

Aberration correction in energy loss spectrometers and monochromators

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Early electron energy-loss spectrometers made sure that spectra were focused to first-order in the energy dispersion direction and sometimes also in the non-dispersion direction, but they did not worry about higher-order focusing. This was the case for the pioneering post-column spectrometer built by David Wittry during his sabbatical in Cambridge UK [1], which introduced important innovations such as a magnetic prism with a large entrance distance that enabled it to focus on the small crossover in the back-focal plane of the microscope's final projector, thereby allowing spectra to be recorded in all the regular operating modes of the microscope.

Second-order aberration correction for spectrometers used in electron microscopes was introduced by Crewe et al. [2]. There are two principal second-order aberrations to correct [3]: d^2x/dx'^2 and d^2x/dy'^2 , i.e. the second-order focus in the energy dispersion direction ($= x$) for electrons rays displaced in the x direction in the entrance aperture of the spectrometer ($x' = dx/dz \neq 0$), and those displaced in the y direction ($y' = dy/dz \neq 0$). The two terms can be corrected simultaneously by two sextupoles acting on the electron beam at locations in which the beam aspect ratios (width in x divided by width in y) are different. Curved entrance and exit faces of a magnetic prism produce sextupole moments and can thus be used for the correction too. Surprisingly, Crewe et al. designed a symmetric spectrometer in which the beam had the same aspect ratio at both the entrance and the exit of the prism. The curved entrance and exit faces of their prism therefore only corrected d^2x/dx'^2 , and they made d^2x/dy'^2 two times worse than it would have been with an uncorrected prism.

Simultaneous correction of the two coefficients plus minimization of the tilt of the spectrum plane (a second-rank aberration described by $d^2x/dx'dE$) was accomplished by an asymmetric prism with entrance and exit curvatures of opposite signs [4-6]. Second-order correction was also introduced for in-column magnetic imaging filters [7]. In all these instances, use was made of the general principle that a series of sextupoles (or sextupole moments produced by curved prism faces), each one acting on a beam whose first-order properties are different from all the other sextupole locations, can correct several different second-order aberrations. The effect of each sextupole is of course not pure: it changes a *mixture* of second-order aberration terms. The mixture proportions are determined by the first-order properties of the beam inside the sextupole. A combination of sextupole excitations that together null all the chosen aberration coefficients does, however, usually exist.

Thorough use of the above principle was made in post-column imaging filters. For instance, the first Gatan imaging filter [8] used 6 sextuples in addition to curved entrance and exit faces of its magnetic prism, i.e. 8 second-order correcting elements in total. Correction of two second-order spectrum aberrations and six second-order image aberrations (or distortions) was achieved because the first-order properties of the beam in each sextupole were very different. The design maximized the differences in the beam properties, with the result that typically one or at most two sextupoles affected each aberration/distortion. This made setting the filter's correcting elements to their proper excitations much easier than if all 8 elements affected all the 8 aberrations/distortions nearly equally.

