and, in 1997, in building the first microscope whose resolution was substantially greater than that of the uncorrected device.

This opened the way to atomic resolution. However, imaging atoms means entering the quantum physical world, which we know is inaccessible to intuitive perception. This may seem grotesque at times when, under initially quite unspecific conditions, one obtains images that resemble a ball-and-stick model of atomic structure. In reality, one can understand these images only when one has calculated their formation with the help of iterative solutions of the relativistically corrected Schrödinger equation.

This talk gives a brief sketch of the partly quite adventurous path that has led us, against all odds, and although many had long since given up hope for it, to the visualization and measurement of atoms.