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Electron Energy-Loss Spectroscopy (EELS) and Energy-Filtered Transmission Electron Microscopy (EFTEM)

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Abstract

Electron energy-loss spectroscopy (EELS) is a transmission electron microscopy (TEM)-based technique, in which we study the energy lost by the fast electrons of the incident beam as they travel through the thin TEM sample. While the *elastic* scattering that leads to electron diffraction and phase contrast imaging in TEM is related to interactions of the fast electrons with the nuclei in the sample, EELS correlates with *inelastic* scattering, giving a spectrum dominated by electron–electron interactions.

These electron–electron interactions are divided into two main categories, which can be observed as different features when we plot the EEL spectrum of transmitted electron intensities against the amount of energy they have lost (in units of eV). At smaller energy losses, up to about 50 eV, most spectral intensity peaks from the electron beam exciting plasmon resonances – i.e. collective oscillations of the sample's valence or free electrons. This plasmon scattering can be used to measure the sample thickness, as well as obtain phase information. At higher energy losses, usually ~50–3000 eV, the spectrum is dominated by ionization edges, which correspond to the transmitted electron giving enough energy to a single inner-shell electron that the latter is excited to the vacuum or Fermi level. Because of this, the ionization edges correlate to the elemental nature of the sample, and so can be used to measure the sample's chemistry. The extended nature of the ionization edges, which are superimposed on a decaying background, mean that dedicated strategies and models must be used to interpret and quantify them. Sharper or small features at the edge onsets, known as fine structure, can also give useful information on the electronic state of the sample's atoms.

Since the energy lost in these processes is very small relative to the kinetic energy of the incident electron (typically 60–300 keV), these inelastically-scattered electrons can still be used to form images. This can be done in two ways. Firstly, by working in TEM mode and using a filter that creates an image from electrons having a certain energy loss: energy-filtered TEM (EFTEM). Secondly, by scanning a focused electron probe across the sample and recording a spectrum at each probe position (STEM-EELS). With these techniques, we can for instance make elemental maps having a sub-nm or even atomic spatial resolution.

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